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Options for a New Integrated Natural Resource Monitoring Framework for Wales

Project Document

Briefing note: The Potential of Earth Observation Data for Environmental Monitoring in Wales

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Options for a New Integrated Natural Resources Monitoring Framework for Wales

Project Document - Briefing note:

The Potential of Earth Observation Data for Environmental Monitoring in Wales

Three documents are presented here.

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Briefing note:
The Potential of Earth Observation Data for Environmental Monitoring in Wales

Preface

1. **Earth Observation**

Advantages and disadvantages

Main message: there are certain aspects that EO does very well. A simple approach or an approach focussed on one feature or variable is often very effective. Reliable monitoring can only be achieved when EO is combined with some form of field surveying. EO inherently has limitations which should always be kept in mind.

Advantages:

- EO provides a bird's eye view and allows the surveying and monitoring of dangerous, remote and restricted areas.
- Satellite EO can achieve a complete coverage of Wales in a very short period of time.
- EO data is spatially and temporally consistent, available at a range of spatial and temporal scales and delivered through a variety of means (e.g. satellite, aircraft, drone).
- A wide range of EO data is freely available and relatively easy to access.
- EO can detect that something has changed significantly, e.g.: change in land cover, and through time series of simple variables some more subtle changes or trends, e.g.: land subsidence, changes in management, changes in river corridor integrity.
- EO can accurately and easily map and detect changes between core land cover classes (for example, bare, artificial surfaces, non-woody vegetation, woody vegetation, water), many of the field crops, most broad habitats and many finer habitat classes.
- Other cover classes that are mapped relatively well are burnt areas, bare sand, wet versus dry land, flooded non-woody areas, bracken in non-woody areas, dead vegetation, Rhododendron when using hyperspectral data.
- EO can measure height and produce accurate digital surface and terrain models, which is particular effective for hedgerow, shrub encroachment, tree and woodland monitoring.
- EO can often detect vegetation affected by diseases or pests.
- EO can measure woody biomass (when the biomass is low).
- EO can detect land subsidence.
- When collected at high temporal frequencies it can measure dynamics within and across years, potentially providing useful ecological information about condition (e.g. grass productivity, coastal and large lake algal blooms).
- Once methods are established, and despite the large volumes of data, processing of EO to produce consistent measures can be highly automated

Disadvantages:

- EO always requires some form of field based calibration and validation.
- Cloud affects the availability of optical data and although a higher frequency of satellite acquisitions is improving the chances of cloud free observations, there will be areas in Wales which will still have a limited cloud free coverage.
- High data access costs often excludes extensive use of certain observation types for frequent (e.g. annual) and large area monitoring. These are either delivered through airborne campaigns (aerial photography, Lidar), or are very high spatial resolution (cm to m) multi-spectral optical satellite imagery (e.g. World view).
- Free satellite imagery is only available at 10 m resolution or above and so often cannot provide the very detailed spatial information required to map or monitor small patches of cover (e.g. field margins or habitat mosaics within a land parcel). A general rule is that the required spatial resolution of the data should be half the size of the smallest feature of interest.
- The spatial detail if the EO data has a direct impact on the resulting change statistics that can be obtained.
- Aiming for a high number of cover classes will invariably lead to lowering the mapping accuracy of these classes.
- Some cover classes require more effort to accurately map and monitor.
- There are some cover/habitat types and features that cannot be mapped using EO.
- Many useful physical surface and atmospheric characteristics (e.g. surface temperature, soil moisture, surface albedo, atmospheric CO_2, atmospheric Ozone) can currently only be derived at very coarse spatial resolutions (1km or above).
- A steep learning curve to utilise tools and technology, especially with radar.
- The volume of data is great and is expected to increase further

Implementation

To date, the most effective EO based approach to monitor for significant changes and update a land cover map is by searching for anomalies in the EO data (i.e. a hotspot of change map based on unexpected signals, typically derived from NDVI) followed by targeted more detailed investigation of these areas (whether through further EO based approaches or visual interpretation of aerial photography or in-situ surveying). Several operational examples exist (e.g. Forestry Commission to monitor forested land; Milton Keynes Council to monitor urban planning; Natural Resources Wales to update the Landmap).

We should expect the EO derived products that are currently available to be updated more frequently. We should aim for more integrated monitoring systems based on a combination of EO technology providing information at a range of spatial and temporal scales and underpinned by field surveys, networks of ground-based observations and possibly models.

Field observations are crucial to establish a robust link between the surface variable of interest (e.g. land cover class, condition measure) and the EO data. There is a strong case for using EO data in conjunction of environmental and biogeographical predictors such as aspect, elevation, soil type, and climate. Links can be established using existing historical field and EO data and continuously improved, incorporating newly collected field and EO data. Field observations are also required to validate the EO derived surface variables.

Sentinel-1 and-2 will be the main sources of EO-data for land cover mapping, including CORINE land cover.

The Sentinel-1,-2 and-3 satellite series are set to provide more frequent and spatially detailed data from 2015 onwards. For example, Sentinel-2 will revisit the same location every 3 to 5 days which is 4 times more frequent then Landsat (formerly the main source of data for land cover mapping) and provide imagery with pixels as small as 10m (compared with 28m for Landsat). A high revisit frequency increases the chances of cloud free data which will in turn improve the quality of the mapping and monitoring.

Also, the availability of free high frequency data at higher spatial resolutions opens up the opportunity to monitor in greater detail the land surface and vegetation as it changes on a weekly basis. This could be exploited in particular to determine and monitor grassland management practices, establishing grazing or cutting regimes, but requires testing.

The only solution to frequent cloud coverage is radar. Sentinel-1 will provide frequent and high spatial resolution radar data. Although radar 'sees' the landscape differently from optical, it is now being considered as a complimentary source of information in land cover mapping for areas where cloud cover is persistent. However further research and development funding will be required for radar based mapping to become fully operational.

The UK Land Cover Map is currently being updated for 2015 by CEH, this version and any other future versions will be pixel based. By keeping the land cover information in a pixel format it can easily be summarised to fit any custom defined spatial framework. Updating the UK LCM annually is operationally possible but requires external funding.

The Land Cover plus Crops is a newly developed annually updated layer (from 2015 onwards) which enhances the UK LCM with Crop information. This product is a joint venture between CEH and RSAC ltd. First validation results show that the level of accuracy that can be achieved is crop specific. The Crop layer is currently mainly based on sentinel-1 radar data, however there are plans to incorporate the interpretation of time-series of Sentinel-2 data to add information about crop health.

The provision of annually updated land cover (LCM) and use (LCM plus Crops) at the available spatial resolutions (10m to 30m) would greatly benefit current LULUCF estimates and related GHG accounting.

CORINE land cover: The first three UK CORINE products (1990, 2000 and 2006) were derived from the UK LCM through semi-automated generalisation and updating procedures. The latest version, CORINE 2012 was produced through identifying changes from CORINE 2006 using visual/manual interpretation of EO imagery following the standard procedure implemented by the majority of the European countries. Future updates are expected to continue with Sentinel-2 imagery as the main data source.

The production of 2015 very high resolution (~ 5m) layer products for Europe are being initiated by the European Environment Agency: Impervious layer; Forests; Grass and non-woody vegetation; Wetness and water; Small woody features. The accuracy and spatial consistency of the pilot products generated previously varied substantially, with the 'Impervious layer' (urban) being the most successful and the 'Grass' product requiring a total rethink of the implemented approach.

EO related costs:

Setup costs will be higher than running cost. The relative difference will depend on the complexity of the processing chain, the number of different types of EO data that the monitoring approach will require, the existing hardware and software, and the initial experience of the staff involved and amount of training required.

Running cost will be dependent on the type of EO date being used (free or commercial data), the degree of automation in the processing chain and the frequency of the monitoring. Further cost savings could be achieved by making the required field work (for validation and calibration) as effective as possible through well-developed sampling designs, targeted surveying or field data sharing.

The most affordable and effective EO based options will be the ones that

- are based on well-established or tested approaches (i.e. repeatable in space and time)
- require the least pre-processing or well-established automated pre-processing
- exploit existing field based monitoring
- are targeted to deliver a single measure (e.g. Forest cover; productivity; area of change; a basic set of cover classes)
- avoid duplication of effort (e.g. archives of pre-processed data and intermediate products)
- maximise the use of free data and open source software.

Interpretation

EO based applications rely on the conversion of the raw EO signal into useful information about the environment, land or water surface. Depending on the information required, the approaches, algorithms and models used for the conversion vary widely. These also tend to develop with time as both our understanding and technology evolves. For monitoring the key is to maintain consistency in the information that is retrieved from the EO data. Consistency is affected by the several factors: changes in sensor design between missions and sensor deterioration within the lifetime of a mission, changes in pre-processing steps (e.g. improved correction procedures), changes in the approach used to interpret the data (e.g. improved model). This can be managed through version control, detailed documentation of processing chains, product validation and the reprocessing of the historical data with the updated procedures. When re-processing is not an option, the monitoring approach should include strategies for avoiding or managing these inconsistencies.

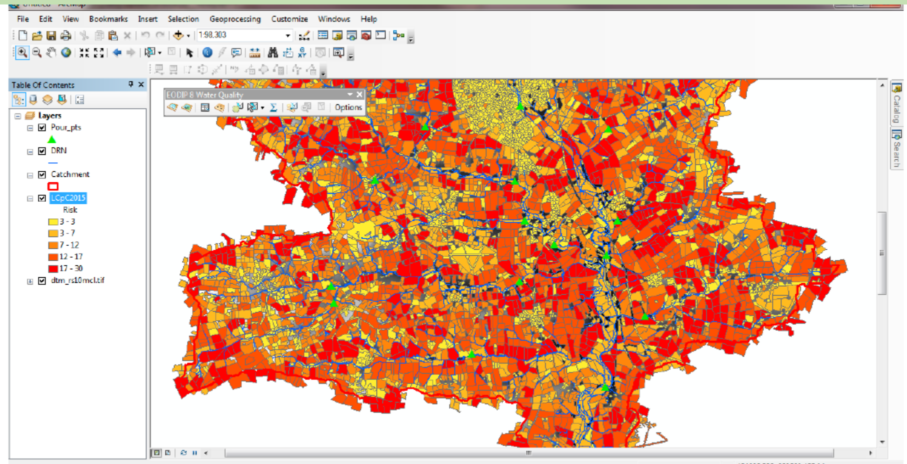
Certain EO image processing options are prone to delivering inconsistent outputs and should therefore be avoided. For example, segmentation an approach used by the NRW Habitat Map of Wales, UK LCM 2000 and the Living Maps to divide the landscape into parcels is sensitive to variations in spatial landscape patterns. Defining the segmentation input parameters which determine the resulting parcel size distributions is very subjective. Working at pixel level avoids this potential source of inconsistency.

For enforcement purposes the information provided from EO has to be accepted by Regulation and Policy as quantifiable evidence. In this context, validating the information derived from EO in a manner that satisfies Regulation and Policy is particularly important.

