Living Wales

A Strategic Plan for Earth Observation in Wales

LIVING WALES

Sêr Cymru II

Ariennir gan yr Undeb Ewropeaidd
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Tyfu Ymchwil Ryngwladol Ragorol yng Nghymru
Growing International Research Excellence in Wales

1872 PRIFYSGOL ABERYSTWYTH UNIVERSITY

Promoting and building national capability in earth observation and economic success whilst ensuring long-term care and maintenance of the environment and resources

Prosperity for Wales

Providing new opportunities for economic development in all sectors by providing open access and usable earth observation and derived products to the population.

Sustainability for Wales

Providing a long-term system for understanding, monitoring and planning landscape change that is applicable at a national level and based on historical and near real time earth observations.

Resilience for Wales

Ensuring maintenance and promoting enhancement of the state and function of Welsh landscapes and their ability to respond to adverse environmental change through integration of earth observation data.

Executive Summary

Living Wales is a unique and novel world-first concept that aims to capture the state and dynamics of Wales's landscape, in near real time, historically and into the future (over the long term) through integration of earth observation data, supportive ground measurements and process models. *Living Wales* will build on existing capability, work with relevant national and international organisations in the field, and strengthen Wales' research capacity and reputation. The benefits of providing publically available data and information through *Living Wales* will include better support for government policies and initiatives, significant costs savings and revenue generation, greater employment opportunities, and skills and knowledge that give a competitive advantage to the commercial sector (including space-based industries) within Wales. Ultimately, *Living Wales* will contribute to more sustainable use of the Welsh landscape and its resources over short to long time (50 year +) scales. The concepts and approach will also be transferable to other countries and regions.

Living Wales is working with and supporting existing initiatives to collate, correctly process, analyze and make publically available the vast archive of optical and radar satellite observations over Wales (at least since the 1980s) and derived spatial outputs that directly address key issues relevant to the Welsh economy, policy and populations. The research component, will focus on:

- The advancement and implementation of algorithms that target the interrogation of dense time series' of earth observation data (including the European Copernicus Sentinels and NASA's Landsat) data to routinely inform on, for example, agricultural, forestry, water and urban use and change.
- The provision of quantitative biophysical data (e.g., on vegetation productivity, structure and carbon dynamics, hydrology and flood sequences) for assessing trends attributed to climate or other environmental change.
- The routine production of detailed and high-resolution land cover and habitat classifications across Wales for multiple points in time based on relevant taxonomies.
- Identification of options for optimizing land use, conserving and restoring landscapes and ecosystems, and monitoring progress.

Living Wales will not reinvent but will instead utilize and capitalize on existing and new geographical information (e.g., on agricultural use), models (e.g., carbon, hydrology) and scientific knowledge (e.g., habitat links to biodiversity) and will additionally focus on coordinating, contributing and collating field, drone and airborne datasets acquired over Wales.

All geographical datasets and new and existing software will be open access (freely available to the public), thereby allowing community, government and business involvement. In the latter case, *Living Wales* will facilitate the development of new products and services using these datasets and software, with this assisted through knowledge and skills exchange partnerships. *Living Wales* will further expand employment in spatial sciences in Wales and new technologies will be developed and promoted through targeted collaboration and dissemination. Liaison with UK and international organisations (e.g., space agencies, top performing universities, the Group on Earth Observations (or GEO)) will ensure concepts and ideas are both imported and exported internationally. *Living Wales* will encourage collaboration and engagement (e.g., from the public to Welsh and UK government) to increase involvement, uptake (including through crowd sourcing, social media) and convergence towards a shared vision. Considerable cost savings are foreseen in terms of providing information (evidence-based) for effective landscape planning and optimising use of resources and environmental protection.

A Contribution to Wales

Natural Resources
Sustainably and responsibly utilized through wise use and planning

New technologies
Strategic investments and targeted exploration and exploitation

Biodiversity
Conserved, restored and thriving

Business
New and existing ventures supported to increase productivity and employment

Carbon stores and sinks
Maximized and emissions reduced

Productivity and yields
Strategically increased for agriculture, forestry and fisheries

Environment and climate
Resilient to change events and processes including disease and disasters.

Space sector
Earth observation technology use significantly increased and future investment encouraged.

Clean and safe environments
Improved well-being and health of the Welsh people and Wales' flora and fauna

Science base
Greater investment in scientific research and increased impact on the world stage

Education
Skills and knowledge in earth observation and environment substantially increased

EARTH OBSERVATION

Earth observations from aircraft and satellites are a valuable and important asset for Wales as they provide a historical record of the changes that have shaped the landscape over the past 70 years and allow quantitative retrieval of environmental variables.

In the early years, and even as late as the 1990s, remote sensing data provided only snapshots of the extent and condition of land covers in Wales. Hence, these data were rarely used for environmental applications. However, public access to data, particularly following public release of Google Earth (2001), the Landsat archive (2012) and Sentinel optical and radar data (from 2015), has helped to realize the potential and benefit of earth observations.

The concurrent development of advanced computing infrastructures, data cube configurations, and open source software has allowed these data to be stored, processed and analyzed to provide useful information on the changing state and function of landscapes. By coupling earth observation data with this computing capability, significant advancements have been made in quantifying environmental variables and interrogating dense time-series of data to classify landscapes and understand and quantify natural and human-induced change.

For the first time in decades, Wales is presented with the unique opportunity to fully utilize these data to benefit the environment, society and economy. The *Living Wales* concept is based on the desire to ensure that these earth observation data and derived products and the knowledge obtained are made accessible and useable by all interested parties and become a resource that has longevity and is adaptive and responsive to the needs of the Welsh population and environment.

Essential background

Satellite sensors have been in operation since late 1950s and have provided observations at spatial resolutions ranging from less than 1 m to over 1 km. The frequency of observation has generally been greater (typically sub-daily) for coarser and least for moderate to fine spatial resolution sensors. However, multiple sensors of the same or similar type (e.g., CubeSats) can provide near daily observations at sub-meter resolution. Sensors also operate in different regions of the electromagnetic spectrum.

- *Optical sensors, including those mounted on drones, record sunlight reflected from surfaces and provide information on the composition, structure and moisture content of surface materials. When captured in stereo, these data can be used to generate three-dimensional surfaces and volumes.*

- *Radar provides cloud-free observations and information on the three-dimensional geometry, moisture content, and size of landscape components and surface elevations.*

- *LIDAR measures the time and hence distance of light transmission and can measure, with high fidelity, the height of the terrain surface and the vertical and horizontal distribution of plant materials.*

Whilst data from individual sensors can be useful, the capacity to quantitatively describe the varying states and dynamics of environments is increased substantially when they are used in combination.

CUBESATS

Aim: In collaboration with Planet Labs Inc., to introduce and facilitate the use of CubeSat data for routine monitoring of the Welsh environment.

RapidEye image of forest and coastal habitats, southwest Anglesey

From early 2017, the Welsh landscape has been observed (cloud permitting) on a daily basis at high (3-6 m spatial resolution), primarily in the visible wavelength regions, by approximately 120 of Planet Labs Inc. CubeSat miniature satellites. These complement the five RapidEye sensors, which additionally provide spectral reflectance data in the near infrared and red edge region with the latter being particularly well suited for plant species discrimination and retrieval of herbaceous biomass and hence crop and grass yields.

The dense time series of Planet Labs data allows changes in the landscape to be observed as they occur, including the growth and harvesting of crops and forests. Of importance to Wales is that daily acquisitions significantly increase the ability to obtain cloud-free imagery.

CubeSat data there present a unique opportunity to observe the state and dynamics of Welsh environments for years to come.

This will be achieved through:

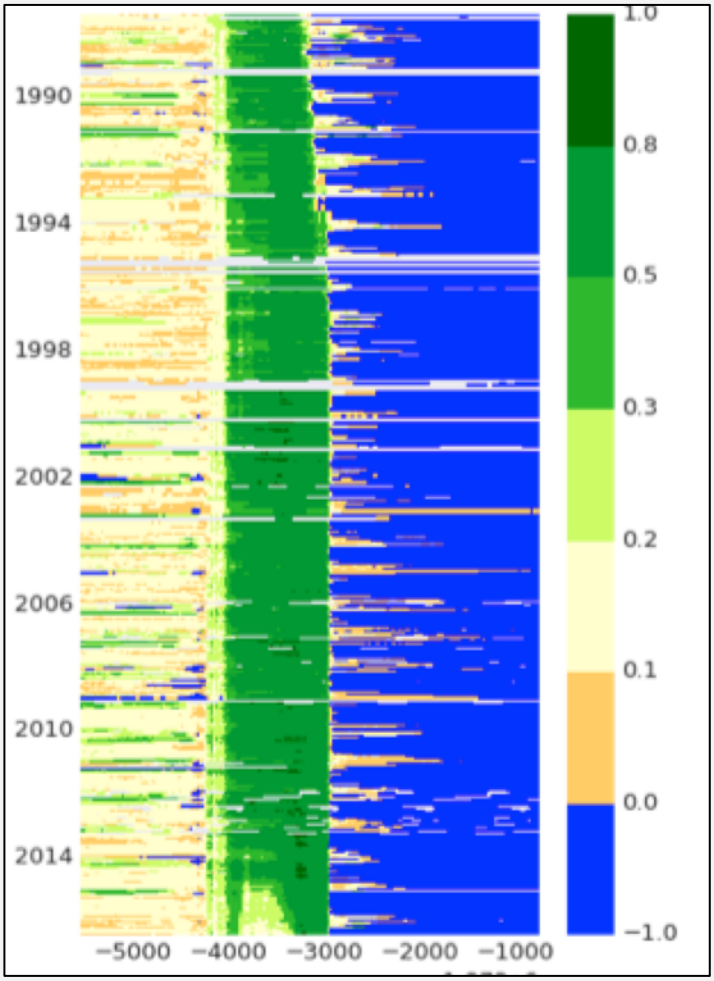
- Collaboration with Planet Labs Inc., initially through their Ambassadors Program, to evaluate the potential of CubeSats (with RapidEye) as a routine data provision source for environmental monitoring, using Wales as a test bed.
- Development and validation of routines for calibrating and cloud masking CubeSat data.
- Developing methods for routinely detecting and providing evidence of change through integration of dense time-series of CubeSat and other remote sensing data.
- Demonstrating potential cost savings in in environmental protection (e.g., compliance) and agricultural production.
- Establishing relationships between *in-situ* observations of key biophysical parameters (e.g., herbaceous biomass) and CubeSat data.

Indicators

- Routine provision of calibrated CubeSat data across Wales on a daily basis (cloud permitting; e.g., through a data cube platform).
- CubeSat data used routinely for characterizing and monitoring changes in the Welsh landscape.
- Key environmental parameters (e.g., herbaceous biomass) and vegetation and soils indices retrieved routinely from Cubesat data.
- Demonstrated benefits for compliance monitoring and increasing agricultural and forest management and productivity.

DENSE TIME-SERIES

Aim: To routinely use high temporal frequency (from 16 day to monthly) and moderate spatial resolution satellite observations of the Welsh landscape to describe changes that have taken place since at least 1987.



Visualization of fortnightly changes in NDVI (low to high productivity being 0 and 1 respectively) from 1987 to 2016 along a coastal strip.

This will be achieved by

- Providing all available Landsat and Sentinel-2 Analysis Ready Data (ARD) for Wales, with this involving radiometric calibration and both atmospheric and topographic correction.
- Evaluating and developing routines for establishing historical trends in, for example, vegetation phenology and water inundation.

