The Scottish GHG Flux Network

Review of site operation and data status

The James Hutton Institute

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GHG FLUXES The James Hutton Institute

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Introduction

The many different reasons for measuring carbon exchange over a landscape are well described elsewhere but one of the major policy interests is in quantifying the carbon budget of different ecosystems, site-to-site variation, and how it may be modified by changes in land use, land management or climate change. The standard method employs fast-response instruments to measure trace-gas concentrations and wind speed/direction which estimate the net exchange of CO_2 and CH_4 using the eddy-covariance theory. In 2013 The James Hutton Institute began measurements at a site in the Flow Country (Lonielist, Forsinard RSPB Reserve, Caithness & Sutherland) and subsequently has installed a further 9 towers across Scotland, to date. The main focus of the GHG monitoring network is on Scottish peatlands because of their key potential role in mitigating climate change, maintaining biodiversity and managing water resources when in good ecological condition, but there is also a site at the Centre for Sustainable Cropping at the Balruddery Research Farm (https://csc.hutton.ac.uk/). Three new eddy-covariance based stations are currently awaiting delivery, for deployment on grasslands on peat. An autochamber system currently still awaiting delivery will possibly be installed over either a peatland at the Glensaugh "Climate Positive" Research Farm (https://glensaugh.hutton.ac.uk/) or on a restored floodplain within the Dee catchment (https://www.deepartnership.org/project/easter-beltie-restoration/).

The site network is designed to fill important evidence gaps in our understanding of Scottish land use impacts on emissions and forms an important part of the UK-wide network of sites that contribute to e.g., the continued development and revision of the peatland Tier 2 emission factors in the UK GHG Inventory. They also feed directly into the training and validation of models that could allow for future Tier 3 level reporting of emissions and more refined international land surface modelling efforts, e.g., the peatland specific implementation in the UK land surface model, JULES, which is a component of the UK Earth Systems Model (UKESM), and which contributes to international efforts to understand future feedbacks on global climate.

Executive Summary

Details of the network operation, sites, their current status and future plans are given in the following document. In summary, we have obtained the data coverage shown in Table 1 (for a full list of which parameters are logged as fast or slow see Table 12 in Site Operations - Hardware and infrastructure). The network locations are shown as a map in Figure 1.

Table 1 Overall data capture at each site, up to August 2022

Site	LUC[a]	2014	2015	2016	2017	2018	2019	2020	2021	2022
Fast										
UK-ARN Arnol	MEB	ND	ND	ND	ND	ND	ND	ND	ND	39%[1]
UK-BAM Balmoral	MEB	ND	ND	ND	ND	46%[2]	83%	41%	17%	4%
UK-BLR Balruddery	C/M	ND	ND	ND	ND	ND	ND	ND	21%[3]	52%
UK-CLS Cross Lochs*	NNB	*	*	19%[4]	92%	74%	57%	58%	83%	58%
UK-DKE Dyke	W/RB	ND	ND	30%[5]	41%	36%	77%	70%	61%	41%
UK-DKF Dyke FIRE	RB-F	ND	ND	ND	ND	ND	14%[6]	48%	88%	25%
UK-ECH Elchies	W	ND	ND	ND	ND	ND	ND	ND	9%[7]	44%
UK-GST Girlsta	MEB	ND	ND	ND	ND	ND	ND	ND	21%[8]	33%
UK-LNS Lonielist	RB	31%[9]	51%	55%	52%	92%	78%	84%	79%	45%
UK-THE Talaheel	RB	ND	27%[10]	49%	59%	38%	31%	48%	72%	39%
Slow										
UK-ARN Arnol	MEB	ND	ND	ND	ND	ND	ND	ND	ND	51%
UK-BAM Balmoral	MEB	ND	ND	ND	ND	48%	87%	80%	49%	1.0%
UK-BLR Balruddery	C/M	ND	ND	ND	ND	ND	ND	ND	21%	34%
UK-CLS Cross Lochs*	NNB	ND	56%	95%	62%	41%	91%	85%	98%	55%
UK-DKE Dyke	W/RB	ND	ND	81%	72%	36%	67%	75%	57%	22%
UK-DKF Dyke FIRE	RB-F	ND	ND	ND	ND	ND	19%	87%	67%	15%
UK-ECH Elchies	W	ND	ND	ND	ND	ND	ND	ND	3%	31%
UK-GST Girlsta	MEB	ND	ND	ND	ND	ND	ND	ND	21%	40%
UK-LNS Lonielist	RB	28%	51%	46%	41%	84%	100%	97%	94%	55%
UK-THE Talaheel	RB	ND	37%	64%	76%	75%	57%	48%	100%	21%

*earlier data is held by UKCEH but will be included in future work. [+]ND – no data as prior to site installation; [a]Land use classes, as per current UKGHG Inventory are as follows: MEB – modified bog with modified eroded bog components; C/M – cropland on mineral soil; NNB – near natural bog; W – woodland; RB – rewetted bog; RB-F; rewetted bog recovering from wildfire (2019). The W/RB assignation denotes a transition from a woodland to rewetted bog, with the two land uses captured in sequence. 1. from April – September 2022, 2. from July 2018, additional data may be retrieved after repair of some corrupted data files, 3. from August 2021 4. from October 2016, 5. from June 2016, 6. from September 2019, 7. from September 2021, 8. from September 2021, 9. from July 2014, 10. from August 2015. NB the data from some of the sites has had to retrieved locally due to telemetry issues and so may not be complete to date. Data capture is calculated relative to a whole year, hence some years may not be complete if the system was newly installed or the site down for extended periods.