Experience to date

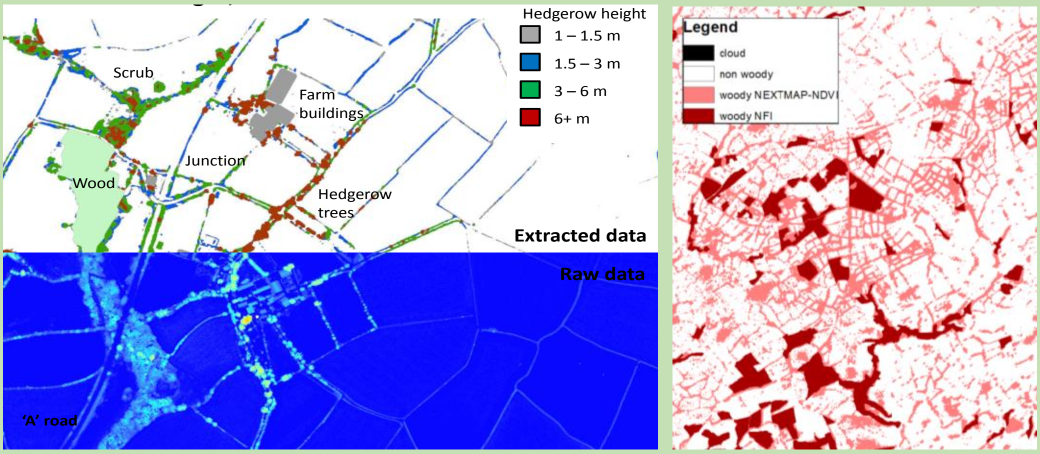
Case study: Currently in England water quality is determined through ~250,000 samples annually taken from 19,000 chemical and 6,900 ecological Water Framework Directive monitoring sites. Many sites show little change. Landcover Plus – Crop Map produced from Sentinel 1 radar data, combined with soils, slope, altitude, groundwater and rainfall data has enabled the development of a prototype system to support the targeting of monitoring effort to a smaller number of priority sites with the aim of enhancing the efficiency of EA's national water quality monitoring programme in

England. Tools built to utilise these integrated data will also help with field investigations into the causes of water body failures.



The figure shows modelled weightings of risk factors to create a heat map for a catchment. Image source: Defra Earth Observation Data Integration Pilot Project.

Case Study: EO can accurately measure height using Lidar, radar or stereoscopic aerial photography. The degree of spatial detail and vertical precision that can be achieved is dependent of the spatial resolution of the data and the technology used, respectively. Height data, when combined with a greenness measure can deliver detailed maps of hedgerows, and woody vegetation (line of trees, shrubs, small woodland patches). The image below shows 2 examples of such a map.



Left: a hedgerow and woodland map derived using height information from airborne Lidar, open-licence Ordnance Survey Vector Map data and the Forest Commission's National Forest Inventory dataset; Right: a map of woody vegetation derived using height information from aerial photography (NEXTMAP), greenness information from satellite NDVI and the Forest Commission's National Forest Inventory dataset.

Case study: Operational algorithms exist to detect and monitor algal blooms and sediments in the surface waters along the coast or in large lakes. The methods require multi-spectral narrow bands observations which so far were only available at coarse spatial resolutions (1km and above). The Sentinel-3 satellite series (launch in 2016 and 2017) will soon enable operational algal bloom monitoring at higher spatial resolutions (300 m). The image below is sourced from a publication (Ryan et al 2014) and compares a range of algorithms developed to detect algal blooms in Monterey Bay (USA).

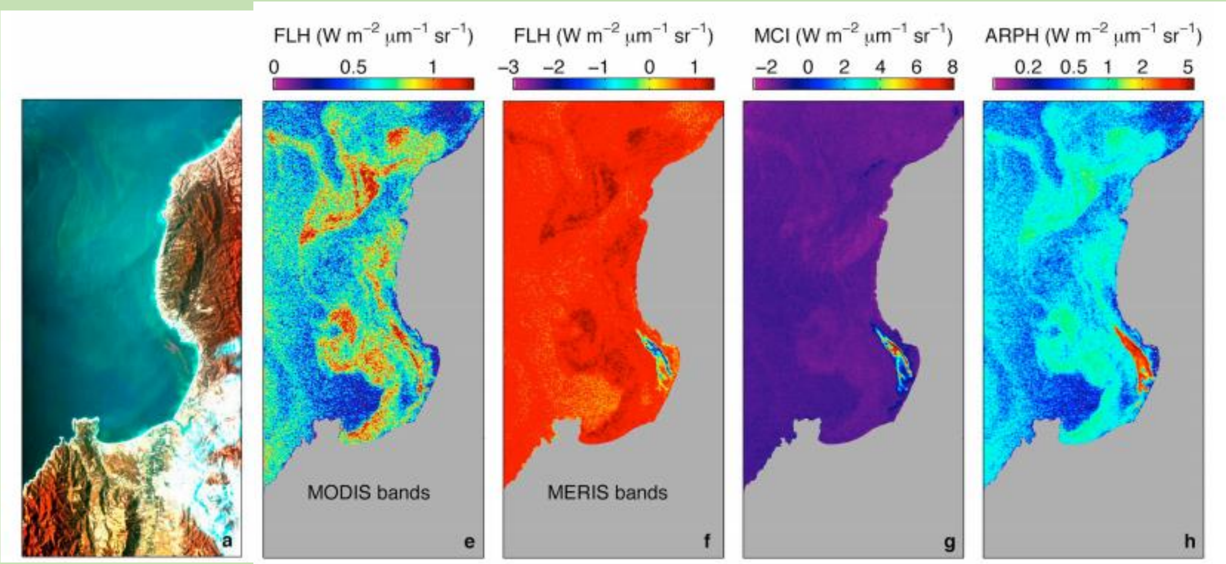


Image Source: Ryan JP, et al. Application of the Hyperspectral Imager for the Coastal Ocean to phytoplankton ecology studies in Monterey Bay, CA, USA. Remote Sens 6:1007–1025 (2014); doi: 10.3390/rs6021007.

Case study:
Unmanned Airborne Vehicles or Drones are becoming increasingly more affordable. The most basic of data captured by a £1000 drone and camera setup (see image below) can quickly be converted into a spatially detailed digital surface model and RGB image allowing for a quick reconnaissance of an area in support of field surveying. More expensive setups ranging from £50K to £100K are being investigated for monitoring vegetation condition. The area coverage that can be achieved is typically small.

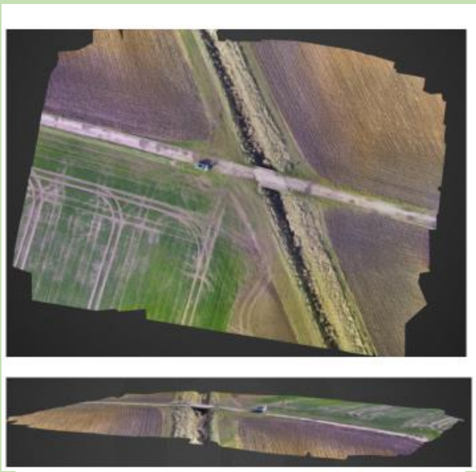


Image source: CEH

Case Study: A detailed new assessment of the extent and condition of the full Welsh peat soil resource was carried out based on an integrated analysis of BGS soil mapping data, CEH land-cover data and the use of aerial photographs to identify and map drainage ditches. This work has enabled the generation of spatially explicit emission factors for peat soils impacted by changing land use across Wales (see image below). Work is ongoing to generate a UK wide map of wetland soils and modification using a similar approach.

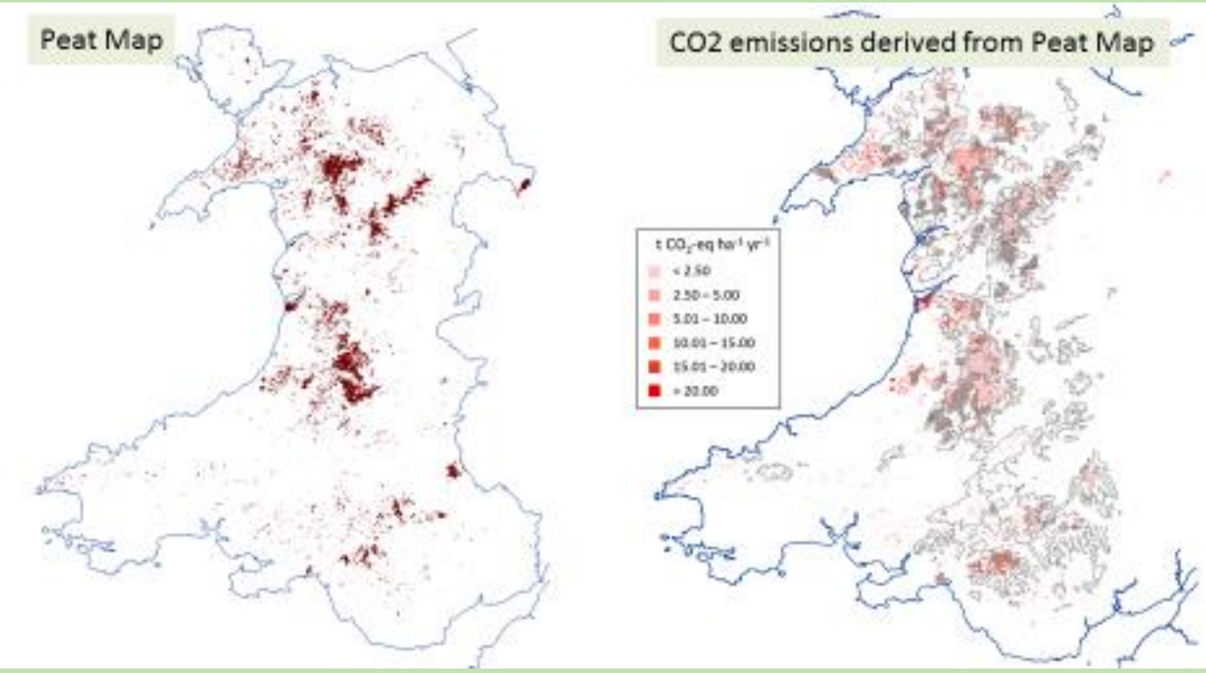
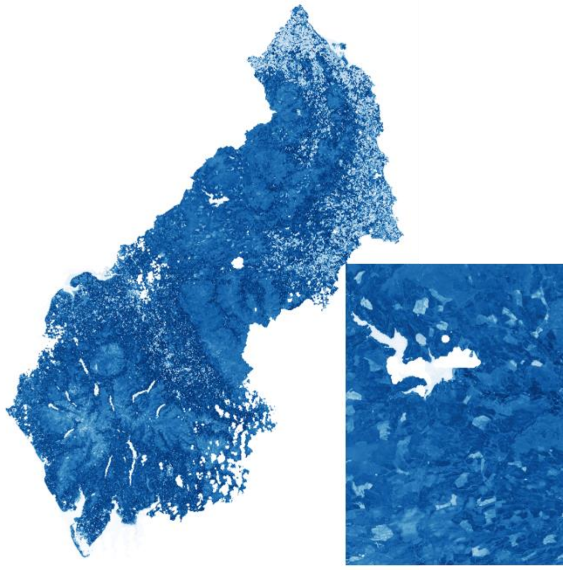


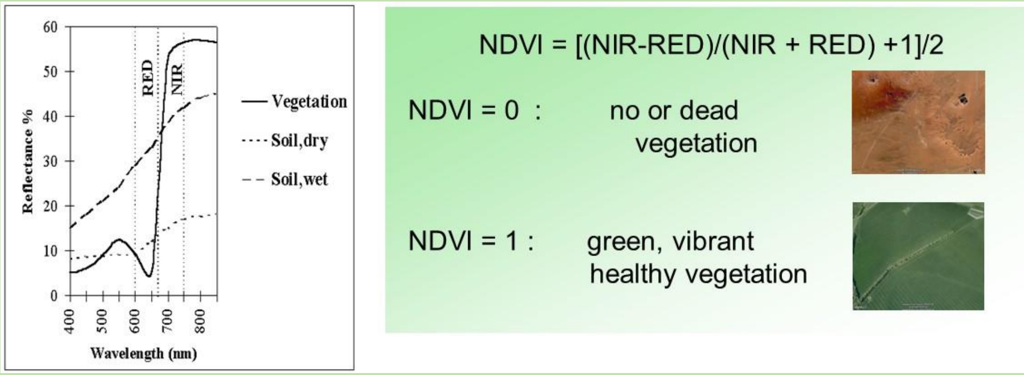
Image source: CEH

Case study: Normalised Difference Vegetation Index (NDVI) as an intermediate product. An EO Data Integration Pilot (EODIP) project on the generation of intermediate products clearly demonstrated how this can be achieved with a very high degree of automation using the available Landsat data. The next steps to progress this work will include establishing an automated process for Sentinel 2. Sentinel 2 can generate large volumes of data, but the maximum it could be for all of the UK, assuming that all images were cloud free and stored would be 82TB. This includes 2 indices being stored as well as the processed imagery. Although this is a large amount of data, the processing and storage is readily achievable at modest operating cost, based on other EODIP findings.