The Landsat and Sentinel-2A/B sensors have provided the majority of optical data acquired over Wales. Archives of Landsat sensor multi-spectral data extend back to the mid 1980s and have been released at not cost by the United States Geological Survey (USGS).From conception, data from the European Space Agency's (ESA) Sentinel data have been designated as publicly available and with the launch of two satellites, data are now available for Wales at least every 5 days.

A particular advantage of dense time-series of satellite sensor data is that long-term intra- and inter-annual variations and trends in landscapes can be identified and detected. An number of algorithms and methods are also being developed which allow for the interrogation of these temporal signatures to provide information on changes in landscape productivity, vegetation health, starts and ends of leaf flush and fall, cropping cycles and flooding sequences. As such, they provide a unique opportunity to detect events and processes that lead to change and be used to indicate drivers and impacts of change. There is also an increased ability to identify and react to adverse events or processes. Whilst cloud and cloud shadow limit observations of terrestrial and marine environments, radar has the capacity to penetrate cloud, thereby filling the gaps left by optical sensors. The availability of Sentinal-1A/B observations every 5 days has increased the potential of using radar data for temporal classification (e.g., of crops) and analysis.

Indicators:

- All historical and newly acquired Landsat and Sentinel-2 optical data for Wales provided as ARD and freely available for download, and full engagement with existing initiatives.
- Existing algorithms extracting and describing trends in land cover characteristics implemented in the Welsh context.

RADAR

Aim: To ensure full exploitation of all radar data acquired over Wales to better characterize land cover and change and retrieve temporal information on the structure and moisture content of materials.

C-band image of agricultural crops.

This will be achieved by working within existing frameworks to:

- Obtain and centralize the archives of all X-, C- and L-band SAR data acquired over Wales.
- Ensure continued provision of and access to SAR data by routinely obtaining and pre-processing new and freely available SAR data acquired over Wales, with particular focus on ESA's Sentinel-1A/B C-band and Argentina's SAOCOM L-band sensors.
- Facilitating the provision and public release of data and data products generated from commercial SAR (e.g., ALOS-1/2 PALSAR-1/2, Tandem-X SAR, CosmoSkyMed) including digital terrain models (DTMs).

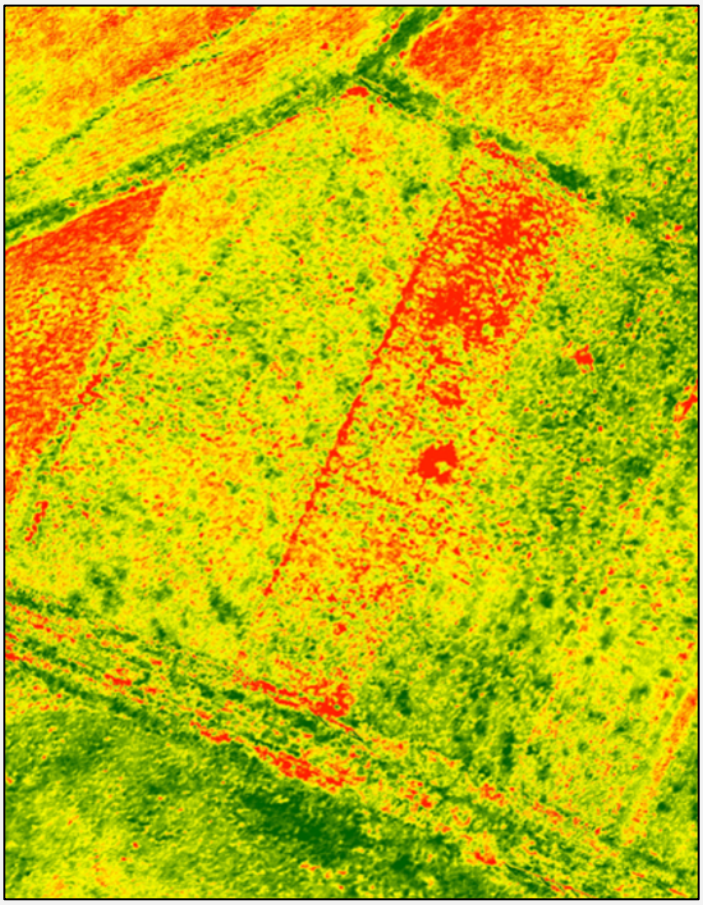
Spaceborne Synthetic Aperture Radar (SAR) have been acquiring data over Wales since the early 1990s. Microwaves transmitted from SAR at X- (~ 2.5 cm wavelength) and C-band (~ 6 cm) interact primarily with smaller elements of the landscape (e.g., leaves and rock fragments) and can be used to differentiate crop types as well as stones and gravels from fine sediments and snow conditions. The longer wavelength L-band microwaves (~ 25 cm) penetrate into the volumes of materials, providing information on the distribution, geometry and amounts of woody trunks and branches. SAR data also allow detection of soil moisture and water beneath vegetation. These SAR data therefore facilitate retrieval of vegetation biomass (both woody and herbaceous), flood mapping and soil wetness. Interferometric SAR from space involves observations from two or more satellites that allow retrieval of digital terrain models (DTMs) and surface deformation. A particular advantage of SAR is that microwaves can penetrate cloud and are therefore able to provide observations independent of weather and indeed illumination conditions, as they do not rely on reflected sunlight. However, when used in combination with optical sensors, they can provide new insights and descriptions of land covers, particularly vegetation.

Indicators

- Routine use of open source software for pre-processing of available SAR data sources and providing analysis ready data.
- Centralized and accessible archive of all available SAR data and externally derived products (for Wales.
- Increased and regular access to X-, C- and L-band data from space agency archives.
- Routine integration of SAR data for classifying and detecting changes in land covers.
- Routine retrieval of key environmental variables from SAR data across Wales, with these including forest biomass and soil moisture.

DRONES

Aim: To embed the use of drone imagery to facilitate better characterization of landscape features and elements at high spatial resolution and provide permanent records for key points in time.



NDVI image of forests obtained from drone imagery.

This will be achieved by:

- Establishing a directory of drone operators across Wales and linking capability.
- Reviewing and recommending protocols for drone operations to ensure consistency and reliability in capture.
- Developing a central and open database for drone datasets and associated metadata.
- Facilitating the collection of supportive, robust and consistent ground data, ideally at the time of drone data collection, including land cover and change information.
- Promoting benefits and efficiencies gained by using drones, including rapid surveys.

Drones are becoming an increasingly valuable source of sub-meter resolution data that can be used to inform on the state and dynamics of environments in Wales. Relatively simple drones, such as quadcopters and fixed wings, can support sensors that observe in the visible and near infrared and are available at low cost. For this reason, a large number are being operated across Wales, including by hobbyists. As a result of Global Positioning Systems and gimbals, images from drones can be accurately registered. Drones also have the unique capacity to provide stereo viewing, which allows the generation of high-resolution point clouds, digital surface models (DSMs) and orthomosaics. These DSMs can characterize the ground surface topography and the heights and three-dimensional structure of vegetation. The ability to mount lidar, hyperspectral and thermal sensors has increased through modification of these for size and weight and by increasing the payload capacity of the drones themselves. Data from these sensors can also now be calibrated to standardized units (e.g., reflectance, temperature). A further benefit of drones is that they can be operated on an as needs basis and the data made available in near real time. Much of the data collected for Wales is rarely accessible or open and yet represents an archive that can inform on the historical distribution of land covers in multiple dimensions.

Indicators

- Successful completion of annual workshops and events that demonstrate and encourage the use of drones for environmental applications across Wales.
- Coordinated scientific drone missions that engage the drone pilots and users to acquire publically accessible datasets for key sites in Wales and over time.
- A centralized and open source repository for drone data acquired to minimum standards.
- Agreement and compliance of drone operators with protocols for data collection in support of environmental applications.

LIDAR

Aim: To obtain national high resolution leaf on and leaf off LIDAR coverages for Wales, at least every five years with these data being openly and freely available.

Overview of LIDAR data available for Wales (1 m DSM)

Increasingly, countries are realizing the society and economic benefits of acquiring repeated LIDAR data at a national level. Many are now routinely and openly providing DTMs of, for example, urban areas, forest and water courses with these used for a wide range of applications including urban planning, air and noise pollution assessments, forest carbon stock retrieval and modeling and flood risk mapping. Whilst LIDAR data that have already been acquired are available across the UK, these have often been obtained at different times and during leaf off periods to optimize the retrieval of the ground surface elevation. However, acquisitions at full leaf cover allow the generation of a canopy height model and information on the three-dimensional distribution of plant material in vegetation canopies. Hence, a combination of acquisitions during the leaf on and off periods is beneficial. Open source software are being released to facilitate the processing of LIDAR data, with these including SPDLib. These significantly reduce the cost of data processing and provide access to these data for a wide range of users.

This will be achieved by:

- Reviewing the availability and potential use of all LIDAR datasets acquired over Wales.
- Facilitating, planning and seeking funding to support national full waveform LIDAR coverages during both leaf on and leaf off conditions to support land cover mapping and retrieval of biophysical variables.
- Reviewing and developing algorithms for retrieving key biophysical variables relevant to Wales, including plant canopy cover, plant biomass and material distribution in the vertical profile.
- Updating ground surface topography from the LIDAR data and integrating with those generated using drones, stereo photography and interferometric SAR.
- Providing and implementing open source software for processing multiple mode LIDAR data.

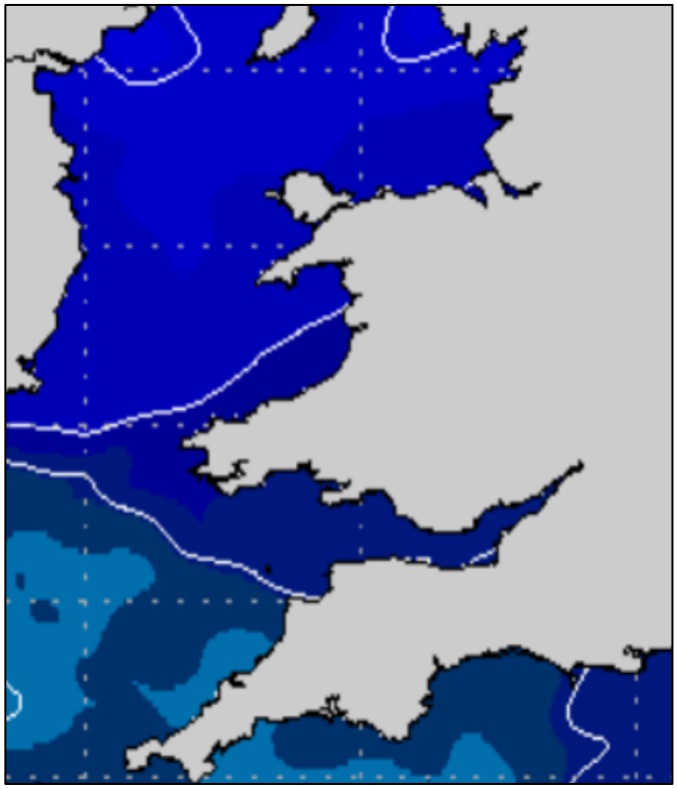
Indicators

- Virtual centralization of all LIDAR data acquired over Wales.
- Agreement on the terms and conditions for a dual season national LIDAR coverage for Wales.
- Algorithms developed for retrieving key biophysical properties to acceptable degrees of accuracy and error.
- Demonstrated adoption of open source LIDAR data across five application areas.
- Release of tutorials for targeted and/or advanced processing of full waveform LIDAR data.