The fast data is what gives us an estimate of the greenhouse gas exchange and the processes contributing to it can be examined using the slow data. The slow meteorological measurements are also used to gap fill the gas exchange results using standardised modelling techniques for CO_2 (Wutzler *et al*, 2018), while novel methods will be developed for the CH_4. The data capture given here is gives an overview of the wealth of data we have collected to date, while a more detailed description of what we have for each site and each parameter will be given in future reports. As a whole, the data is an extremely valuable resource for assessing peatland GHG exchange in Scotland across a range of peatland habitats. It has contributed to key papers such as the Evans *et al* 2021 Nature paper and others given in the reference list. Data analysis is ongoing with new papers preparation and developing collaborations with other researchers in the field across the UK, Europe and the rest of the world. Future efforts will prioritise completion of QC and gapfilling of the peatland datasets, and collation of gapfilled data for submission to data repository (by February 2023).

Data capture is calculated using the number of half-hourly data files we have retrieved from each site for the fast parameters. In future reports we will break this down further into CO_2 or CH_4 flux results and filter for data quality; the data coverage and quality for the two gases may differ considerably. For example, at Lonielist all the instruments have operated consistently over the years and so any loss of data is mainly due to power supply constraints

or failures, while at Balmoral a series of issues with instruments, logging and power have caused loses of both variables, with the CH_4 coverage particularly poor up to September 2022. The Dyke-FIRE tower has also suffered from a series of issues, giving low data capture for significant periods.

A further three eddy covariance-based systems and one autochamber-based system have recently been purchased via a CAPEX grant from Scottish Government and are to be installed when the equipment has arrived. There are major delays at present with the delivery of e.g., the gas analysers, due to global chip and other component shortages, hence current efforts are focused on prioritising installation of the instrumentation that can provide future gapfilling and modelling data at site level.

The sites are distributed across Scotland, with a focus on peatlands. Figure 1 shows all the sites currently maintained by JHI and others proposed for affiliation.