Example of standardised NDVI product based on Landsat data. Image source: Defra Earth Observation Data Integration Pilot Project.

Case study: EO derived Vegetation Indices such as NDVI are very effective to monitor the greenness of vegetation over time. Figure below shows how NDVI was successfully linked to field based Above ground Net Primary Productivity (ANPP) which is used as an indicator of how improved a grassland is. The model used 296 plots collected from 82 x 1km^2 Countryside Survey samples. The model performs best for EO data acquired in spring (e.g. May)



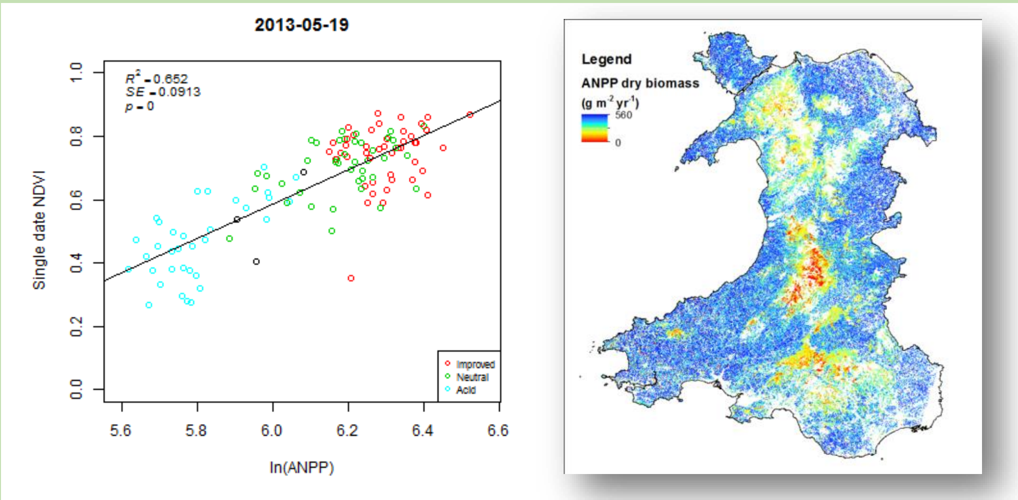


Image Source: CEH

Current assessment of technology

Could you try and fill in attached following traffic-light scheme:

	Local / investigative	National monitoring	2-5 years	➢ 5 years	Comments
Land cover		UK LCM; UK LCM + Crops; National Forest Inventory (with triennial loss/gain all woodland >0.5Ha). Updating Landmap of Wales through identifying hotspots of change. Derivation of landscape metrics from Land cover	Annual updates of UK LCM; and LCM + Crops; NFI; UK wide hotspot of change map linked to field or higher resolution data, provide drivers of change information as is already done in NFI and for Landmap of Wales. Coarse resolution monthly global night light products provide information on urbanisation and light pollution: http://commercedataservice.github.io/tutorial_viirs_part1/	Additional condition layers added to the UK LCM	EO is the only cost effective method for national land cover. Accuracy and consistency of maps is key for reliable monitoring.
Habitat area	Detailed maps produced using aerial and satellite data can be used to target field investigations (eg; south Glamorgan, map was starting point that updated unimproved grassland mapping) or change detection (as in Warwickshire).	National Scale mapping possible but requires high spatial resolution imagery, field validation and expert input (Wales Phase 1 update, Peatland); Resource intensive, so main contribution is to provide spatial framework for future change detection and condition monitoring	Opportunities to improve stock (area) and range of habitats features accurately detected, e.g: Wales Lidar coverage (as planned in England) would provide very accurate tree/hedge asset. Coastal airborne hyperspectral - Lidar (e.g. England) provides opportunity for very accurate coastal habitat mapping.	Convergence with Land cover mapping – more habitats can be detected as availability of higher resolution satellite data (higher frequency, lower cost) improves.	Detecting habitats at a finer classification than broad habitats in land cover is more resource intensive. Accuracy and temporal consistency needs to be proven. EO cannot identify all habitats, but the range of habitats that can be determined reliably will increase.
Habitat condition	Research is currently focussing on this topic. Variables with real scope: % bare ground, % dead material, % woody cover, forest density, 3D structure, productivity, wetness and surface temperature	Investigating hotspots of change within a spatial framework with targeted field effort or higher resolution data would characterise change in condition and give drivers of change.	Building up research and knowledge base to interpret seasonal and multi-year signals for variables that can be generated and analysed within the spatial framework of habitat or land cover maps. Linking to drivers of change (grazing, cutting, drainage etc). Some methods are already established eg: detection of moorland burn with radar.	Range of variables that can be reliably interpreted is likely to increase through the use of more sophisticated methods combining EO data and other data with physically based models.	Whilst variables can be efficiently calculated across Wales, understanding their significance will be habitat specific and monitoring effectiveness will vary with habitat.

	Algal Blooms in surface waters of large lakes and along the coastline.				Algal Bloom monitoring is limited to large water surfaces free of vegetation.
habitat diversity	Is based on using proxies which will rely on condition measures	Being used to assess habitat diversity for Wales already e.g. for GMEP			Will always be derived by proxy and may never be as effective as field surveying.
Soil & GHG		Peatland condition map in Wales	Improved peat mapping through a dedicated airborne campaign; Inclusion of annual LCM and Crops and soil moisture information into GHG accounting	Improved peat mapping through a dedicated airborne campaign; Inclusion of annual LCM and crops, soil moisture information into GHG accounting	Further research improving retrieval algorithms and models will make this possible.
Waters		EA Pilot used UK LCM + Crops to identify high risk area and target sampling	Hot spot of change map or LULUCF from annually updated LCM, combined with UK LCM + Crops rotational data helps identify high risk areas and target sampling.		
Animals	Density of life stock, through patterns recognition and counting of animals from very high spatial resolution imagery	Tracking greenness of woody vegetation in time is used to predict deer movement.			Examples exist, however a more feasible option could be analysing the animal movements dataset held by RPA/AHPA to establish stock densities spatially.
Health and disease	Still under development. EO could support the prediction of pollen densities, levels of Ozone, tick, midge or mosquito densities using spatially detailed land cover combined with other EO derived variables, models and ancillary data.				Research is being carried out. The degree of success will be determined by the suitability of the EO data and effectiveness of models.
Extreme weather events	Mapping of flooded areas locally is done operationally at national level.	Impact of weather extremes on cover/habitats; through combined use of models EO and networks of in situ			Research is being carried out to better establish the impact of weather extremes. The degree of success will be determined by the suitability

		observations (e.g. weather, soil moisture, phenology)			of the EO data and effectiveness of models.
Archaeology	Local manual mapping of archaeological features using aerial photography or LIDAR data.	National mapping of archaeological features is possible through a rolling programme of manual interpretation.			Implementation is solely dependent on finance. Cost of manual interpretation by expert staff is high. Cost reduction is possible by combining with other EO surveys.

Data and informatics

EO data has to be acquired from the supplier, stored and distributed. Easy access of (archived) data to build up time-series is important. EO data also has to go through some form of pre-processing before it can be used. The pre-processing varies with data type. For example, optical data requires an atmospheric correction, a correction for topographic shading, conversion to reflectance and geo-registration, and in certain circumstances a correction for effects of a varying viewing and solar angle geometry is also required.

Certain intermediate products such as vegetation indices (e.g. NDVI for greeness, NDWI for wetness), cloud and cloud shadow masks or snow masks are used repeatedly for a variety of applications. The ability to build up and make available long term time-series of pre-processed data and intermediate products will enable future long term trend monitoring.

A centralised national hub that acquires, stores, pre-processes and distributes standardised and version controlled EO data and intermediate products relevant to national monitoring would avoid duplication of effort, cut cost and expedite the use of the EO data (e.g. NASA's tool: REVERB http://reverb.echo.nasa.gov/reverb/). Plans exist for UK focussed Sentinel data distribution points (e.g. http://sedas.satapps.org/) however these will not necessarily include intermediated products and other relevant EO data sources. One of the DEFRA EO strategy goals is to have by 2020 *"Secured access to data handling infrastructure and operators so that the rapidly growing sets of data and information products can be used efficiently to meet our policy and operational needs."*

Similarly, certain downstream products such as a generic UK land cover map, Wales character map, a digital terrain model, a hotspot map of change will assist a variety of users and so would benefit from a centralised data management approach.

Most applications use freely available EO data. However, some applications will remain dependent on expensive EO data such as airborne data (e.g. aerial photography, Lidar data) or very high spatial resolution (< 10 m) multi-spectral satellite imagery. These type of data are critical to identify and monitor small or narrow landscape features and land parcels. Procurement of country wide coverage for shared data access is the most cost-effective. For example, in 2010 a full coverage of Rapid eye imagery was acquired for the territory of France; The Netherlands have a rolling programme of Lidar surveys and procured near-daily DMC imagery (30m) for 2012-2016 period.

Next steps / immediate opportunities for development as a monitoring tool

Immediate

- Investigate feasibility and cost of securing Lidar coverage for Wales by adding Lidar acquisitions to the Welsh rolling 3 year aerial photography campaign (e.g. investigate combined aerial photography/Lidar Surveys in other European countries and the England plan for 1m Lidar coverage).
- Stimulate engagement and thinking across community (Wales and UK) to identify the types of change and drivers of change that EO is likely to help deliver through the derivation of simple reliable Wales-wide variables such as NDVI and the implementation of current operational or near-operational systems which are geared towards monitoring and change detection (e.g. UK LCM plus Crops, algal bloom monitoring, a hotspot map of change as one of the variables for risk based monitoring).

- Instigate an expectation that anything developed within Wales would be shared and developed as part of a wider community of practice.
- Review the projects underway through the EO Centre of Excellence to see which may have relevance for Wales.

Next steps:

- As overall priorities for information are clarified use a tiered approach to help find efficient solutions using EO's strengths combined with the strengths of other methods eg;
  - First the lowest cost/unit area: establish which parts of the requirements can be met Wales-wide through automated processing of freely available EO data (Sentinel-1 radar, Sentinel-2 optical, Sentinel-3 optical and thermal, other data) combined with relevant field sampling.
  - Secondly which parts of the requirement can be met by adding the three year aerial photography refresh (and Lidar if added) to determine and analyse change within existing data sets or spatial frameworks (e.g. LCMUK, habitat phase 1, Landmap, etc)
  - Thirdly which more subtle or detailed changes can be picked up with localised or targeted use of much higher spatial resolution data from satellites or drones, combined with field effort
- Following the Welsh Government's investment in developing a pre-processed Landsat Archive for Wales, develop a coordinated approach to the acquisition, pre-processing, production of intermediate products and distribution of EO data. Focus on data from Sentinel 1 and 2 in first instance but consider other relevant EO data sources. A UK level partnership may proof beneficial. The Defra EO strategy is working towards acquiring this capacity by 2020.
- Consider supporting research into monitoring using radar or combined radar, optical data: monitoring grassland management using time-series of radar and optical data.
- Evaluate the added value of expensive very high spatial resolution world view imagery to provide multi-spectral data with higher spatial resolution than Sentinel-2. Based on outcomes, consider the procurement of this data (consider a UK wide procurement).
- Evaluate the potential for using the very high spatial resolution EO-derived products planned by Europe.