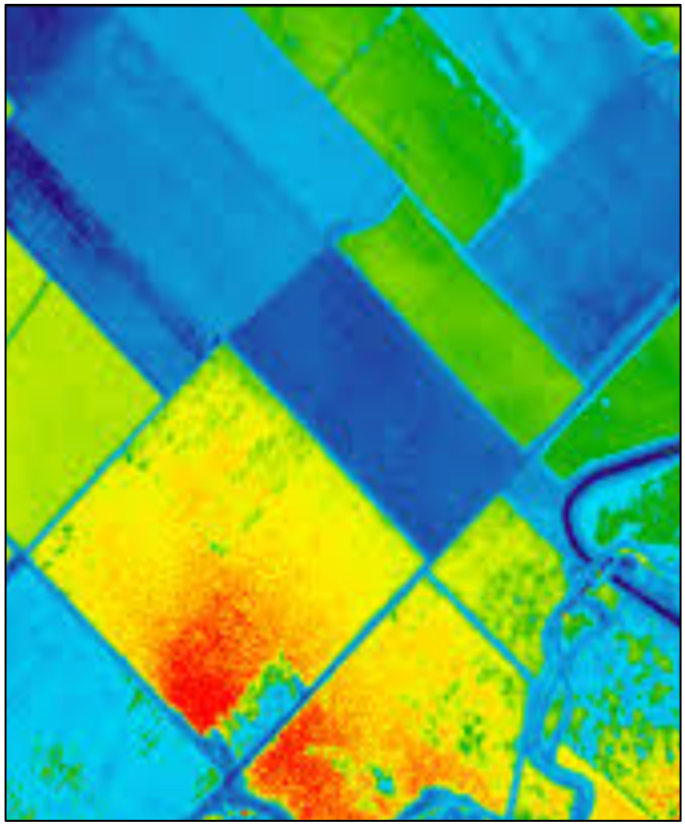
ENVIRONMENTAL VARIABLES

Year on year, the Welsh landscape goes through familiar seasonal cycles related primarily to solar position and its impact on climate and day length. The most obvious are the seasonal flushes and fall of leaves and flowering of plants, spring showers and autumn storms and river flows and rising and falling land and sea temperatures. These may occur at and over different times and periods within each year. However, the processes and natural drivers of change are essentially the same and can be consistently quantified, directly (e.g., temperature) or indirectly (e.g., plant biomass), using earth observation data, historically, currently and well into the future.

Living Wales has the vision to, and can provide, consistent environmental monitoring for at least the next 50 years. This will be achieved by using existing or developing new algorithms for routinely retrieving a range of environmental variables across Wales, with these information on the changing states and dynamics of landscapes, providing input to process and species distribution models and facilitating comprehensive classifications of land covers and habitats.



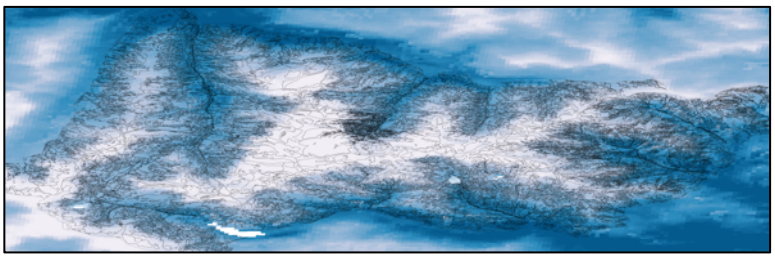
Sea Surface Temperatures for Wales generated from Terra-1 AQUA/MODIS data



Normalized Difference Vegetation Index (NDVI) derived from Terra-1 MODIS data

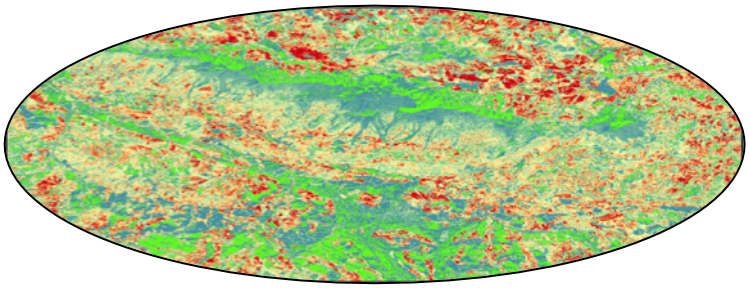
Whilst satellites have been observing Wales for at least the past 70 years, very few continuous environmental variables have been retrieved on a regular basis. The exception is for marine environments, where coarse spatial resolution NOAA AVHRR and Terra-1 MODIS/AQUA data have been providing information on sea surface temperature, chlorophyll-a and concentrations of dissolved organic matter on a daily basis, with these formed into weekly or monthly composites. For terrestrial environments, only the Normalized Difference Vegetation Index (NDVI) and snow cover extent maps are produced from these data as part of global products and have rarely been exploited for national benefit. The increased availability of satellite sensor data for Wales provides the opportunity to retrieve quantitative information on vegetation, soils, water and bare surfaces, changes in which can be used to indicate events and processes that have occurred or are leading to change. In the conceptual design of *Living Wales*, a specific range of environmental variables have been identified for retrieval

WATER AND SNOW HYDROPERIODS



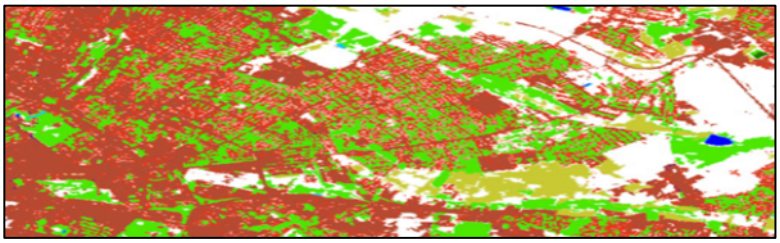
Water or snow cover maps generated from daily, weekly or monthly observations can be combined to map annual hydro-periods. The capacity to map water and snow cover and periods is greatly enhanced by combining CubeSat (daily, cloud permitting) and radar and optical data.

WOODY AND HERBACEOUS BIOMASS



Woody biomass is retrieved by linking ground-based measures with low frequency radar and/or height measures derived from LIDAR. Herbaceous biomass is determined using relationships with spectral data or indices, with yields obtained by compositing measures over time.

IMPERVIOUS MATERIAL

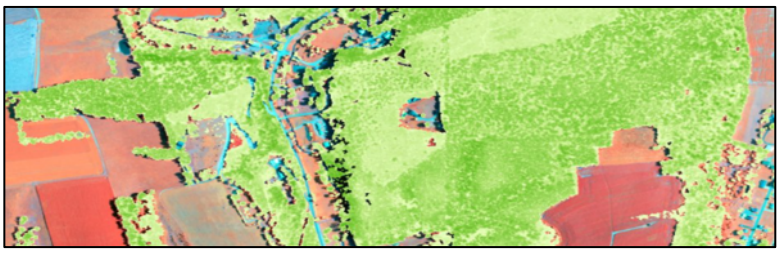


Increases in impervious surfaces are linked to urban expansion and densification, leading to increased flooding and biodiversity losses, and can be detected when the Normalised Difference Vegetation Index (NDVI) remains consistently low over long periods.

WATER TURBIDITY

Changes in water turbidity can indicate flooding events or increased erosion. Water turbidity can be mapped using relationships established with the red and short wave infrared reflectance data and regular observations provide insight into flooding or pollution events.

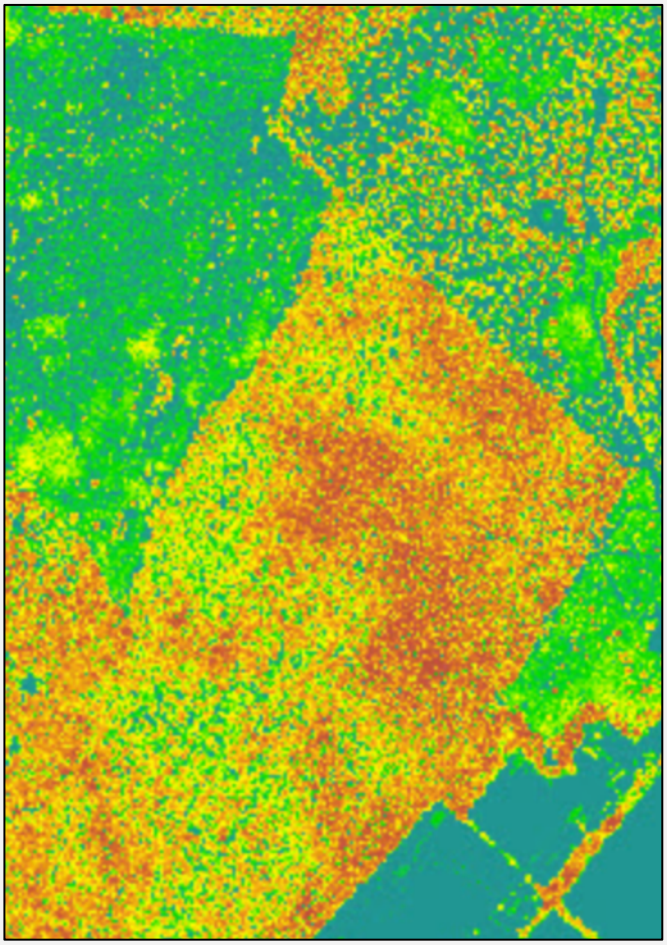
CANOPY COVER AND HEIGHT



Information on the cover and heights of vegetation from LIDAR or stereo imaging can be combined to provide descriptions of structure. Furthermore, changes in cover and height can indicate regrowth but also degradation of forests

VARIABLES

Aim: To routinely and regularly provide national estimates of environmental variables from earth observation data to support land cover classification, change detection and landscape planning.



Forest biomass mapped from LIDAR data

As earth observation technologies have developed, the range of environmental variables able to be retrieved has increased substantially. Many algorithms for retrieval have relied on the establishment of empirical relationships between ground-measured components and satellite sensor data. Increasingly, these components are being scaled up through intermediary products generated from drones or airborne imagery. Other retrievals are based on semi-empirical or theoretical modeling, with validation undertaken with reference to reference datasets. Variables, including canopy cover, water and snow hydro-period and water turbidity, can be used as direct input to land cover maps whilst others provided additional information that can further describe these in terms of their state, function and dynamics, with these include biomass, leaf area, plant species composition, sea surface temperature and wind speed. Other variables can be obtained once classifications of land covers have been obtained, including metrics relating to the fragmentation of landscapes. The frequency and scale of retrieval varies depending upon the observing sensors, with capacity for detailed mapping at < 5 m spatial resolution on a daily basis (cloud permitting). Many variables are interlinked (e.g., plant phenology, biomass and species type) and their integration can provide new insights into landscape structure, function and change.

This will be achieved by:

- Implementing existing and developing new algorithms for retrieving environmental variables from optical, radar and lidar remote sensing data.
- Linking existing data collections, including from sensor networks, of environmental variables to remote sensing observations.
- Providing capacity (through mobile technologies) for real time ground-level collection of environmental data using mobile devices, sensor networks and drones and using community agreed protocols.
- Generating estimates of uncertainty and error.