Briefing note:
The potential of Earth Observation data for Environmental Monitoring in Wales

1. Brief description of technology

The terms Remote Sensing and Earth Observation cover not one technology, but a wide range of technologies that can be implemented for environmental monitoring in different ways. A full coverage of all available technologies is beyond the scope of this briefing note (see Appendix 1 for further info). The nature and capability of EO technologies vary depending primarily on the platform and the type of sensor. A wide variety of platforms are currently available, including satellite, aircraft, unmanned aerial vehicles (UAVs or drones), fixed ground instruments (often in networks) and mobile ground vehicles (e.g. unmanned robots or tractors).

A range of sensors are available, with the most common being optical sensors, radar, Lidar and thermal sensors (further detail is given in the Appendix). Optical sensors measure reflected light in wavelengths humans can see and cannot see. The radar signal responds to vegetation structure (i.e. tall, short or dense) and vegetation/soil moisture content, and in some circumstances can be processed to estimate height i.e. 3-d information. Lidar uses laser pulses to measure height and is typically used to produce very high resolution digital elevation models. Thermal sensors measure water or land surface temperature.

The constraints of the sensing technology and the limitations of the platform, along with a range of other variables including weather, military operations and other operating restrictions, affects the frequency (i.e. the time between repeat images of a site) of observations, the spatial scale of the observations, the spatial extent of the coverage and the cost. Satellite sensors offer panoramic and regular repeat views and so are better suited for wide-scale monitoring (i.e. national or greater). Airborne sensors generally have a much higher spatial resolution, but with narrower geographic and temporal scope so are limited to more targeted, or sample-based monitoring. Data acquired from airborne sensors are sometimes used for calibrating or validating satellite derived measurements. For monitoring change access to repeat observations that capture seasonal variations is key. Cost effective monitoring strategies will come from intelligent combinations of multi-scale EO data and field sampling. For example coarser spatial resolution satellite sensors can locate change that targets the use of higher cost very high spatial resolution data, or to optimise field samples to pick up what cannot be done remotely.

The type of EO dataset used affects the characteristics of the information that can be derived. Identifying appropriate methods and EO datasets for monitoring requires the feature(s) of interest and the expected update frequency to be clearly identified, but with flexibility in how these are measured, as EO may be able to measure proxies cheaply, allowing a more targeted approach to direct measurements. Ground based reference observations are essential for the interpretation and validation of EO data so the most effective monitoring strategy is one that integrates ground observations with EO.

For the purposes of operational monitoring, any EO derived data product should ideally meet the accuracy and precision level required for its purpose and have its uncertainty well documented and quantified. It should also be spatially and temporally consistent and repeatable.

The use of EO data for an application is determined by the cost of the data and the four main characteristics of the available data source:

- the type of sensor available (e.g. optical, Lidar, radar)
- the spatial detail (spatial resolution) of the observation
- the repeat frequency (temporal resolution) of the observation, this is particular important for optical data which are affected by cloud, or for applications that require a time-series of observations to capture within year dynamics.
- data continuity – for applications requiring a comparison with a long term baseline, comparable EO data (i.e. data from similar sensor-platform setups) need to be available from the past, present and future.

This review will focus on the type of data products that can be derived from EO data, rather than the underlying EO data.

2. *Applications and current state of development*

There is a strong principle of collaboration within the EO field in the UK creating opportunities to build on wider best practices and successes.

A range of products that use EO are already available for Wales including a range of complete coverage products (UK land cover map series; updated Phase 1 Habitat Map of Wales; NFI), some that focus on specific land cover types (CEH Land cover plus: crops 2015; GMEP woody cover); products that quantify one aspect of condition (GMEP ANPP; vegetation parameters; the Welsh Peat Map) and finally a network of fixed sensors (COSMOS-UK soil moisture and phenology cameras). EO is a rapidly developing area with other products under development through Copernicus or other organisations, such as EODiP MEOW.

UK Land Cover Map Series

Three UK-wide land cover maps have been produced for 1990, 2000 and 2007 at a spatial resolution of ~25m and a map for 2015 will be complete by the end of the year. This will provide Wales with a land cover map with 23 land cover classes, based on Broad Habitats, for 4 time points. Currently, there are issues with accurate, robust mapping of change over time, which is complicated by the spatial and thematic differences between the existing maps, however, methods are being developed by CEH that would resolve some of these issues.

Updated Phase 1 Habitat Map of Wales

The original field-surveyed Phase 1 Habitat Survey of Wales (surveyed 1979-1991) represented the primary spatial dataset of semi-natural habitats and the extent of agriculture across Wales for many years. Driven by a strong user requirement for up-to-date and accurate habitat data for Wales, an alternative approach to discriminating and mapping habitats was implemented by Environment Systems and Aberystwyth University using image segmentation and rule-based classifications applied to SPOT-5 and other satellite sensors to generate a revised Phase 1 map of habitats in Wales for 2006.

CEH Land cover plus: crops 2015

The CEH 2007 land cover map has been enhanced with updated crop information for 2015. A time series of Sentinel-1 radar data have been used to produce the 2015 crop data, with more than 350 individual images of the UK being processed covering the whole crop growing season. The crop classes in 2015 are winter wheat, winter barley, spring barley, oilseed rape, field beans, potatoes, sugar beet, maize, other (vegetable crops, oats, rye, peas and early potatoes and maize) and improved grass. The map is currently being validated. The plan is to deliver an annually updated product.

National Forest Inventory

All woodland areas larger than 0.5 ha are available as a GI layer, with a tri-annual (soon to be annual) EO based update based on detecting wood loss and new planting. There is research underway managed by the Forestry Commission through the Defra EO Centre of Excellence that is looking at how to improve the range of canopy related information and size of woodland unit that can be detected using Sentinel 1 radar data.

GMEP EO work

The aim was to extrapolate information gathered from the 1km GMEP survey squares to a Wales-wide coverage and so enhance the monitoring and mapping of High Nature Value farmland. So far two products have been developed.

- ANPP – Aboveground Net Primary Productivity, based on a calibrated relationship between spring satellite imagery and GMEP x-plot field data. Due to the requirement for spring-imagery, a complete coverage of Wales may not be possible every year.
- Woody Cover – map of woody cover features such as copses and treed hedgerows that are not identified by the LCM or National Forest Inventory (i.e. <0.5ha), but play an important role in landscape connectivity.

Vegetation parameters

Research with CEH, more recently Environment Systems, and others has identified the potential to use Sentinel-1 and -2 derived parameters to help determine aspects of habitat condition (productivity [see above], scrub cover, bare ground and dead material). In combination with land cover mapping (eg: UK Land Cover Map, Updated Phase 1 Habitat Map of Wales) this provides the opportunity to monitor at site to national scales drawing on comparisons within season and between years. JNCC is developing a service to provide parameters to support condition monitoring covering the countries of the UK.

Welsh Peat Map

This is a detailed new assessment of the extent and condition of the full Welsh peat soil resource, based on an integrated analysis of soil mapping data, land-cover data and the use of aerial photographs to identify and map drainage ditches. This work has enabled the generation of spatially explicit emission factors for peat soils impacted by changing land use across Wales. Work is ongoing to generate a UK wide map of wetland soils and modification using a similar approach.

COSMOS-UK network

The COSMOS-UK network is a fixed sensor network established to represent the variety of soils, climates and land-uses across the UK. The network is primarily designed for measuring soil moisture, but also includes plant phenology observations from a camera, and a weather station. It is included here as an example of a different type of remote sensor, but one that is likely to play an increasing role in the future.

Other and related products

Other EO derived products are being developed as part of the SSGP (Space for Smarter Government Programme) programme and EODiP is currently identifying a set of intermediate EO derived products (e.g. NDVI) that are expected to cover multi-user needs. The production of 2015 very high resolution (~ 5m) layer products for Europe are being initiated by the European Environment Agency: Impervious layer; Forests; Grass and non-woody vegetation; Wetness and water; Small woody features. The accuracy and spatial consistency of the pilot products generated previously varied substantially, with the 'Impervious layer' (urban) being the most successful and the 'Grass' product requiring a total rethink of the implemented approach.

There are other spatial data sets, such as the OS open data layers and commercial products, such as the Blueskys' tree map. Welsh Government invests in aerial photography coverage of Wales which refreshes every 3-4 years. A variety of other data, such as soils data and topographic data (from a digital terrain model) provide useful ancillary information that supports and is essential to the interpretation of the EO data and the development of rule based classifications. LiDAR is now also freely available and accessible via the Welsh Government Lle GeoPortal. There are a range of biophysical data from both Welsh Government and Natural Resources Wales which provide invaluable supporting data and data from the Basic Payment Scheme (land ownership, management, livestock, crop etc.) are very useful for validation.

3. What are the advantages and disadvantages?

Advantages:

- EO provides a bird's eye view. This allows for the detection and monitoring of two and three dimensional patterns in the landscape, which are not easy to observe from the ground.
- Satellite EO can achieve a complete coverage of Wales in a very short period of time
- EO data is spatially consistent
- EO data is temporally consistent, and when it is collected at high temporal frequencies it can be exploited to measure the dynamics of several parameters within and across years, potentially providing useful ecological information about habitat condition.
- EO data is available at a range of spatial and temporal scales.
- A wide range of EO data is freely available and relatively easy to access.
- EO allows the surveying and monitoring of difficult, dangerous and remote areas or where access is limited. This is particularly relevant if very high spatial and/or temporal resolution data is needed.

Disadvantages:

- EO often indirectly observes the surface variable or landscape feature that needs to be monitored. Identification of suitable proxies relies on aligned field assessment.
- Cloud affects the availability of optical data and although a higher frequency of satellite acquisitions through sentinel-2 (providing optical data potentially every 3 to 5 days) is improving the chances of cloud free observations, there will be areas in Wales which will still have a limited cloud free coverage (see appendix).
- High data access costs often excludes extensive use of certain observation types for frequent (e.g. annual) and large area monitoring. These are either delivered through airborne campaigns (aerial photography, Lidar), or are very high spatial resolution (cm to m) multi-spectral optical satellite imagery (e.g. World view).

- The relative coarse resolution of free satellite imagery (10 m or above) means that it cannot provide the very detailed spatial information required to map or monitor small patches of habitats. A general rule is that the required spatial resolution of the data should be half the size of the smallest feature of interest. It is also important to remember that the level of spatial detail at which a feature is being mapped and monitored has a direct impact on the resulting change statistics that can be obtained. There are some habitat types and features that cannot be mapped using EO.
- A steep learning curve to utilise tools and technology, especially with radar.
- The volume of data is great and is expected to increase further.

4. What could the technology deliver in 1-5 years time?

As the European Copernicus program matures, the next years will see an increase in the frequency of multi-spectral, radar and thermal satellite observations for the UK. Sentinel-1 (radar, high resolution every 6 days), Sentinel-2 (optical, high resolution, every 5 days) and sentinel-3 (optical and thermal coarse resolution, daily) are the most relevant for Wales. The trend is for more temporally and spatially detailed data with improved signal quality which will enhance the reliability of the information that can be derived from EO. The availability of high frequency data at higher spatial resolutions opens up the opportunity to monitor in detail the land surface and vegetation (within coarse categories) as it changes on a weekly basis, although for optical data frequent cloud cover is likely to substantially limit what can be achieved. As a result we should expect an extensive increase in research and development focusing on the use of radar.