Indicators

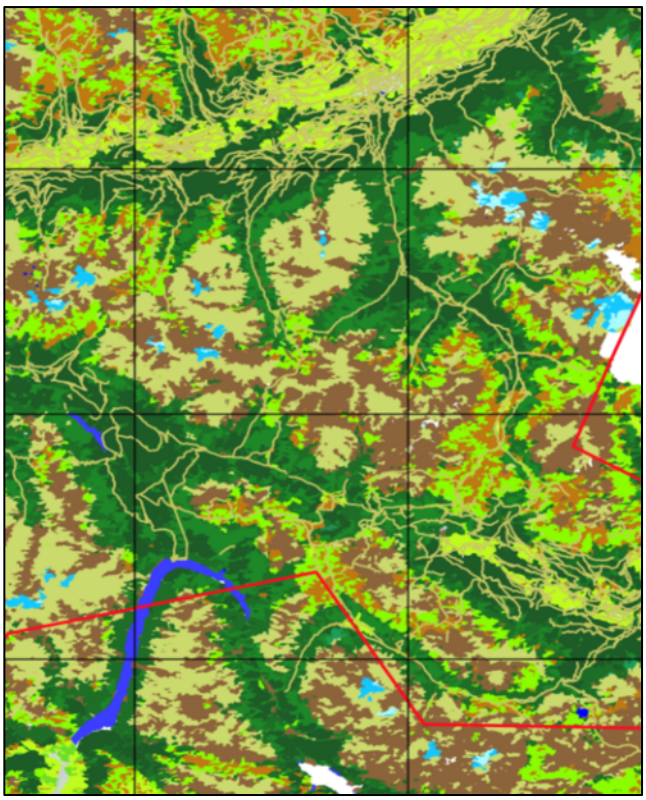
- Algorithms for routinely retrieving environmental variables from earth observation data established for national application.
- National maps of environmental variables generated routinely from earth observation data
- Systems in place for automatically linking sensor networks and cameras, including phenocams, to remote sensing data
- Mobile applications available for field-based recording of environmental variables.

LANDSCAPE CLASSIFICATIONS

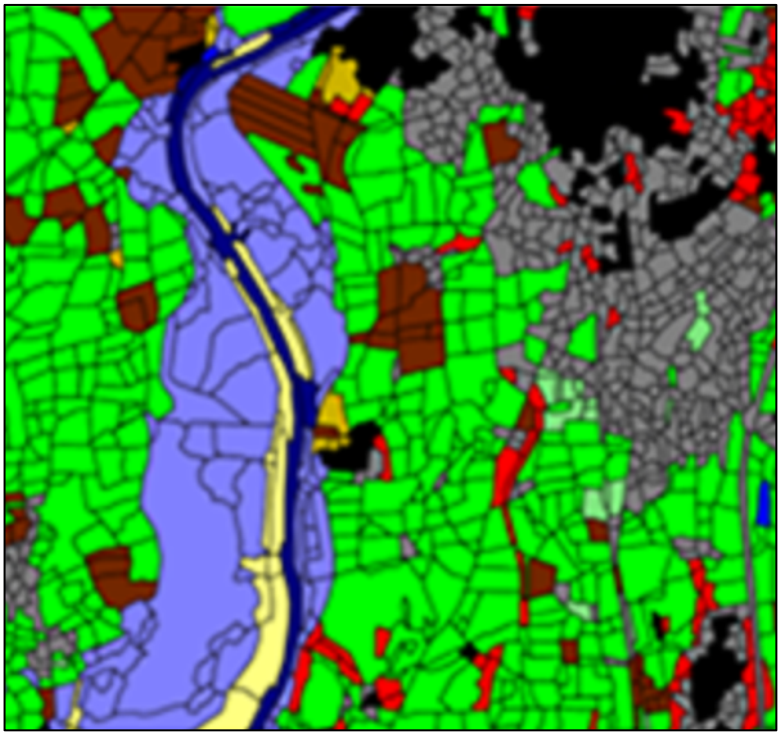
Land cover classifications are commonly used to fulfill reporting requirements against national and international legislation but also to inform of trends. Typically, mapping is undertaken at a national level and often describes broad land covers.

In the UK, land cover mapping has been a significant undertaking and hence products have been generated for 1990, 2000, 2007 and 2015, with these based on classifications of Landsat sensor data at a nominal resolution of 25 m. Typically, data from both the winter and summer months have been used as the seasonal variation in, for example, vegetation and water extent, is better captured.

For Wales, the revision of the 1980s Phase 1 habitat maps was generated for the nominal year of 2006 at a nominal spatial resolution of 5 m using combinations of SPOT-5 and ASTER data but has not been updated.



FAO LCCS2 classification generated by the EODESM system.



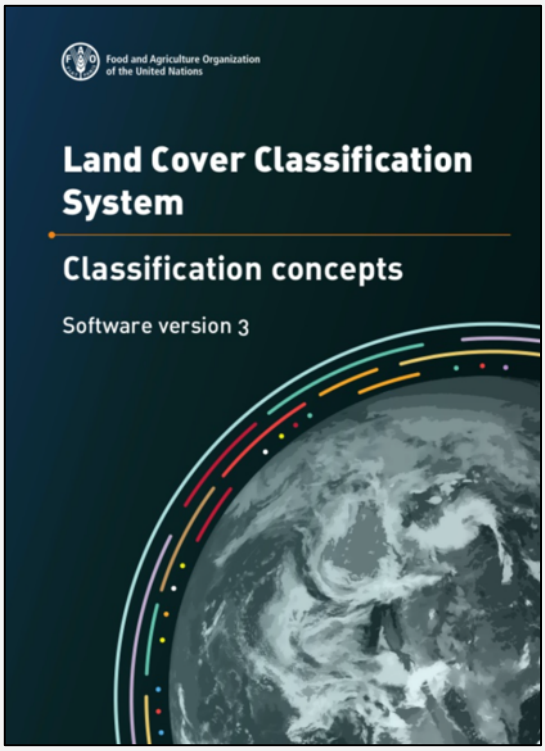
Extract of the UK CEH Land Cover Map 2015 that describes 25 classes

For Wales, the EODESM approach to land cover mapping based on the Food and Agricultural Organisation's (FAO) Land Cover Classification System (LCCS2) will be adopted, with this providing a hierarchical classification of land covers from thematic (e.g., leaf type, water state) and continuous environmental variable layers (e.g., hydro-period, canopy cover). The system is applied to both pixels and segments and allows for the integration of the best available data layers from optical, radar and lidar sensors but also other layers (e.g., urban extent) and the inclusion of additional information not used in the classification (e.g., biomass, sea surface temperature). The system also facilitates the translation to other land cover and habitat taxonomies.

The classifications are comprehensive, highly detailed but also easy to understand. Furthermore, the EODESM system has been designed to optimize the detection and mapping of change that exploits the hierarchical and modular design of the LCCS2 approach.

GLOBALLY-RELEVANT TAXONOMIES

Aim: To classify land covers in Wales according to internationally recognized and globally applicable taxonomies, thereby placing Wales in the context of efforts aims at global land cover assessment and change monitoring.



The FAO LCCS: A global approach

Living Wales will:

- Generate national land cover classifications for Wales based on the EODESM FAO LCCS2 taxonomy and using environmental variables derived from earth observation data, including forest canopy cover and water hydro-period and turbidity.
- Attribute landscape objects with environmental variables not used for the classification (e.g. soil pH, water salinity).
- Hindcast and forecast classifications based on knowledge and earth observation data, including for years where cloud cover or low acquisition rates create gaps in coverage.
- Use and augment the open source software for classification and transparent demonstrations of use and capability.

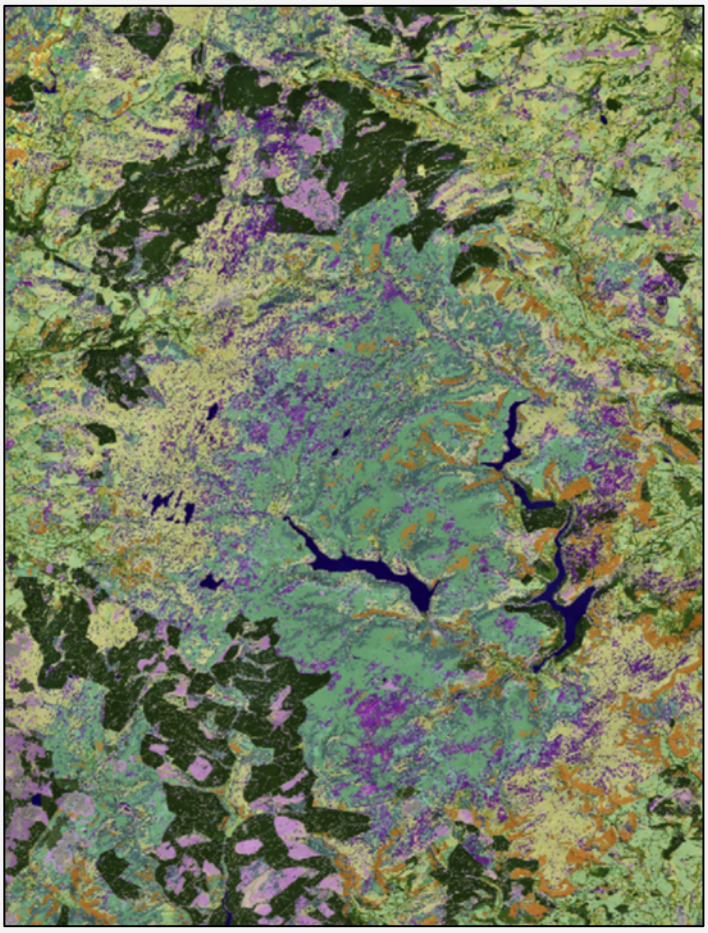
For the classification of land covers, a wide range of taxonomies have been developed at local to global scales. A limitation of local and often national schemes is that they are generally unable to be translated to other regions or countries. However, these are often most applicable for land management and associated activities. National, continental or global mapping taxonomies often allow for reporting at these levels but the datasets are rarely applicable or relevant for many users and hence the datasets are rarely used at the local or even national level. Many of the classes are also relatively broad and hence provide insufficient detail and are difficult to update and generate using remote sensing data as many classes cannot be differentiated with confidence. The Food and Agricultural Organisation's (FAO) Land Cover Classification System (LCCS2) was designed for application across large areas and specifically Africa. However, it has the advantage of being applicable at any scale (including using high resolution imagery from drones) and the classes generated can be translated to other systems, including habitat classifications. As it is a globally consistent and scalable classification, it can be applied at a national and sub-national level, which allows comparability between the land cover classes of different countries.

Indicators

- Maps of FAO LCCS categories generated for Wales for any point in time at a nominal spatial resolution of at least 10 m using a combination of spaceborne optical, radar and lidar data.
- Maps of LCCS categories generated for selected sites using higher resolution airborne remote sensing data, including LIDAR and drone imagery
- Open source EODESM software adopted across the range of potential users.

CONVERSION TO HABITAT CLASSES

Aim: To provide translation of land cover taxonomies to habitat categories, thereby facilitating alignment with current vegetation mapping and supporting mapping of habitats and change events and processes.



Revised Phase I habitat map for Wales

This will be achieved by:

- Providing and implementing open source software for translating land cover taxonomies, primarily the FAO LCCS, to habitat categories including Phase I and General Habitat Categories.
- Generating habitat maps and change layers for selected periods of time.
- Conveying the advantages of using the FAO LCCS maps for habitat mapping to end-users including monitoring teams and conservation agencies.

Land cover indicates the features that cover the surface of a landscape, with these typically relating to vegetation, bare surfaces and water whereas land use indicates how the landscape is being used (e.g., for agricultural production). Habitats differ in that they describe the collective components of landscapes that are important for plant and animal species. Ecosystems are components of landscapes that are comprised of particular (and often unique) combinations and functions of plant and animal species.

In Wales, land cover maps have been generated from remote sensing every 5-8 years by the NERC Centre for Ecology and Hydrology (CEH) whilst the Phase I map and its satellite-based refinement represents the habitats of Wales, which are also described according to the Annex I scheme. In many cases, there is a direct link between land cover, habitats and ecosystems and translation rules can be developed. However, ancillary information is often required to reliably translate some categories, with this including soil acidity, topographic position, relative wetness of environments and proximity to the coast. Procedures for translating the FAO LCCS2 land cover categories to habitats have been published and are available to *Living Wales.*

Indicators

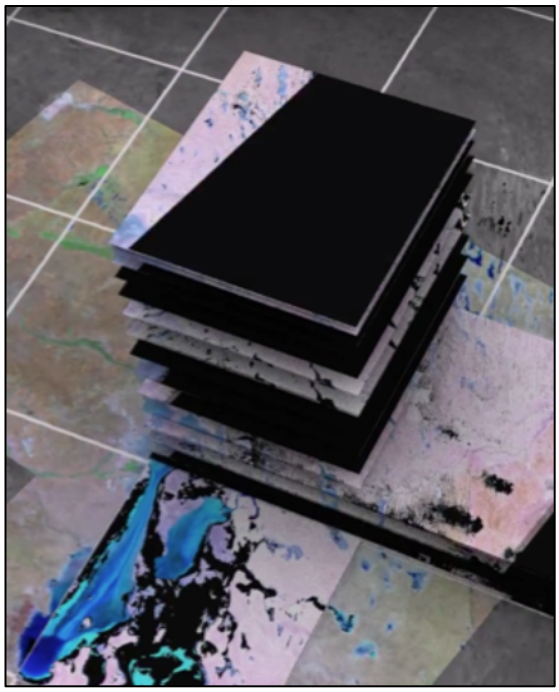
- Maps of habitat extent generated by translating land cover maps for selected periods in time.
- Habitat maps adopted and routinely referenced by Welsh Government and its agencies as well as other users across Wales.

ADVANCED COMPUTING

High performance computing (HPC) has been an active area of research and has been the result of intensive interdisciplinary research on hardware parallel programming and algorithms and networks. System performance has continued to increase exponentially since the early 1990s with potential capacity for exascale computing architectures.

Supercomputing Wales has provides scientists and industry with access to HPC facilities. Other centralized but dispersed systems including the Amazon Cloud, which allows also for storage under a transparent costing system, which facilitates external access but also reduces the requirement for continual upgrading of local computing infrastructure. The advantage of these latter systems is that they can be made accessible to the wider community.

HPC and networks are highly complementary to earth observation data analysis.



Data cube environments provide unique access to long and dense time-series of satellite sensor data.

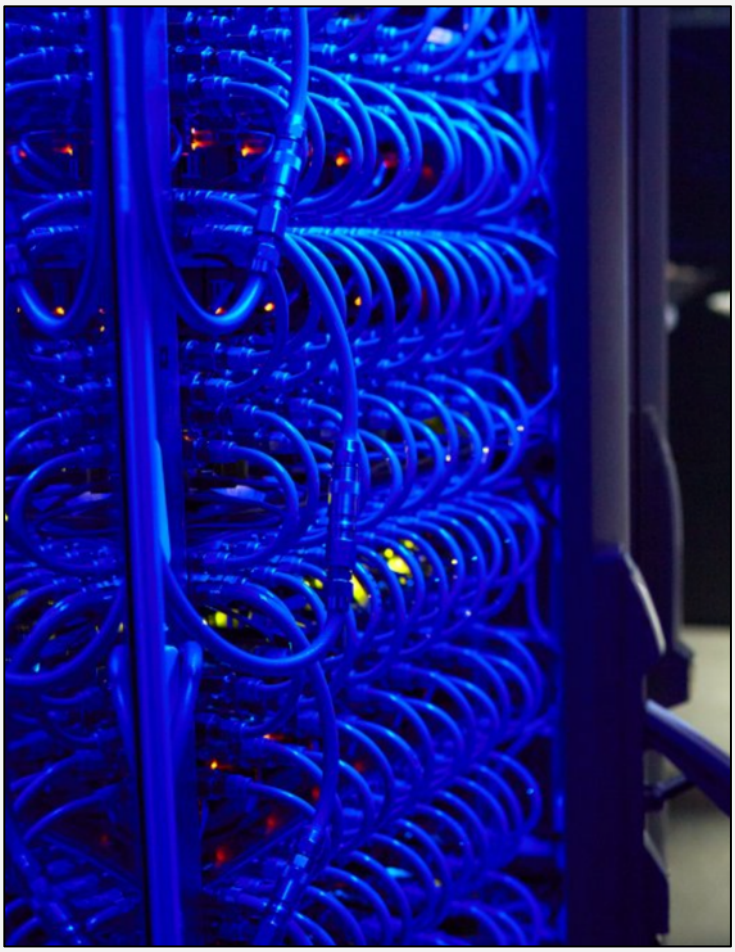
Data cubes are temporal stacks of pre-processing earth observation data tiles that can be readily interrogated in a centralized location to provide information on historical environmental change that can support management decisions and government policy development and response.

To date, the majority of data cubes (which include the Google Earth Engine and the Australian Geoscience Data Cube) have focused on using dense time-series of co-registered Landsat and, more recently Sentinel-2A/B sensor data but pre-processed radar data, particularly from Sentinel-1 missions, are being integrated.

The development of data cube environments is particularly essential given the anticipated rise in data volumes over the next few decades, including from CubeSats, and the increasing length of the historical data archive.

HIGH PERFORMANCE COMPUTING

Aim: To fully utilize high performance computing facilities in Wales in the development and implementation of environmental monitoring.



SuperComputing Wales facilities

Since the launch of the Sputnik I satellite in 1957, the number of satellites in orbiting the earth has increased substantially with 1071 being operational in 2017, 50 % of which have been launched by the United States and most are a few hundred kilometers above the surface. Sensors on board of these satellites are increasingly operating in a diversity of modes, with many recording reflected and thermal energy (passive) or emitting their own sources of energy (as in the case of lidar and radar). The temporal frequency of observations has also increased substantially, particularly given the launch of CubeSats.

This increased capacity for observation brings substantive amounts of data which require processing capability in order to generate the information needed for characterizing, mapping and monitoring the earth's surface. Key to addressing this issue as been the parallel development of high performance computing, which uses multiple cores to process data in parallel with substantive savings in time from data ingestion to product outputs.

Many of the algorithms proposed for *Living Wales* are based on open source software suites, which can be used within a HPC environment.

Living Wales will:

- Develop algorithms and software for processing earth observation data that can be operated within and benefit from the facilities provided by SuperComputing Wales.
- Supporting open access to HPC facilities, including through cloud-platforms.

Indicators

- Successful implementation of pre-processing, biophysical retrieval, classification and change detection algorithms on the SuperComputing Wales HPC.
- Generation of national land cover and change classifications and biophysical maps using HPC facilities.

DATA STORAGE AND DATA CUBES

Aim: To centrally store all pre-processed satellite sensor data acquired over Wales within a dedicated data cube, thereby allowing algorithms to be applied without the need for duplicate datasets and facilitating rapid access for decision making, understanding historical and future change and providing near real time assessments of environmental change.

Centralised storage facilities

Living Wales support the development of a data cube for Wales by:

- Developing or facilitating access to software that allows pre-processing of the main satellite sensor data acquired over Wales.
- Adopting procedures developed by and working with other countries to support the development of a data cube for Wales.
- Proposing the infrastructure needed for a data cube and ensuring a pathway to implementation.

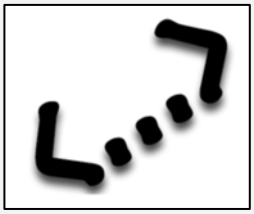
With the vast quantities of satellite sensor data becoming available, there is a desire to centrally locate these such that they can be accessed and analyzed remotely. The key benefit of a data cube is that individuals, groups or organisations can access a centrally-stored archive of multi-temporal satellite sensor data and generate products by uploading and applying their own algorithms. The data can also be interrogated to forewarn and understand environmental processes that are occurring. A particular benefit is that algorithms can be developed by a wide range of users and collated within the data cube and can then be further developed or explored by, for example, scientists or land managers. By providing free access to the data archives, there is a greater willingness to share and divulge algorithms. The data cube should be capable of storing both raw and pre-processed data, with the former being important to allow the development of algorithms for, as examples, advance retrieval of biophysical attributes or detecting surface movements through SAR interferometry. Capacity also needs to be in place to allow analysis and integration of data as and when required in order to obtain information on, for example, vegetation change as a function of climate variables. Such capacity can greatly increase understanding of landscape change in relation to policy, management or adverse events or processes (e.g., associated with climate change).

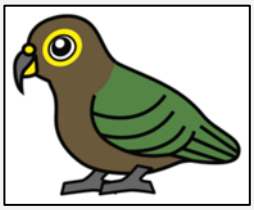
Indicators

- Open source software developed that can be used to pre-process data needed for a Wales-focused data cube.
- Computer storage, processing capability and software in place to ensure operation of the datacube.
- Successful implementation of algorithms within a data cube environment including those that can quantify changes in land cover and environmental variables.

OPEN SOURCE SOFTWARE

Aim: To ensure the development of provision within a centralized system of open source software that facilitates routine pre-processing and generation of outputs products from earth observation and ground data.





Living Wales will support the development of and access to open source software by:

- Virtually centralizing all relevant open source software such that they can be used to support environmental mapping and monitoring in Wales from earth observation data.
- Ensuring knowledge of and access to open source software.
- Generating enhancements of and new software for implementation of land cover and change classifications and retrieval of environmental variables.

The transition to open sources software in recent years has significantly reduced the costs associated with the processing of earth observation data, allowing greater access to these data to users. A potential limitation of open source software is that these are not sustained or supported into the future but this has been alleviated by widening contributions from the community such that they become routinely and regularly reviewed and updated. Notable examples including the R statistics package and QGIS. Software available for *Living Wales* includes:

- RSGISLib for generation processing of earth observation data and associated geographic information.
- SPDLib for processing discrete return and full waveform LIDAR data.
- ARCSI for atmospheric correction of data acquired by optical sensors including Landsat, Sentinel-2A/B, RapidEye and Worldview data.
- EODESM for land cover classification according to the FAO LCCS2 taxonomy and change detection and description based on evidence.
- ESA's Sen2Cor suite for pre-processing of SAR and optical data.

Open data kits for standardized collection of supportive ground data.