There will be applications which will remain dependent on the more expensive airborne data (e.g. Lidar data for detailed elevation models) or the very high spatial resolution multi-spectral satellite imagery. Without government intervention to ensure regular and affordable coverage of this type of data, these applications will remain underdeveloped. In Wales, inclusion of Lidar acquisitions as part of the Welsh national aerial photography campaigns would transform the monitoring of small three-dimensional landscape features such as hedgerows, ditches, shrubs, tree lines and archaeological features and enable forest density monitoring.

The use of unmanned drones has expanded dramatically in the past 5 years and is expected to continue to expand. Their use has become increasingly easy and the range of EO instruments available for use on drones is expanding. Unmanned drones show great potential for use in support of the field surveying at local scales (see appendix), but more work is required to realise their potential for ongoing landscape monitoring (see appendix) [1]. Also current aviation laws could limit their use in on-going landscape monitoring. This could potentially be circumvented through the use of autonomous high altitude drones. Similarly the technology supporting network of sensors has matured substantially and could in the future contribute to country wide monitoring.

The hardware and software to handle large volumes of data automatically is continuously progressing and data download services for Copernicus and other free EO data sources are proliferating. Accessing EO data should become easier. The challenge will be to match this with operational data processing chains to support efficient EO based monitoring. The EO archive for Wales project (currently focussing on pre-processed imagery) is a good starting point.

The recently developed Welsh Space Strategy (http://space.aerospacewalesforum.com/strategy), which was jointly launched by industry, Welsh Government and Satellite Applications Catapult, is

[1] See MEOW 3 report, work carried out by CEH to look at UAV data for CS squares

providing a mechanism for progressing and building the EO capacity in Wales and has the potential to speed up the developments described above.

In terms of derived data products we would expect the products currently available to be updated more frequently and for more integrated monitoring systems to be developed. More integrated monitoring systems would be based on a combination of EO technology at a combination of scales and underpinned by networks of ground-based observations and field surveys. Such a system could operate at a combination of scales (Figure 1) and would become increasingly integrated with meteorological data and models to enable accurate detection and attribution of change (e.g. an earlier spring vs a change in vegetation condition due to drought, a change in management, a change in cover). The different levels of observations could include:

Coarse scale EO (>250m pixel size) – such data would provide monitoring at landscape scale, detecting gradual changes in vegetation condition (e.g. a gradual shift over many years towards more improved grasslands), and sudden anomalous behaviour against a baseline from previous years (e.g. a sudden change in cover or a drought event). It would provide the background for the finer resolution data. This method is already being used by the Forestry Commission to detect hotspots of forest cover change and so indicate where the detailed manual interpretation of aerial photographs is required.

Soil moisture and surface temperature are particular examples of satellite derived products that for now will only be available at coarser scales (1km), but with the potential of highlighting landscape areas showing sudden changes or gradual trends.

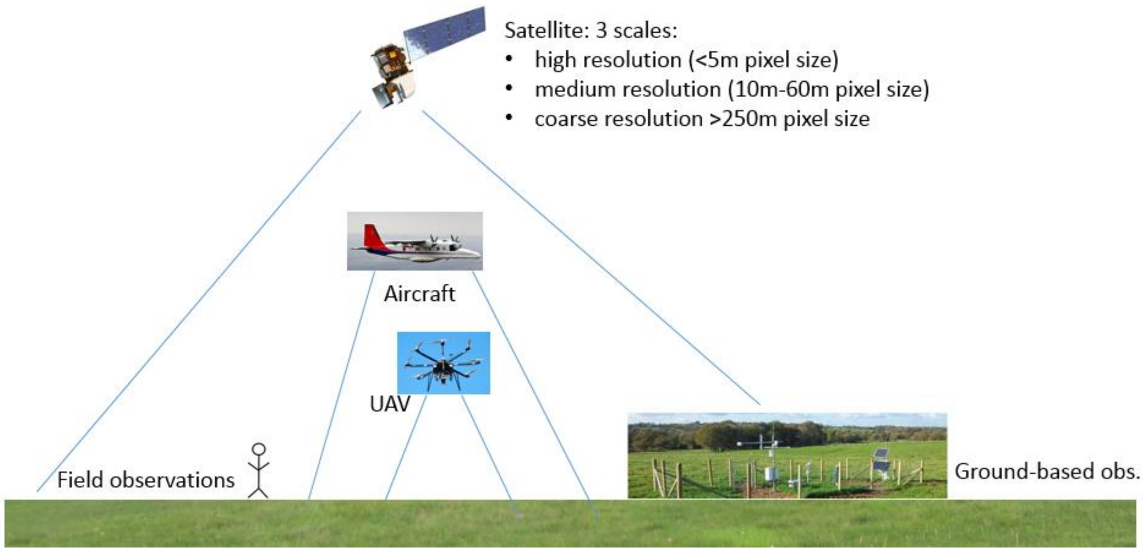


Figure 1: Range of observations scales in a fully integrated monitoring system based on EO.

Medium resolution (10m-30m pixel size) – a range of products could be produced, such as:

- A land cover map (based on a mix of optical and radar), which is updated every year or possibly less frequent but incorporating an annually updated crop map.
- An impervious surface map, e.g. from Copernicus high resolution layers (repeat every 3-5 years)
- Grassland productivity, condition and management (annual, but based on time-series of optical and radar observations)
- A woody cover map (repeat every 3-5 years)

High resolution (<5m pixel size) – including aerial photos, airborne Lidar and high resolution multi-spectral satellite data could be used for more detailed investigation of areas highlighted as potential hotspots of change but may increasingly be used to produce countrywide derived data sets as part of a rolling medium term monitoring programme. The types of derived data are likely to be similar to the medium resolution data sets, but with higher spatial resolution and additionally will include more targeted measures for key habitats or areas, such as cities or floodplains, where there are specific data requirements.

One alternative to complete-coverage or targeted mapping, is to use a random sample-based approach within a statistical framework that is linked up with the field surveying.

Field observations – field observations will be key to validating and calibrating the EO data and will require observations distributed widely and systematically across Wales. EO is also very effective in targeting where detailed field surveying could be required.

Networks of ground-based observations – advances in telecommunications and low cost technology (e.g. Raspberry PI) mean that remote sites can be used for real-time measurements, so fixed sensor networks are likely to become increasingly important in future monitoring strategies as the diversity of sensors increases.

5. Costs

Setup costs will be higher than running cost. The relative difference will depend on the complexity of the processing chain, the number of different types of EO data that the monitoring approach will require, the existing hardware and software, and the initial experience of the staff involved and amount of training required.

Running cost will be dependent on the type of EO date being used (free or commercial data), the degree of automation in the processing chain and the frequency of the monitoring. Further cost savings could be achieved by making the required field work (for validation and calibration) as effective as possible through well-developed sampling designs, targeted surveying or field data sharing.

The most affordable and effective EO based options will be the ones that

- are based on well-established or tested approaches (i.e. repeatable in space and time)
- require the least pre-processing or well-established automated pre-processing
- exploit existing field based monitoring
- are targeted to deliver a single measure (e.g. Forest cover; productivity; area of change; a basic set of cover classes)
- avoid duplication of effort (e.g. archives of pre-processed data and intermediate products)
- pre-processing, creation of intermediate products)

maximise the use of free data and open source software.

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FURTHER READING

More background on the technology

The term Earth observation (EO) is used to cover a variety of activities that represent 'the gathering of information about planet Earth'. In this briefing note EO refers to activities that involve the use of remote sensing technologies that collect electromagnetic signals reflected, scattered or emitted by the Earth's surface (Figure 1). Typically the range of electromagnetic waves used in EO covers (listed from short to long waves or high energy to low energy) the visible, the near- and shortwave- infrared, the thermal infrared and finally the micro waves (i.e. high frequency radio waves). Other parts of the spectrum worth mentioning are the gamma rays (high energy) and cosmic rays (very high energy).

Different technology is used to observe different parts of the spectrum (Figure 2):

1. Analogue photography and digital cameras observe the reflected sunlight in the visible and near-infrared,
2. Lidar systems record the reflected intensity and timing of near infrared light beamed onto the Earth's surface,
3. Multispectral and hyperspectral scanners view the reflected sunlight in the visible, near- and shortwave- infrared,
4. Thermal infrared cameras or scanners observe emitted thermal infrared signals,
5. Radar systems receive the backscatter and phase of microwaves transmitted onto the Earth's surface, and
6. Radiometers observe emitted microwaves.
7. Cosmic ray probes or gamma ray spectrometers are specialist instruments designed to capture cosmic or gamma rays radiated from the Earth's surface.

Except for the cosmic ray probes which are used in-situ and gamma ray spectrometers which are used on board aircraft, currently the technology exist to have any of the sensors listed above on board aircraft and satellites. Through recent advances in miniaturization, digital cameras (multispectral, hyperspectral and thermal) and lidars can now be carried by lightweight unmanned drones. Digital cameras, multispectral sensors and cosmic ray probes are also used operationally in-situ as part of regional, national or international networks (e.g. http://phenocam.sr.unh.edu/webcam/gallery/ ; http://cosmos.ceh.ac.uk/). Most EO observations acquired from satellite and in-situ networks are frequent and consistent for medium to long term periods. Observations acquired from aircraft are dependent on good weather conditions and so tend to be opportunistic or part of a low frequency rolling program. Unmanned drones, also dependent on good weather, are mainly used for local one-off or short term repeat observations.

Our ability to remotely sense the Earth using different parts of the spectrum is limited by the following key constraints:

A first main constraint is the atmosphere which interferes with the electromagnetic signal. Clouds and smoke will block all signals from the visible to the thermal spectrum (i.e.

affecting signals received from cameras, lidars and spectral and thermal scanners), leaving the microwave range (i.e. radars and microwave radiometers) unaffected.

The second constraint is the magnitude of the desired signal relative to the background noise, also referred to as the signal-to-noise ratio. Signal-to-noise ratio becomes smaller with increasing wavelength which results in a direct link between the spatial detail that can be achieved and the length of the wave observed. For example, on board satellites, digital cameras can achieve cm to m detail colour imaging. In contrast, surface temperature derived from infrared radiometers is delivered at a 1km resolution and soil moisture derived from microwave radiometers at 36km. For radar systems, which actively send a signal to the surface to collect the backscatter of that signal, the signal-to-noise ratio is determined by the power that can be generated on board the satellite (i.e. the size of the solar panel) and the maximum size of the antenna that can be achieved. So in the case of radar, the signal-to-noise ratio and spatial detail that can be achieved is linked to the size of the satellite.

A third constraint is the volume of data that can be stored and transferred between locations and manipulated at any one time. This constraint is prevalent throughout the processing chain, from the moment of data capture (on board the satellite or airplane) all through to the delivery of an application. A general rule is that every increase in spatial detail and in repeat visits represents an exponential increase in data volume. For example, although the Sentinel-1 satellite has the potential to provide a near daily global coverage of 20m radar observations, the current European infrastructure is not capable of handling the large volumes of data this would generate. As a consequence, for now, high frequency data collection is limited to Europe (Figure 3).

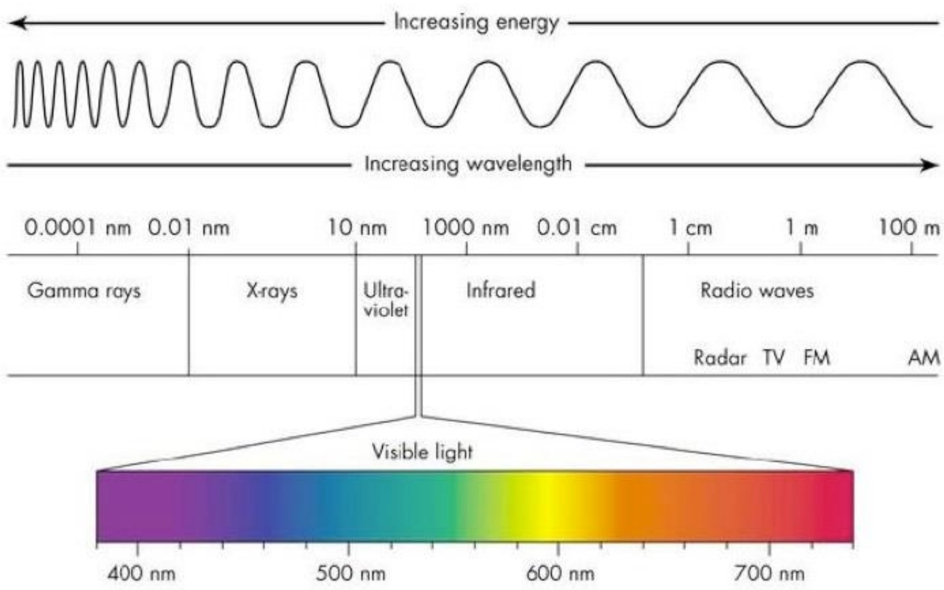

Figure 1: *Schematic showing the electromagnetic spectrum.*

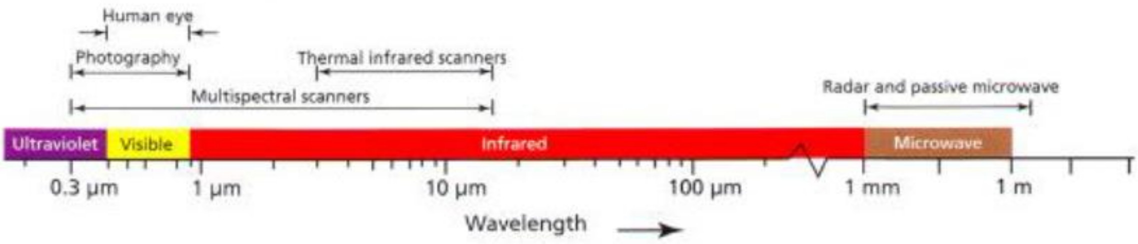

Figure 2: *Schematic showing the type of technology used to observe parts of the electromagnetic spectrum*

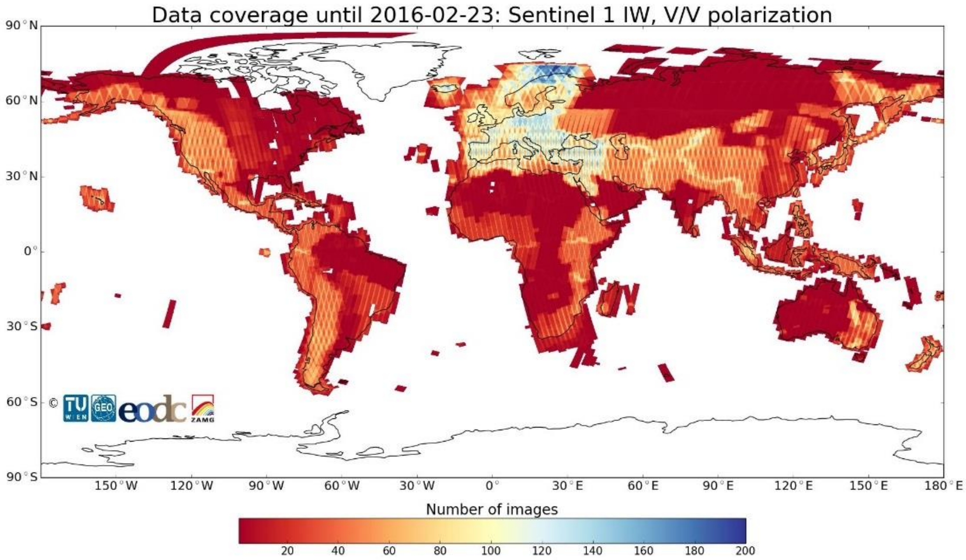

Figure 3: *Data coverage for Sentinel-1 SAR-C radar imagery since the time of the satellite launch in 2014 until 23 Feb 2016*

The manner in which a surface reflects, scatters or emits electromagnetic radiation in different part of the spectrum provides information about the physical and chemical properties of that surface. Some EO based applications rely on the direct conversion of the electromagnetic signal into measures of these physical and chemical surface properties (e.g. temperature, colour, moisture content, height). However often the information is inferred or modelled indirectly from the properties that influence the signal (e.g. biomass, land cover type, habitat type, area where change occurred) (Figure 4). The information could be quantitative (e.g. height, biomass) or qualitative (e.g. colour, land cover type).

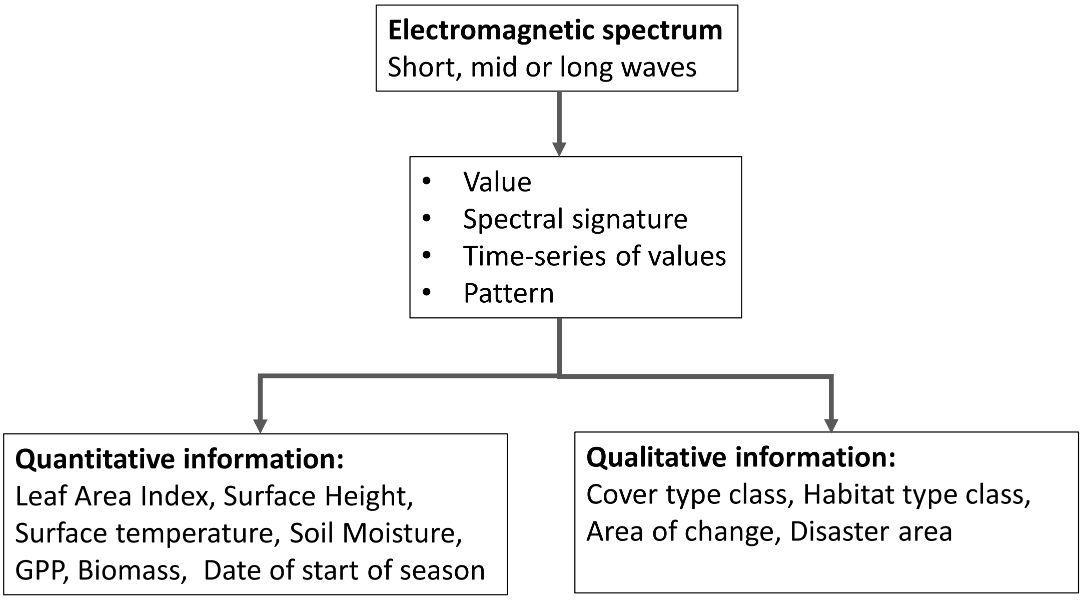

Figure 4: *Schematic illustrating the conversion flow of EO data into relevant information.*

The Crick Framework (see tables below) provides a way to categorise how well Earth Observation (EO) techniques can be used to identify particular habitat and features on the ground (e.g. many features of grassland habitats can be identified with EO and clarified with field survey, but sub-tidal habitats are very poorly characterised by current EO techniques). EO data and techniques differentiate vegetation types and habitats by identifying specific features that are shown up by different spectral bands or combinations of bands. In the same way that some plants are easy to identify because of the colour and shape of their leaves in field survey, some plants can similarly be easily identified from imagery. Where these plants comprise some of the main cover species of a habitat then this habitat can be picked out with relative certainty. Where two habitats are more difficult to distinguish – they have similar spectral features, or cover small areas of ground, etc – the habitats may be distinguishable using both spectral data and ancillary datasets. This wide range of interacting factors has been considered along with ecological knowledge, to develop a generic classification system that proposes categories (tiers) of habitat groups.

This set of Tiers is the first and most accessible component of the Crick Framework, providing a categorisation for habitats, based on existing ability to map and monitor them using EO, with or without ancillary data sets. The framework has been designed to consider Biodiversity Action Plan (BAP) Priority habitats and Habitats Directive Annex I habitats, which are necessary for EU reporting targets. For example, habitats such as heathland dominated by ling heather and bilberry are a solid 3a habitat which from the MEOW projects' experiences have always been easy to identify.

Table a: The Crick Framework

<table>
<tr><td>Tier 1</td><td colspan="6">Likely to be identified solely using EO</td></tr>
<tr><td rowspan="2">Tier 2</td><td colspan="6">Likely to be identified using EO and ancillary data</td></tr>
<tr><td>Tier 2a – Likely to be identified using EO together with ancillary data</td><td>Tier 2b – Likely to be identified using VHR[1] EO together with ancillary data</td><td>Tier 2c – Likely to be identified using EO (in some cases VHR) but ID dependent on good geological data</td><td>Tier 2d – Likely to be identified using EO methods such as fuzzy membership values</td><td colspan="2">Tier 2e – Likely to be identified using EO including LIDAR to give detailed information about vegetation structure</td></tr>
<tr><td rowspan="2">Tier 3</td><td colspan="6">Likely to be identified using EO and ancillary data but also dependent on availability of <u>time series</u> of imagery</td></tr>
<tr><td colspan="2">Tier 3a – Likely to be identified using EO together with ancillary data</td><td colspan="2">Tier 3b – Likely to be identified using VHR EO together with ancillary data</td><td colspan="2">Tier 3c – Likely to be identified using EO (in some cases VHR) but ID dependent on good geological data</td></tr>
<tr><td rowspan="2">Tier 4</td><td colspan="6">Currently unlikely to be determined using EO</td></tr>
<tr><td colspan="3">Tier 4a - Habitats distinguished by low frequency or small features</td><td colspan="3">Tier 4b – Habitat hidden from above for most of the year</td></tr>
<tr><td>Tier 5</td><td colspan="6">Cannot be identified using EO</td></tr>
</table>

[1] *VHR: Very High spatial Resolution*

Table b: Number of habitats expected to be detectable using a specific EO approach

		UK BAP Priority Habitats	EC Habitats Directive Annex I habitats
Tier 1		0	0
Tier 2	2a	6	6
	2b	7	2
	2c	2	5
	2d	1	1
	2e	1	1
Tier 3	3a	6	5
	3b	9	11
	3c	4	6
Tier 4	4a	3	26
	4b	12	9
Tier 5		0	3

Applications at the current state of development

Below are details of an example list of missions that are available for land monitoring in the UK

1. Aerial photos: on demand (Visible and Near Infrared, <1m) – pan government
2. Multi-Spectral:
    - WorldView-3 [2]: on demand (VIS,NIR, SWIR, 1.24m to 3.7m) - expensive
    - SPOT [1]: on demand (VIS, NIR, SWIR, 5m to 20m) - expensive
    - Landsat [1]: every 16 days; (E)TM [3], OLI [2] (VIS, NIR, SWIR, Thermal 25m) - free
    - Sentinel-2 [1]: every 5 to 10 days; MSI [2] (VIS, NIR, SWIR, 10m to 60m) - free
    - Sentinel-3 [1]: daily; OLCI [2] (VIS, NIR, SWIR, 300m); SLSTR [2] (Thermal, 1km) - free
    - Terra and Aqua [1]: daily; MODIS [2] (VIS, NIR, SWIR, Thermal; 250m, 500m, 1km) – free
3. Airborne LiDAR: on demand (1m to 3m) – pan government
4. Radar:

[2] Name of Satellite Mission
[3] Name of sensor on board the satellite

- Sentinel-1 [1]: every 6 to 12 days; SAR C-band [2] (resampled to 20m standard; interferometric wide swath mode, IWS - VV and IWS - VH) - free
- Terra-SAR X [1] and COSMO sky med [1]: on demand; SAR X-band [2] (25cm, 3m & 6m resolution; Multiple polarisation available) - expensive

Spatial and temporal resolution

The spatial resolution of EO data can vary from < m to 25 km. A general rule is that the required spatial resolution of the data should be half the size of the smallest feature of interest. It is also important to remember that the level of spatial at which feature is being mapped and monitored has a direct impact on the resulting change statistics that can be obtained. Also if the spatial discrepancy between the EO derived observations and the field-based observations is too great, the task of reconciling or consolidating change statistics from both sources may become insurmountable.