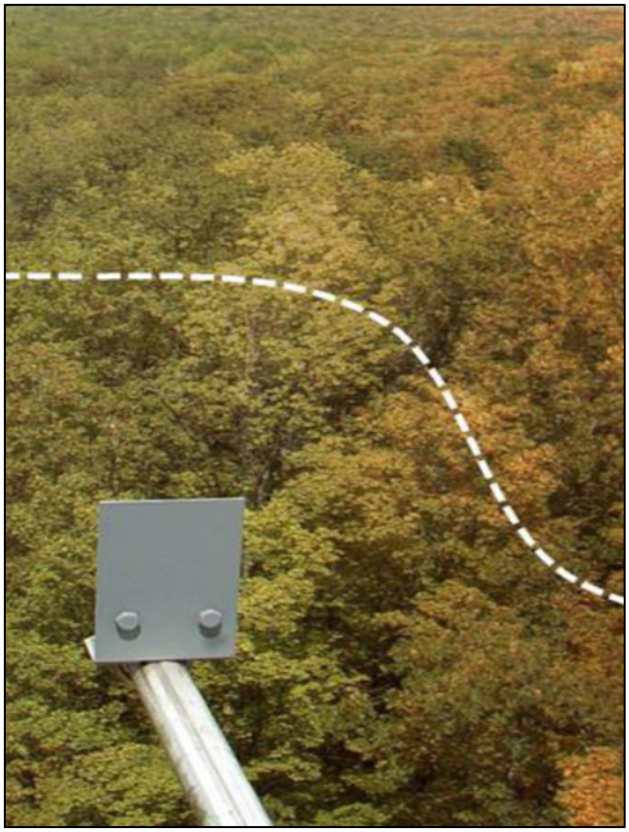
Indicators

- End-to-end processing achieved for key elements of earth observation data preparation and analysis using existing open source software.
- Centralised repository of open source software to fully support mapping and monitoring from earth observation data.
- Organisations and individuals using training and dissemination material relevant to open source software.
- Trained groups and organisations with full capability to use open sources software.

GROUND-BASED MONITORING

Wales has a long history of ground-based environmental monitoring, with this often undertaken in conjunction with process modeling and, in some cases, earth observation. Monitoring is often focused on specific landscape components with the timing, frequency and locations varying accordingly. Across Wales, ground-based measurements include the abundance and presence of flora and fauna, air quality, climate variables and water flows and quality. Intensive monitoring of multiple variables occurs at locations across Wales (e.g., Environmental Change Network sites). Land cover change monitoring is conducted through the Countryside Survey through intensive sampling of 70 1 km squares. Monitoring of landscapes across Wales using earth observation has not been routinely adopted, partly because of the low availability of optical imagery (because of cloud) and topographic shadowing. The complexity of SAR data processing and a limited understanding of the information content of these data has also limited uptake.

Intensive ground-based monitoring in Wales



Ground data collection using mobile devices.

The generation of products from earth observation data requires ground truth data to train and validate maps (e.g., of land cover or habitats), develop algorithms for retrieving environmental variables and assess uncertainty. The timing and frequency of ground observations varies with the mapping purpose and environmental variables retrieved.

- Concurrent with observations capture temporally dynamic properties of land surfaces, water and air (e.g., soil moisture).
- On a sub-annual basis and often regularly, including plant phenology, crop productivity.
- Annual or multi-annual, including woody biomass and land cover.

The nature of the change event or process and the spatial resolution of the observing sensor(s) also determine the location and spatial coverage of ground data collection. Increasingly, ground truth data are being provided through drones, sensor networks and mobile devices.

NEAR REAL TIME MONITORING

Aim: To promote the use of near-real time recording of environmental information at the ground level using mobile devices and freely available and supportive applications.

Fieldtrip GB: A mobile app for field data collection

This will be achieved by:

- Undertaking a continual review of basic data collection requirements that are common to all ground data collections and recording methods and protocols
- Developing mobile applications for the routine collection of information on land cover according to globally applicable taxonomies for the majority of sampled sites throughout Wales.
- Embedding the collection of land cover and associated environmental information in Welsh Government and associated agencies and encouraging engagement with external partners, including commercial organisations and non-governmental organisations.
- Establishing the capacity to store and collate information within centralized databases that are open access and routinely and freely available, where appropriate.
- Linking with ongoing promotion and use of citizen science for ground-based field data collection (e.g., through research projects such as COBWEB).

To facilitate the development of algorithms for retrieving environmental variables and classifying the state and dynamics of the Welsh landscape, timely provision of ground-based measurements are essential. Such data are also needed to validate retrieved variables and assess the accuracy of classification and change. Increasing use is being made of mobile devices that allow collection of data as and when it is being collected, with this often achieved using ruggedized laptops and more recently mobile phones. A number of open source options for creating data recording forms and apps for use with these devices have been developed including Field GB and Open Data Kits. These allow collection of both thematic information and continuous variables and avoid the need for post-entering of datasets from paper forms. They increase the consistency in data collection within and between individuals and groups. Furthermore, surveys can be monitored in near real time from the office and also uploaded and collated in centralized databases.

Indicators

- Integration of common information within all mobile applications with these aligning with those currently undertaken using similar technologies or paper notebooks.
- Release of mobile applications facilitating recording of land cover according to globally–recognized taxonomies, plot-based measurements associated with detailed plant survey, primarily based on quadrats or fixed plots, and biophysical measurements with particular focus on those retrieved from remote sensing data at a national level.
- Acceptance by organisations, groups and individuals as well as government of the importance and need for obtaining information to support earth observation.
- Centralized databases of ground-based information from across Wales associated with existing repositories and routinely accessed by a wide range of users.

GEOBON

Aim: In collaboration with partners, form a National Biodiversity Observation Network (BON) for Wales, which will build on the extensive knowledge, expertise and data held with in Wales. As such, Wales will be in a position to respond and contribute to the design of biodiversity observation and data collection protocols and exchange and make freely available tools for obtaining, storing, processing and interpretation data that supports the conservation of and the reversal of declines in biodiversity.

GEOBON in action

Living Wales will support the proposed national BON by providing:

- Spatial datasets of prospective Essential Biodiversity Variables (EBVs) that can support classifications of land covers, assessment of change and species distribution models.
- Collection and collation of supportive ground truth data.
- Options for sustaining, improving and planning future landscapes.

The vision of the Group on Earth Observations (GEO) Biodiversity Observation Network (BON) is to provide a global biodiversity observation network that contributes to effective management policy for the world's biodiversity and ecosystem services. Its mission is to improve the acquisition, coordination and delivery of biodiversity observations and related services to users including decision makers and the scientific community. The importance of GEOBON has increased in recent years given that there is no systematic method for monitoring biodiversity and assessing the impacts of conservation measures, increases in populations and changes in activities and policies activities at the local to international levels. GEOBON has also identified a set of Essential Biodiversity Variables (EBV) that can be contribute to the quantification of biodiversity from earth observation data.

GEOBON is encouraging countries to form national BONs and Wales is in a strong position to do so given its long-history of rigorous and detailed collations and collections of biodiversity information.

Wales has the NBN Atlas of *Living Wales*, Local Record Centres and the Wales Biodiversity Partnership with which BON Cymru can directly align or originate from. The capacity to contribute to GEOBON is significantly increased by the use of earth observations through *Living Wales*.

Indicators

- Formal acceptance of a Wales BON (BON Cymru) by GEOBON and production of the strategic plan.
- Integration of selected biodiversity datasets within BON Cymru and public release on the GEOBON portal.
- Publication of methods for assessing biodiversity across Wales.
- Uptake of methods proposed by members of GEOBON and other national BONs.

Natural Resources

Vision

Earth Observation data will be used as an additional and vital tool for quantifying, monitoring and planning the use of natural resources in Wales such that they are maintained or enhanced into the future and their relative and actual contributions to the Welsh economy are increased.

Wales's natural resources include those that are used for economic and societal benefit. The primary natural resources of economic benefit for Wales arise from its soils, geology, vegetation and water, which collectively support agriculture, forestry and fisheries. Approximately 90 % of agricultural production is through the beef, sheep and diary industry, with the remaining 10 % associated with arable farming. Forestry and fisheries industries account for 4000 and 1400 jobs respectively.

Whilst Wales once had a highly productive mining industry, the majority of mined resources are now imported for processing, particularly iron ore and oil. Wales is also a net exporter of energy from nuclear, coal, wind and hydroelectric sources and also drinkable water, particularly to England. Natural resources include the broader landscape, with its aesthetic qualities and recreational facilities benefiting the health and well being of populations and attracting significant tourism investment. Biodiversity is also an essential natural resource of Wales that is often overlooked in its contribution to the economy and society.

Objectives

- To routinely provide spatial datasets at a national level that inform on the past, present and future distributions, amounts and potential of natural resources in Wales, with particular focus on carbon, water, soils and biodiversity.
- To inform on adverse impacts of natural and human-induced processes (including climate change) on past, present and potential natural resources in Wales.
- To provide capacity for planning and predicting the future of natural resources across Wales.
- To greatly increase the scope and representativeness of the current evidence base on natural resources usage such that it is more inclusive and responsive to issues across the full range of scales.

Initiatives

- To routinely generate maps of carbon in vegetation as well as peatland extent and condition to support management, maintenance and/or enhancement of carbon resources.
- To derive information on habitats and input to species distribution models to support national assessments of biodiversity distributions and change.
- To provide tools for planning future landscapes that maintain and/or enhance natural resources, including restoration of forests and peatlands
- To provide information on land cover extent, composition and change and link with environmental models to inform on the placement and impact of renewable energy generators.

Measuring progress

- Routine production of maps indicating natural resource quantity and quality and change.
- Adoption of *Living Wales* products in assessing biodiversity as a natural resource.
- Uptake of *Living Wales* products in natural resource management plans.
- Tangible increases in resource amount and quality, with focus on carbon and biodiversity.

Biodiversity

Vision

Earth Observation data are used routinely to support the conservation and restoration of faunal and floral diversity in Wales and the reversal of current declines.

Wales has a diverse range of flora and fauna species, largely because of the wide range of coastal, mountain and lowland habitats that occur, with many being unique and characteristic to Wales. However, there have been significant declines in the abundance and range of many species across Wales, which have been associated with changes in agriculture and forestry, urbanization, climate change and disruption of migratory routes. Many visitors to Wales are attracted by its wildlife, and particularly its unique bird species and marine life, and hence declines can have an impact on economy and societal interest, health and well being.

Objectives

- To provide capacity to better quantify the changing distribution of flora and fauna across Wales by integrating past, current and future earth observation data.
- To routinely monitor and report on the extent and condition of habitats across Wales.
- To facilitate the collation and collection of ground-level information on the distribution of selected plant species to facilitate advancement of algorithms for their mapping from earth observation data.
- To support the National Biodiversity Network's (NBN) Atlas of *Living Wales* and other initiatives aimed at providing open data on biodiversity.
- To provide open access to a common evidence base for use across Wales, with this enabling and encouraging greater collaboration between stakeholders and increasing information to the public.

Initiatives

- To routinely provide at least annual mapping of land cover for Wales and algorithms for translating these to commonly used and recognized habitat taxonomies, including the Phase I and General Habitat Categories.
- To report on the changing condition of habitats based on landscape metrics derived from temporal land cover maps and biophysical layers.
- To specifically provide key inputs to species distribution models, including temporal land cover and habitat maps and associated environmental layers.
- To provide near real time monitoring of landscapes to optimize the use of land and ensure conservation of existing and newly created habitats.
- To facilitate the collation and collection of biodiversity information that supports the interpretation of remote sensing data and validation of products, including species distribution models.

Measuring progress

- Generation of temporal maps of the changing distribution of tree, shrub and herbaceous plant species able to be discriminated from earth observation data , with examples being bracken, heather, bilberry and selected tree species.
- Routine use of earth observation data in species distribution modeling at a national level.
- Increases in habitats of importance for biodiversity.
- Increases in the abundance of flora and fauna observed in landscapes planned with contributions from *Living Wales*.
- Incorporation of *Living Wales* products in the design and implementation of environmental schemes, including agri-environment and grant-funded projects.
- Uptake of mobile devices for routinely providing biodiversity information.