The temporal resolution or the frequency at which an observation is repeated automatically can vary from hourly (in situ sensor or geostationary satellite), every 16 days, every ~5 years (rolling programme of airborne campaigns) to a one-off (e.g. on demand acquisitions). Except for the commercial mission offering very high spatial resolution imagery (e.g. WorldView) most satellite missions collect data automatically and regularly. Except for radar observations, in areas with frequent cloud cover, the chances of a cloud free image will increase with increasing temporal resolution. As most of the monitoring involves observing temporarily dynamic vegetation or soils, matching the timing of the EO data with periods of the year that are the most suitable for monitoring is crucial.

Applications in function of the types of observation available:

The visible and near infrared part of the spectrum, captured by cameras or multi-spectral scanners, is typically used to map land cover or landscape features, detect changes in the land cover and monitor the condition of vegetation (Figure 7), including crops. Some have used this data to monitor large populations of animals (e.g. birds) in the landscape. The approaches used rely on covers showing differences in reflectance values in space and time, but also differences in textures or shapes when data is available at very high spatial resolutions. When the imagery is available at high spatial resolution (cm) and as a stereoscopic pair it is used to derive digital terrain and digital surface models.

Lidar systems use the near-infrared spectrum to measure the height of surfaces. The most prolific use of this technology is for the production of digital terrain models, digital surface models, vegetation and building height, mapping of hedgerows and boundary walls (Figure 8), and the identification and mapping of archeological features. Another possible product is a solar irradiation map.

When the visible and near-infrared spectrum is observed in combination with the shortwave-infrared the land cover mapping can be more detailed in terms of number of classes and better mapping accuracies are achieved. The shortwave-infrared, particularly sensitive to vegetation water content, is also used for vegetation condition. In addition, when the visible to shortwave spectral range is observed using a hyperspectral sensor at high spatial resolutions (m) it is possibility to estimate plant canopy traits such as % water content, dry matter content, N and P).

The thermal spectrum so far has been mainly used at global and continental level to routinely produce daily observations of the sea and land surface temperatures and map temperature anomalies linked to fires which are typically delivered at 1km spatial resolutions. The potential exist to use thermal imaging to infer soil moisture or plant stress.

Radar systems exploit the microwave part of the spectrum and have the main advantage of not being affected by cloud. Radar is used for flood mapping and the production of digital terrain and digital surface models. Radar has also been relatively successful in measuring forest biomass. In the UK radar has been used operationally to monitor crops growth and more recently to differentiate different crop types (i.e. Land Cover map Plus Crops). Combining radar with multi-spectral to further enhance land cover maps, especially for areas with frequent cloud cover, is the obvious next step. Microwave signals are also used to derive soil moisture where the woody vegetation cover is sparse and the topography is relatively flat; an example 1km soil moisture product will produced for the UK by September 2016.

Cosmic ray probes are used operationally as part of networks to measure in-situ soil moisture across an area with a radius of about 300 m. These sensors are particular attractive as they match more closely the spatial resolution of satellite observed soil moisture (1km), making them ideal for validating the satellite derived measures. In the UK these are combined with an in-situ camera and a weather station which in the long term will enable the monitoring of vegetation condition and identifying the possible causes of observed changes (Figure 9).

Gamma ray spectrometer data, collected as 300m x 300m samples on a regular grid from low flying aircraft, have been converted into maps showing soil organic matter content and soil moisture saturation levels (Figure 10).

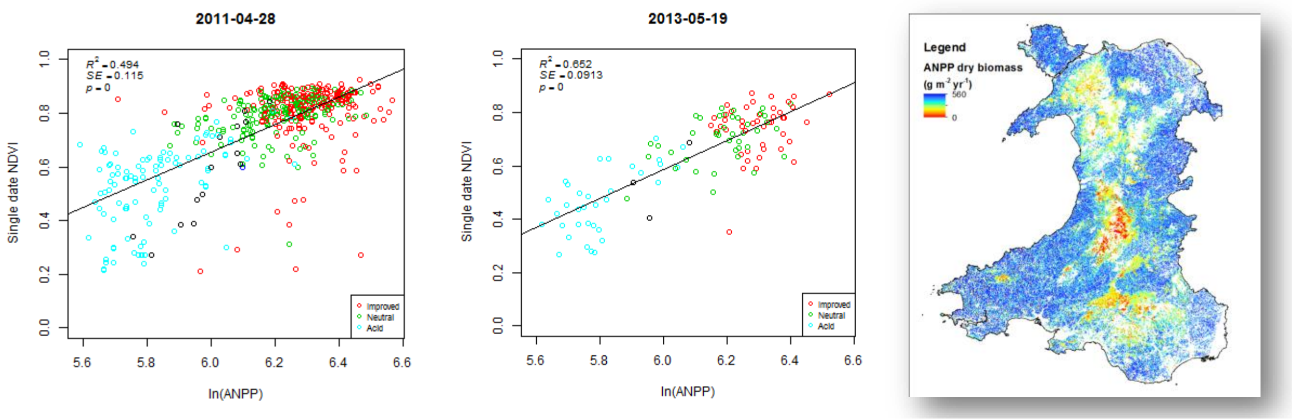

Figure 7: *Grassland above ground productivity (ANPP) estimated for Wales using an empirical model linking EO data from the visible and near-infrared spectrum (NDVI) with field based sample observation of grassland productivity. The model used 296 plots collected from 82 1km² Countryside Survey samples. This example also illustrates how the timing of the EO observation impacts on the model performance.*

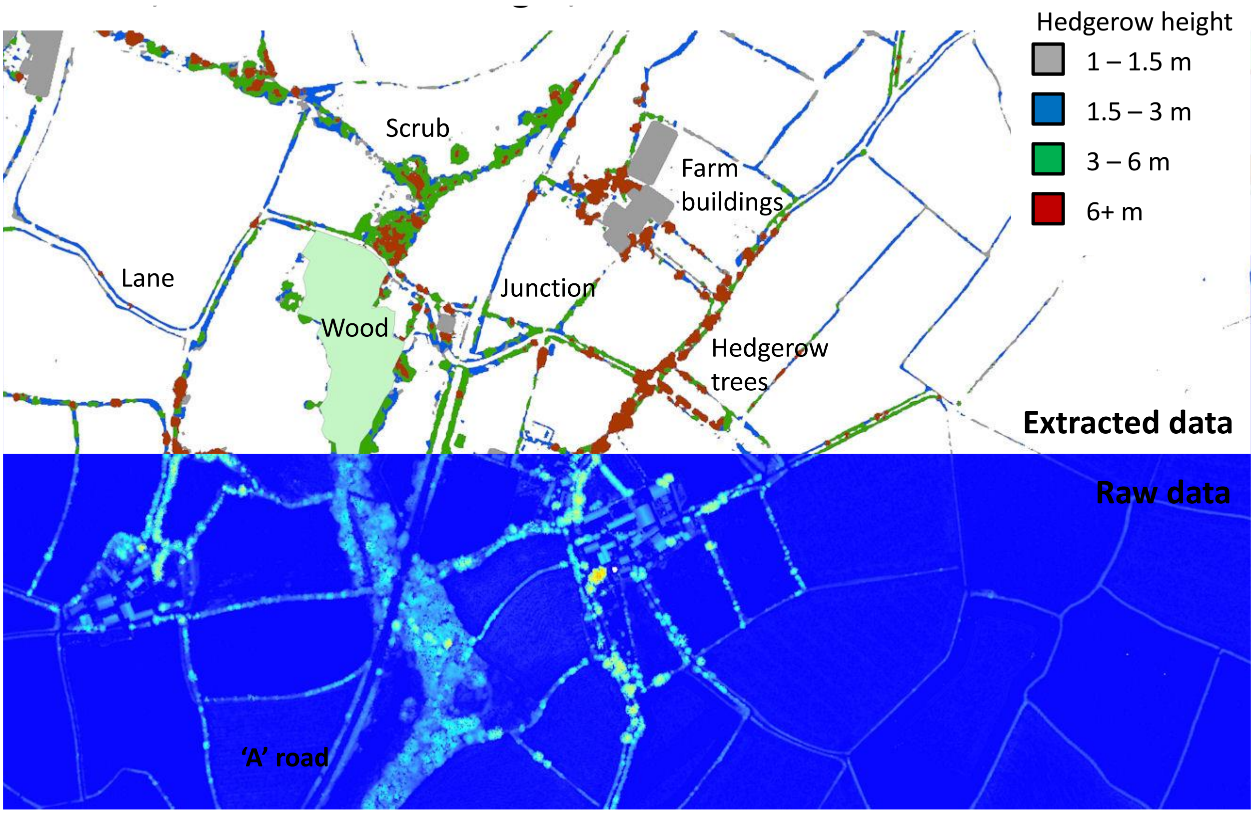

Figure 8: *Example of a woodland, roadside hedge (or wall), and farmland trees map using the digital terrain and surface models derived from free 1m lidar data captured for Cornwall and Devon during a 2014 airborne campaign. The lidar data was combined with freely available and open-licence Ordnance Survey VectorMap data to help identify buildings, temporary outbuildings and parked cars in driveways; and the free Forest Commission's National Forest Inventory dataset to identify woodland blocks greater than 0.5 ha (Source CEH, TELLUS-HOW project).*

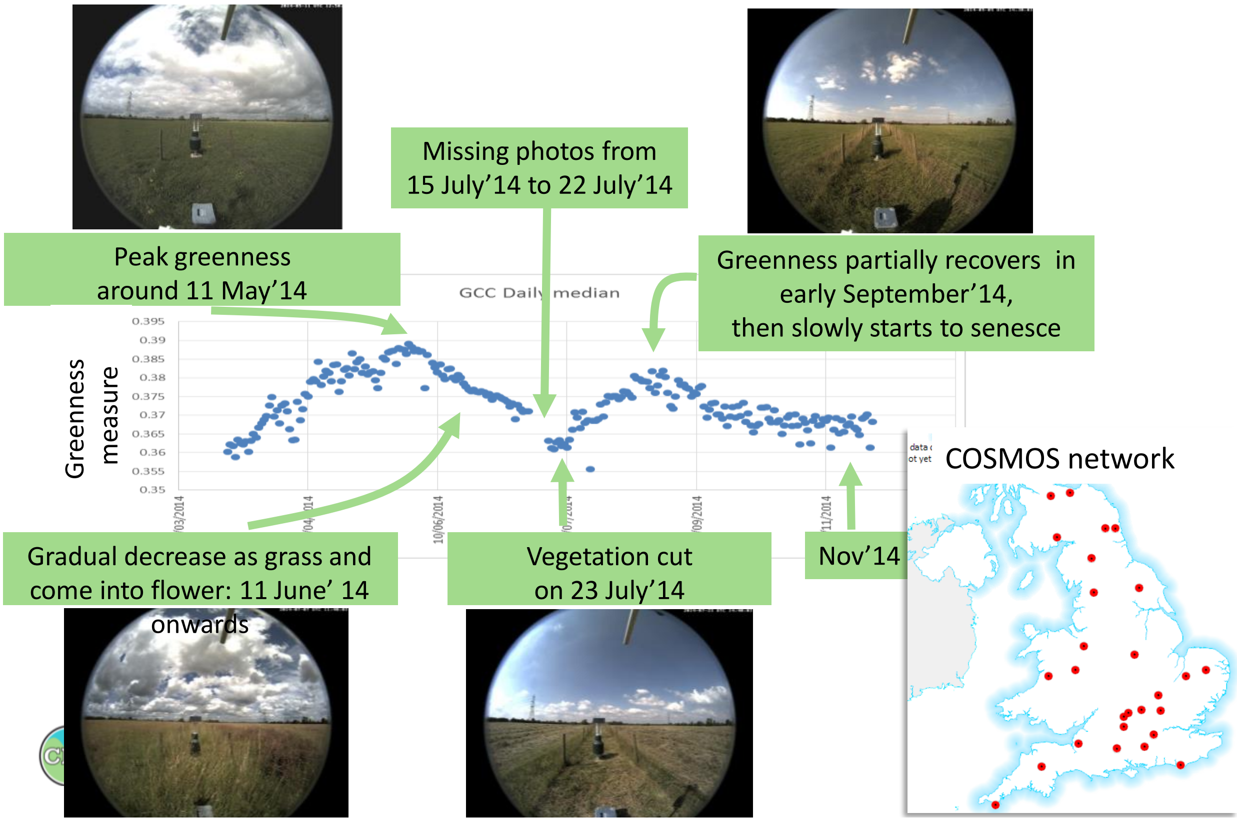

***Figure 9**: Example of a digital camera (phenocam), which forms part of the COSMOS-UK soil moisture network, capturing daily records of vegetation greenness (Source CEH, COSMOS-UK network).*

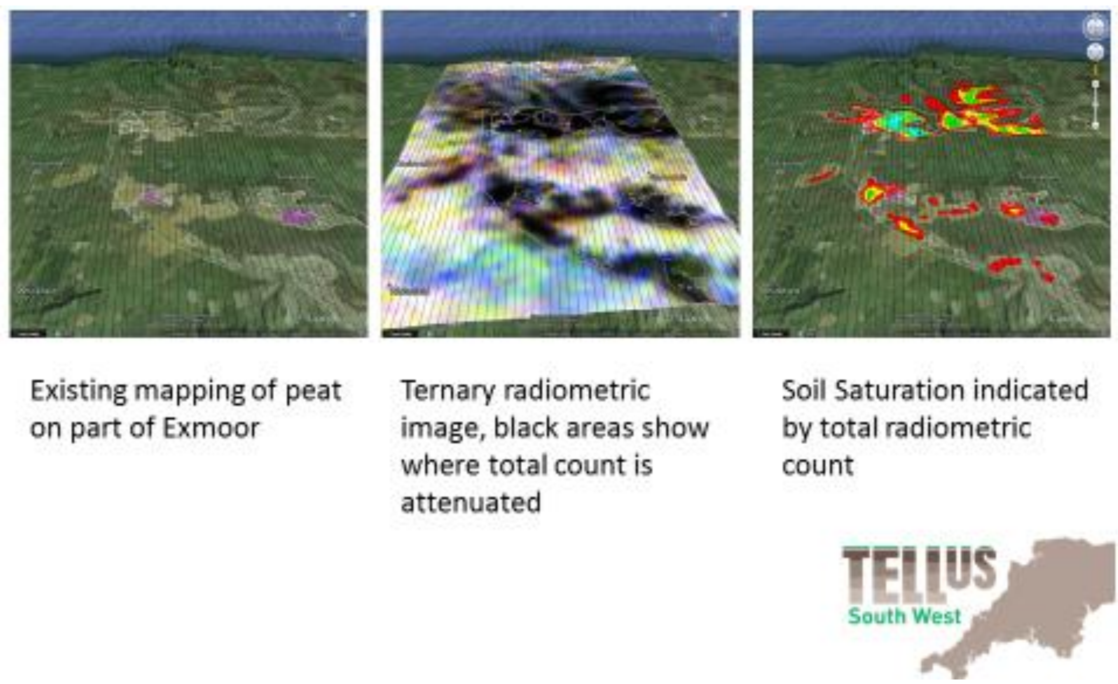

***Figure 10:** Example of how Gamma ray radiometry acquired for Cornwall and Devon during a 2014 airborne campaign could be used to map peat soils and determine levels of soil saturation (source BGS, TELLUS-SW project).*

Advantages and disadvantages – cloud cover

The availability of useful EO data from the visible, near- and shortwave-infrared spectrum is heavily reduced in areas where there is a high occurrence of cloud, haze or smoke. Figure 5 shows the impact of cloud on satellite MODIS NDVI data on a seasonal basis. This MODIS product is provided at 250m resolution as an 8 day time-series which is a composite of cloud free data selected from daily observations within an 8 day window. Figure 6 shows cloud free data availability for daily satellite MERIS imagery (300m resolution) on an annual basis.

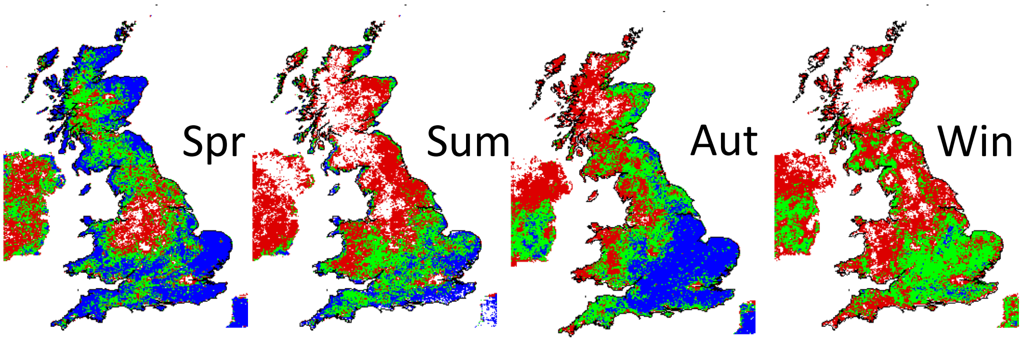

***Figure 11**: Cloud cover: MODIS NDVI 250m example for 2002-2012 period. In each year there are 46 8-day periods, however due to cloudiness, haze or snow, an observation may not be available for a particular 8-day period in the 10-year record. Figure 5 shows for each 250m pixel, the number of 8 day periods within a season for which there are 6 or more years of good quality data (red = 1 – 3, green = 4 – 6, blue = 7-10(max)).*

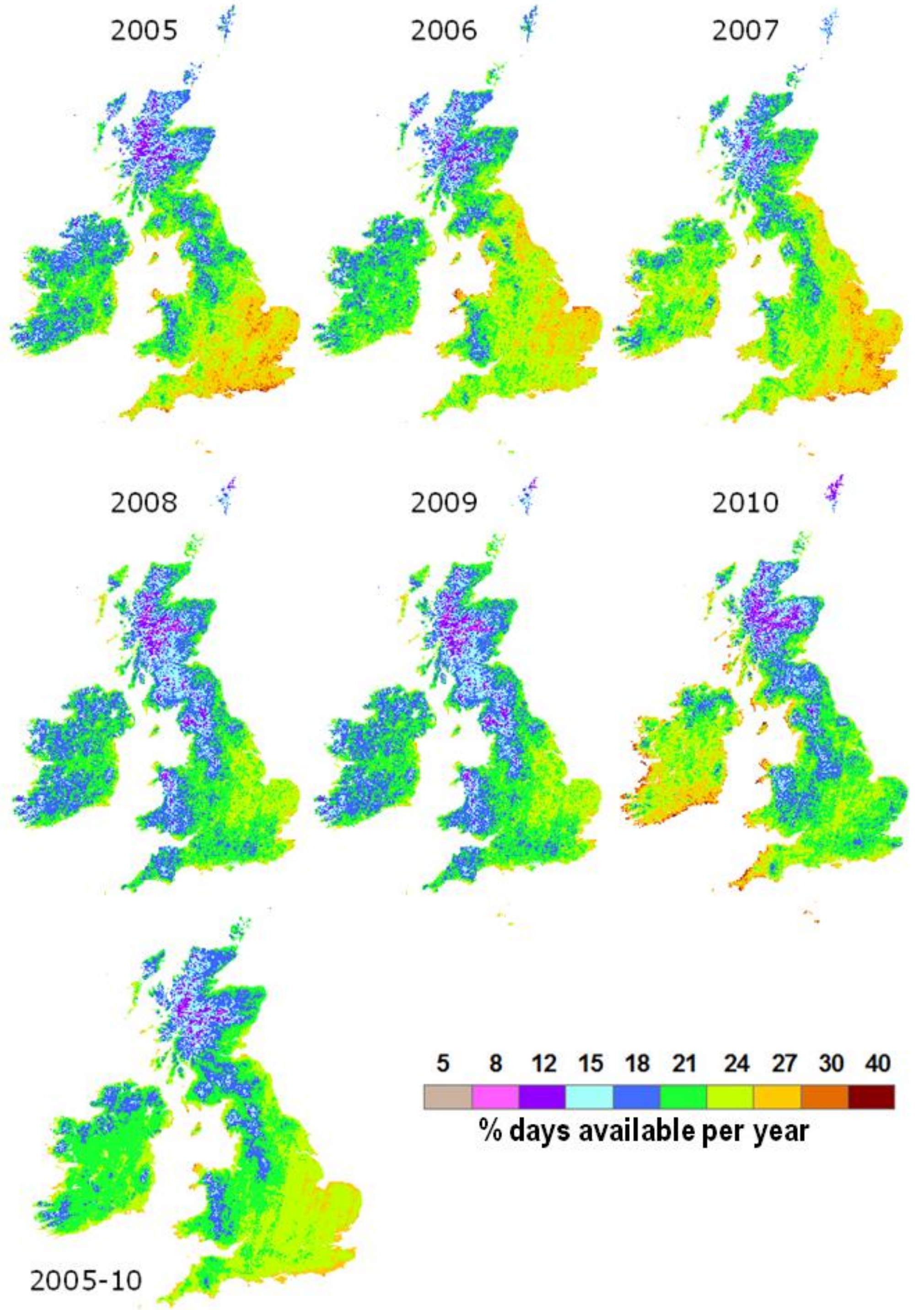

Figure 12: *Cloud free data availability for daily MERIS imagery as a percentage of the total number of days for each year from 2005 to 2010 (above) together with a 6 year mean availability for the total period (right). Source: Final PHAVEOS report to STB – project No 130517 by Astrium GEO-Information Services.*

What could the technology deliver in 1-5 years time? – unmanned drones (UAVs)

CEH carried out a comparison between field and UAV-based observations. The key finding were:

- From UAV imagery it was possible to identify between 30-50% of the polygons recorded in field survey
- Field survey recorded 50% more habitat types than could be interpreted from UAV imagery
- Variance between the extents of habitat recorded in the field and interpreted from UAV imagery were between <1 and 19.6%
- 1.4 detailed vegetation/management codes were mapped against each polygon recorded from the UAV data compared to 3 for field survey data
- Length of linear features interpreted from the UAV imagery were 46% of those recorded in the field.
- Lines/belts of trees were under-predicted by 50% and managed hedges were over-predicted by 78%. Around 60% of the linear features interpreted from UAV imagery were co-incident with a field surveyed feature.
- It was possible to predict that a hedge would be of mixed species from UAV imagery but no other detail (as collected in the field) was possible.
- 54% of point features located in the field survey were interpreted from the UAV imagery. Only 30% of these features were recorded accurately (i.e. as the same feature as recorded in the field). As for linear features, additional attribute data (beyond identification of point type) could not be interpreted from the UAV imagery.
- Mapping from the UAV image took within 5 minutes of 2 hrs for each of the squares (flight times not included). Mapping in the field took approximately 1.5 field days for each of the squares.

NERC SCIENCE OF THE ENVIRONMENT

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Athena SWAN Bronze Award

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