Carbon

Vision

Earth Observation data will support the quantification of carbon stocks, sinks and sources at a national level, thereby supporting routine national reporting and contributing to national and global efforts at reducing greenhouse gas emissions.

Wales contains significant quantities of carbon within its vegetation and soils and particularly its forests, peatlands, agricultural land and semi-natural habitats. In recent years, a number of initiatives (e.g., the LIFE projects) have focused on restoring peatlands and their associated carbon. However, losses of carbon have still occurred because of the spread of plant diseases, including those associated with ash and larch dieback. Continual monitoring and prediction of future carbon stocks is therefore essential to ensure Wales continues to make a positive contribution to global efforts at mitigating greenhouse gas emissions.

Objectives

- To optimize carbon budgets in Wales such that carbon stores are retained and enhanced, sinks are maximized and sources (emissions) are reduced
- To provide information on the relative importance of landscape change on carbon budgets in comparison to other sectors to ensure optimized and sustainable use of landscapes.

Initiatives

- To generate estimates of above ground biomass (carbon) in forest vegetation across Wales using combinations of Synthetic Aperture Radar (SAR) and airborne LIDAR data linked with forest productivity models and tree species mapping.
- To continually monitor the extent and condition of land covers associated with large carbon pools from earth observation data, including lowland and upland peat bogs, agricultural land and semi-natural habitats.
- To ensure inclusion of earth observation data when planning future landscapes that specifically enhance carbon stocks and sinks.
- To integrate past, current and future information on carbon amounts from earth observation into carbon models to increase understanding of the carbon dynamics of Wales' landscapes and allow prediction of future changes in carbon.

Measuring progress

- Inclusion of estimates of carbon in vegetation (particularly forests) into existing carbon models for Wales and in reporting to national and international bodies (e.g., the United Nations Framework Convention on Climate Change or UNFCCC).
- Measurable increases in the amount of carbon stored in Welsh vegetation and soils.
- Increases in carbon stores and sinks in landscapes planned through the integration of earth observation and carbon models.

Environment and Climatic Change

Vision

Earth Observation data will provide historical assessments and real time monitoring of the distribution and condition of landscapes across Wales to ensure resilience to human-induced and natural events and processes, including those associated with climate change.

Wales has experienced many changes in the landscape as a result of human activities including historical removal of expansive tracts of natural vegetation (forests, grasslands) to facilitate agriculture, mining and expansion of urban areas and associated infrastructure. In recent decades, degradation of environments has continued across the country that has collectively reduced the quality and value of landscapes and compromised their ability to provide essential ecosystem services. Furthermore, Wales has been subject to recent animal and plant diseases including foot and mouth, *phytopthora ramorum* affecting larch and bilberry and ash dieback. Predicted changes in climate are also being realized, including increased temperatures and rainfall, with potential implications for agricultural productivity, flooding and biodiversity. Monitoring, predicting and understanding environmental and climate change is therefore essential to ensure preparedness for any future adverse changes, for capitalizing on changes, and for planning future landscapes.

Objectives

- To provide a historical record of changes in land cover and a defined set of environmental variables that have occurred across Wales since the mid 1980s in the context of historical land use, policy and climate.
- To provide earth observations input to alert systems for animal and plant disease and climate change indicators.
- To facilitate the planning of future environments using earth observation data to ensure resilience to future environmental and climate change.

Initiatives

- To report on changes in the extent and condition of different land covers, as observed from earth observation data, in relation to policy, economic and societal drivers.
- To implement algorithms that collate evidence for automatically and routinely describing change based on land cover mapping and biophysical retrieval, identifying the causes and consequences of change and quantifying sources and sinks of material, namely sediments, water, carbon and air pollutants.
- To provide information on environmental variables that might contribute to the spread of both plant and animal diseases, including soil and vegetation moisture.
- To develop methods for routinely monitoring the health of vegetation across Wales, thereby providing an alert system that informs and protects against plant disease.
- To actively provide earth observation input to future landscape planning initiatives.

Measuring progress

- Links established between drivers of change and particular events and processes.
- Uptake and use of algorithms for detecting, describing and predicting change and inclusion in policy and emergency and mitigation planning.
- Formal inclusion in early warning for animal and plant disease and prevention of spread as a consequence of earth observations.

Clean and Safe Environments

Vision

Earth Observation data will be used to facilitate maintenance of and improvements in clean water, air and soils, forewarn of and monitor pollution events and processes, and encourage green spaces.

Whilst there have been considerable improvements in the water, soil and air quality over the past few decades as a result of rigorous control measures, significant impacts are still evident (e.g., from pollution events, nitrogen deposition, particulate matter from transport). Furthermore, changes in water quality can lead to marine and freshwater fish and bird kills and loss of aquatic plant species and can impact on tourism, health and well being. Contaminated soils also occur throughout Wales with these often manifesting in the reduced productivity and vitality of vegetation.

Objectives

- To routinely monitor the health of vegetation as an indicator of water, soil and air quality, at a national level but particularly around urban and industrial areas and in the uplands.
- To monitor water sediment plumes and/or loads and algal blooms in larger rivers, lakes and coastal regions through earth observations.
- To provide capacity for near real time monitoring of pollution events and mitigation activities.
- To assist in the planning of future landscape components and configurations that moderate water flows and trap sediments and pollutants.

Initiatives

- To develop national indicators of vegetation health that can be routinely derived from earth observation data, including frequent time-series of vegetation indices from optical remote sensing data and combination of radar and optical data to differentiate long term vegetation dieback from short term defoliation.
- To set up pollution alerts based on earth observations of changing water spectral characteristics and vegetation health at a national level and facilitate monitoring during and following pollution events.
- To use earth observation data to inform on the current distribution and health of green spaces within and surrounding urban areas and to assist future town and landscape planning.

Measuring progress

- Completed development and uptake of an early warning system informing on deteriorating or improving vegetation health and/or water quality (e.g., as a function of soil and air pollution).
- Integration of vegetation and water heath measures derived from earth observation data within national reporting systems and inclusion within policy briefings, developments and planning documents.
- Inclusion of high temporal frequency earth observation data in emergency and long-term response to pollution events, including oil spills.
- Maintenance and/or improvements in water quality and vegetation health as a result of landscape planning informed by earth observations.

New Technologies

Vision

Living Wales leads to the targeted and efficient use of new technologies that support earth observations, facilitate environmental protection and expand economic and social opportunities.

Our knowledge and understanding of how the Earth has changed over the past four decades has been significantly advanced by rapid technological developments in of earth observation but also the storage, processing and analysis of acquired data. The progressive launch and successful operation of earth observing satellites (including CubeSats) in an increasing diversity of modes and developments in airborne and ground technology have provided capacity to characterize terrestrial and marine environments in detail and in multiple dimensions. The ability to process these data has been enhanced considerably though high performance computing (HPC), cloud storage and data cubes, and open source solutions. Wales has recognized the significant potential for economic development and has therefore invested considerably in supportive technologies. Notable examples are HPC (Supercomputing Wales), the Wales Unmanned Airborne System Environment (WUASE) and the proposed Snowdonia spaceport,

Objectives

- To optimize the storage and processing of all earth observation data for Wales such that these can be openly accessed and analyzed , including within a data cube environment.
- To maximize the use of existing HPC facilities within Wales and internationally to support the processing and analysis of dense archives of earth observation data.
- To support research into EO–related technologies for economic, policy and social benefit.
- To promote the use and development of drones, sensor networks and mobile devices for monitoring the Welsh environment and to maximize open access to derived data.
- To utilize and build upon existing open source and mobile solutions to support field data collection (through field survey and citizen science activities) and centralized upload and storage.

Initiatives

- To develop and implement a data cube environment for Wales that hosts and can be used to analyze the majority of publically available raw and pre-processed spaceborne optical and radar data and facilitates processing by allowing algorithms to be taken to the data.
- To advance the use of open source software for processing large volumes of earth observation data within a HPC environment associated with the data cube.
- To work with Planet Labs Inc. to demonstrate and secure access to and integration of CubeSat data with other optical and radar data for observing the entire Welsh landscape at high temporal frequencies.
- To develop, through training and demonstration, the use of drones for acquiring information on landscapes that supports earth observation analyses and facilitate centralization of open drone data.
- To develop open source and mobile solutions to supportive field data collections and develop methods that ensure routine integration of sensor network data in support of earth observations.

Measuring progress

- Establishment of a usable data cube supported by high level storage and a HPC environment that routinely allow processing and analysis of earth observation data.
- Routine acquisition and integration of CubeSat with other earth observation data over Wales supported by drones, sensor networks and near real time ground data collection.
- Organisations and new company start ups routinely using a range of new technologies.

Business

Vision

Living Wales will provide new and diverse opportunities that assist existing businesses but also encourage the establishment and expansion of new ventures based on earth observation and associated technologies.

At an international level, there has been a surge in the number of large and small companies that have invested in and developed earth observation technologies, with many focusing on the design, development and launch of satellites and sensors, drones and sensor networks and the provision of data support services in the terrestrial, marine and atmospheric sciences. Wales already has over 120 SMEs and 6 large industry partners working on technological developments and/or analysis of space data and there is significant potential to advance this sector and economic development for Wales, including within regional areas. A particular benefit of technology for Wales is that businesses can often be located away from the main commercial centers. Earth observation also provides opportunities for new businesses to use Wales as a base, particularly if a critical mass of talent and facilities is gathered.

Objectives

- To create new or expanded business opportunities in space technologies, and environmental mapping, monitoring and planning and attract new investments into and throughout Wales.
- To develop long-term partnerships with business and encourage entrepreneurship.
- To support businesses in agriculture, forestry and fisheries through provision of products arising from earth observation data.

Initiatives

- To routinely provide analysis ready earth observation data and derived products, processing algorithms, computing support, knowledge, expertise and advice.
- To provide professional skills training and knowledge exchange in earth observation and access to facilities supporting technological development and processing and analysis of remote sensing data.
- To encourage adoption of the *Living Wales* system in the wider UK but also internationally and pave the way and promote new avenues for Welsh business.
- To facilitate businesses value add and commercialize products and services, including at an international level.
- To work with the commercial sector, academia and government to promote the use of earth observation and related technologies and support regional and national agendas.

Measuring progress

- Increased and routine use of the *Living Wales* earth observation data and products by businesses.
- Increased revenue to businesses as a direct result of *Living Wales* data and knowledge exchange.
- New company start ups in technologies related to earth observation and a sustainable critical mass of individuals and enterprises in Wales.
- Businesses supporting the concept of *Living Wales* and using and developing *Living Wales* technologies and capacity internationally.

Productivity and Yields

Vision

Increased productivity of Welsh agriculture, forestry and fisheries without adverse impact to the environment and well being of populations and general acceptance of earth observation for improved management of production areas.

At a global level, there is an increasing requirement for food and resource production given the rapid rise in global populations and the decreasing area of new land that is available. For this reason, there is a requirement for increasing efficiencies in agriculture, forestry and fisheries production. Alongside this is the need to monitor the impacts of management and policy initiatives and provide opportunities for increasing productivity. These can be met partially using earth observation data through contributions to precision agriculture, informing landholders of how past and current land use is impacting on productivity and supporting production planning.

In Wales, over 77 % of the land area is used to support agricultural production in the form of meat and crops, with the majority of exports being to the European Union with a further 10 % used for commercial forestry. The ability of the Welsh landscape to increase yields can be increased by using earth observation data to information on potential and actual productivity of land units, particularly given the recent increase in the frequency of earth observations.

Objectives

- To provide measures of agriculture and forest productivity that can be used to track the status of herbaceous and woody crops, estimate final yields and review historical levels.
- To identify, in a timely manner, areas where productivity might be improved without detriment to the environment.
- To support sustainable intensification of agriculture and forestry.
- To facilitate ongoing development of precision agriculture.

Initiatives

- To generate maps of variables that indicate and can inform on the past, present and potential productivity of landscapes, including herbaceous and woody biomass and vegetation and soil indices derived from earth observation data.
- To provide near real time data and derived products for farming and forestry to support efficient use and management of agricultural and forestry units, with these including weather impacts and transportability.
- To regularly and routinely report on the impacts of weather and climate events, including extreme frosts, wind damage, flooding, and desiccation.

Measuring progress

- Maps of woody and herbaceous biomass generated routinely for production areas in Wales and used routinely by commercial operators.
- Uptake and use of *Living Wales* products by landholders and inclusion with precision agriculture.
- Acknowledgement of the benefits of earth observation data in farm and forestry management.

Space Sector

Vision

All available earth observation data acquired over Wales are openly available and accessible and support all sectors of the Welsh population.

The UK has the goal of securing 10 % of the 2030 space market (estimated at £400 billion) by 2030 and the Wales Space Strategy (2015) seeks to achieve 5 % of the UK space industry's turnover (~£2 billion annually), largely through downstream segments and space enabled applications and services. Wales is in strong position to achieve its goals with a number of existing space companies and research in earth observation data and technologies focused at specific sites across Wales, including at Broughton Airport, Llanbedr Airfield, Cardiff International Airport and St. Athan. Academic and industry organisations are also developing systems for planetary observations and there is an increasing knowledge base that can advance Wales' role in the space sector. Wales can also benefit from the large volumes of systematically acquired earth observation data provided historically and regularly by a diverse range of sensors through programs such as Copernicus and the NASA and United States Geological Survey (USGS) Landsat Program.

Objectives

- To provide capacity to routinely access and use earth observation data for environmental monitoring in Wales but also internationally.
- To promote the design, development and use of platforms and sensors that can support national and international environmental monitoring, including CubeSats.
- To generate a critical mass of scientists and technologists to allow Wales to become a hub of expertise in the space sector.

Initiatives

- To work with Planet Labs to demonstrate and secure the use of CubeSat data for high temporal observations of the Welsh landscape at a national level.
- To demonstrate potential applications of space data in relation to environmental monitoring, thereby encouraging new opportunities in space technology research and development.
- To liaise with international space agencies to maximize the use of space data across Wales and demonstrate real engagement with data and derived products.

Measuring progress

- The number and size of investments in space technology research and development in Wales.
- Increased employment in the space sector in Wales and particularly in regional areas.
- Routine use of Planet Labs Inc. CubeSat and integration with other earth observation data for environmental monitoring across Wales.
- Demonstrated recognition of capacity in the space sector for Wales businesses and scientists.

Science Base

Vision

Wales advances its position as a world leader in earth observation and associated technologies and attracts significant investment to support the service sector, including academia.

Fundamental support for the development and use of earth observing sensors and data and downstream services has arisen from significant investment in science and technology research at an international level. Within the UK, such investments have been through the research councils, including the Natural Environment Research Council (NERC) and also government initiatives such as the Satellite Applications Catapult. As well as providing scientific input, a strong science base also leads to significant economic development through education and research. Universities in Wales have built up a strong capacity to undertake research in key fields of science and several major facilities exist that support research and development in space and environmental technologies and applications.

Objectives

- To increase investment in earth observation science from a wide range of sources, both national and international.
- To increase capacity for undertaking scientific research on earth observation and environmental monitoring through provision of infrastructure, including computing hardware, software and access to skills and knowledge.
- To ensure long-term support for *Living Wales*, thereby allowing sustained technological development and ongoing monitoring of the Welsh environment into the foreseeable future.

Initiatives

- To coordinate and submit funding applications for earth observation science and environmental monitoring from research councils.
- To develop hardware and software capability and facilities through targeted funding and research.
- To demonstrate and both consolidate and coordinate capacity for scientific research in earth observation across Wales, thereby focusing effort on key areas of need.

Measuring progress

- Amount of funding secured for scientific research and the ongoing and long-term operation of *Living Wales* and the establishment of base and sustained funding for earth observation and environmental monitoring.
- Publications in higher profile peer reviewed scientific journals and high citation indices.
- Sustained funding for scientific research and operation of *Living Wales* and the establishment of base funding.
- Recognition of science undertaken through and in support of *Living Wales* at both a national and international level.

Education

Vision

Wales has a trained workforce that can support the implementation and operation of *Living Wales* and is recognized internationally, with this achieved though world-leading education from primary school through to universities and professional training.

Providing a world class education is essential to support and sustain the development and implementation of earth observation and environmental monitoring, with this becoming increasingly important given the sophistication and range of new technologies and the rapid rates of change that are occurring. Wales already has a strong educational base within its Universities and many have courses at undergraduate and postgraduate level that relate to earth observation and environmental science. However, there are significant opportunities to increase the knowledge base within Wales by developing interest and providing education from the school level, through universities and colleges and at the professional level. Education also needs to be across a range of topics encompassed by the fields that include engineering, mathematics, physics, geography, ecology and biology and agriculture.

Objectives

- To provide educational material for primary and secondary schools that encourages interest in and provides the basic knowledge surrounding earth observation and the environment, including economics, policy and management.
- To significantly increase earth observation and associated technology training in Welsh universities and colleges at both undergraduate and post graduate levels.
- To develop professional training related to earth observation.

Initiatives

- To develop and encourage educational materials within national curricula of schools.
- To provide undergraduate, postgraduate and professional training that aligns with that undertaken in other countries with significant capability in earth observation science, including the United States and China.
- To review, revise and coordinate earth observation course content across universities and colleges that is both broad but focused and interdisciplinary.
- To provide dedicated short courses and online training and facilitate academic support (e.g., for software and environmental assessment).

Measuring progress

- The number of earth observation related materials in school curricula.
- Numbers of students enrolled on higher education courses and opting for course and/or courses with an earth observation component.
- National and international recognition of the quality of courses in Welsh Universities.
- Cooperative arrangements between higher education institutes in earth observation teaching and training.
- Completions of professional training modules by individuals and groups from businesses and industry.

RESPONDING TO POLICY

Living Wales is designed to be independent but fully supportive of policy, sustainable economic development and environmental management and contribute information that can be used to monitor and plan for change, particularly if exerting and adverse impact on the environment. *Living Wales* will also be adaptive and responsive to policy by:

WELL-BEING OF FUTURE GENENERATIONS ACT (2015)

- Securing a share of the global market in earth observation and best value for money from existing investments (**Prosperity**)
- Providing capacity to sustainably manage Wales' natural resources (**Resilience**)
- Supporting expansion of green spaces and monitoring air and water quality and encouraging environmental engagement (**Healthier populations**)
- Providing open source and freely available data to the whole community, thereby increasing transparency and enabling use of a common evidence base (**More equal society**)
- Increasing citizen involvement in environmental governance, sciences, monitoring and conservation through ground data collection via citizen science and bringing organisations, groups and individuals together for a common goal (**Cohesive communities**)
- Providing a catalogue of environmental data backdated to at least the 1980s with enhanced ability to detect and monitor historical sites (**Vibrant culture**)
- Contributing world leading science to assist national and international environmental monitoring (**Globally responsible**)

ENVIRONMENT (WALES) ACT (2016)

- Reversing biodiversity declines but also enhancing biodiversity, by informing decision-making and planning of restoration for degraded and lost habitats and ecosystems.
- Establishing potential impacts of and responses to climate change for the Welsh population and its native flora and fauna.
- Making progress towards meeting greenhouse gas emissions targets, including from land use, land use change and forestry, and promoting low carbon energy and high carbon environments.
- Encouraging effective use of water resources.
- Responding to flooding and coastal erosion.
- Strengthening planning and management of natural resources.
- Contributing to land management agreements.

HISTORICAL ENVIRONMENT WALES ACT (2016)

- Characterizing, registering and monitoring historical sites, parks and gardens
- Providing a new digital resource documenting land cover and habitat change across Wales over at least the past 50 years.

THE PLANNING (WALES) ACT (2015)

- Facilitating planning of urban space and infrastructure
- Supporting expansion of green spaces and recreational areas.

SMART SPECIALISATION IN WALES

- Generating nationally-focused but globally relevant and internationally recognized research and activities that sustain *Living Wales* into the future.
- Providing products and services that render *Living Wales* and indispensible national asset.

WELSH GOVERNMENT OPEN DATA PLAN AND SERVICE

- Delivering open data resources, including specialized software for processing and analysis of earth observation data

TAKING WALES FORWARD

- Developing hubs of expertise
- Increasing all sector employment through earth observation.
- Connecting and uniting Wales in support of sustainable development.

SUSTAINABLE DEVELOPMENT CHARTER

- Ensuring resilience and sustainability through earth observations to inform sustainable management of natural resources (SMNR).

SCIENCE STRATEGY FOR WALES

- Supporting and promoting the innovation strategy by increasing collaboration, openness and inclusiveness.
- Creating a critical mass of individuals and organisations with ability to fully utilize earth observation data for a wide range of environmental applications.

NATIONAL RESOURCES MONITORING

The NRMF has the vision to service the need to deliver the full economic potential of Wales' natural resources. *Living Wales* will contribute the following input to the NRMF

NATURAL RESOURCES

Spatial information on the changing state of natural resources in Wales, namely vegetation, water, soils, air, rocks and sediments and faunal diversity to optimized long-term social and economic benefits.

MONITORING

Historical and near real-time monitoring at a national level, contributions to the coordination of sampling and surveying and target and optimized analysis and interpretation of natural resources.

PROGRAMS

Reviews and evaluations of the design and impact of past and future monitoring programs, including Glastir, though historical and predictive analysis of earth observation and supportive ground datasets.

INFORMATION

Diverse earth observation and ground data that are efficiently delivered as and when required and meet internationally acceptable standards of uncertainty and error.

EVIDENCE

Information from multiple sources to underpin reporting, legislative requirement and commitments and adaptive and responsive approaches to evidence gathering.

TECHNOLOGY

Research and training on and access to new and existing technologies that enhance and standardize remote and ground based environmental monitoring across Wales

MODELLING

Inputs to process models that inform on past and predict future changes in resources and model-based testing of scenarios to underpin data interpretation and policy

POLICY

Advice and information that supports the development and understanding of past, current and future policies, including those outside of WG Environment and Rural Affairs portfolios.

SURVEILLANCE

Facilitate the inclusion of professional and volunteer structured surveys and unstructured records to develop and validate monitoring capability from earth observation.

ENGAGEMENT

Engage with Welsh government, its agencies and the public and private sectors and promote Wales's position at the forefront of collaborative and innovative working.

COORDINATION

Linking with the NRMF coordination board to provide guidance and advice on earth observation and supportive ground datasets.

ECONOMIC S

Build capacity and increase funding into Wales by developing and implementing innovation and novel solutions.

HEALTH AND RESILIENCE

Promotion of social and economic benefits through knowledge exchange