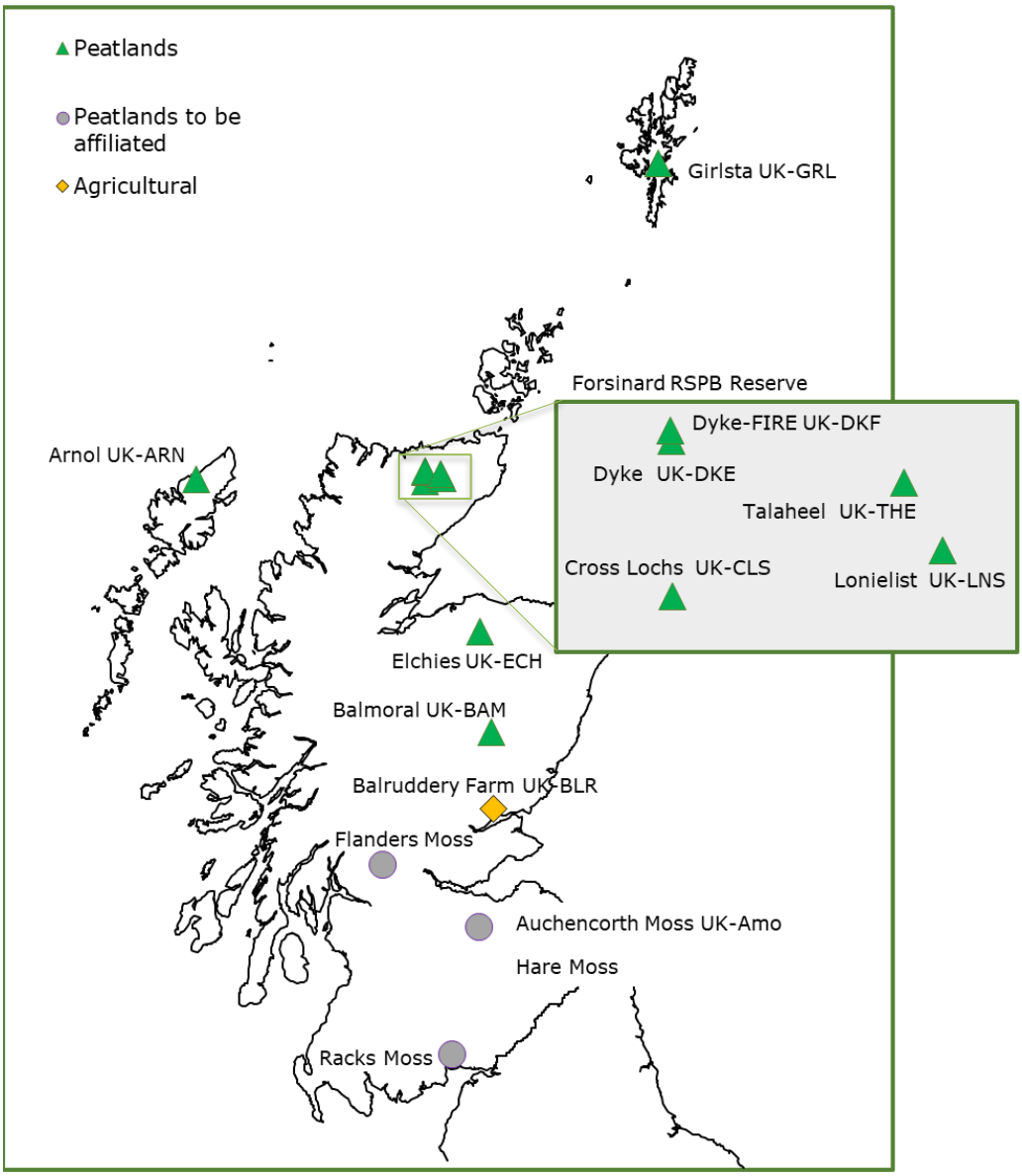

Figure 1 The James Hutton Institute Scottish GHG Flux Network as of September 2022. Sites in grey circles are not owned or maintained by JHI, but contribute to various joint projects (or will, in future). Three further new eddy-covariance stations and one autochamber-based site on peat are currently still in development.

Site Descriptions

Arnol, Isle of Lewis - UK-ARN

UK-ARN Location, Land use and Topography

Grid Reference: NB30744 46354. Lat 58.3228340, Lon[1] -6.6004540. Altitude (asl) 19 m

The location is ideal for the application of the eddy-covariance technique as its topography fulfils the requirement for a flat, open and fairly homogenous fetch[2]. As noted above the area is part of some local common grazing used by the crofting community for many decades for livestock and peat extraction. It has not been intensively used for many years and although the peatland is not in good ecological condition there are relatively few extensive areas of bare peat and relatively moderately ongoing erosion. It is scheduled for some restoration work which will improve water retention and reduce the chances or further erosion.

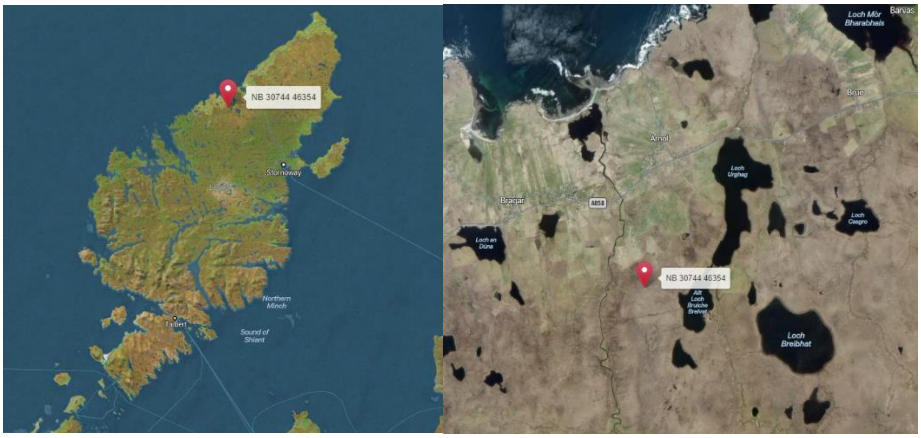

Figure 2 UK-ARN Local Map

UK-ARN Instrumentation Summary

This is site is fully instrumented with equipment from Campbell Scientific© who also manufacture many of the key components. Table 2 lists the sensors with brief description of their function.

[1] Negative longitude denotes West of 0^{O}

[2] Fetch refers to the area upwind from an eddy-covariance flux tower from which it can be calculated that the gas exchange represents and the area for which the theory of micrometeorology stationarity is valid

Figure 3 Photographs of Arnol, UK-ARN. Top left – some of the team on completing the installation; Top right – completed installation; bottom – south westerly view towards the tower

Table 2 UK-ARN Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger	Campbell Scientific	CR1000X & CR6	Store/analyse data
Modem	Sierra Wireless	RV50X	Remote communication
Carbon dioxide and water vapour analyser	Campbell Scientific	CPEC306	Gas exchange, humidity
Methane analyser	Licor	LI-7700	Gas exchange
3D Wind sensor	Campbell Scientific	CSAT3A	Wind speed & direction; turbulence/gas exchange
2D Wind sensor	Gill	Windsonic	Back up wind speed/direction
4 component net radiometer	Hukseflux	NR01-10	Net radiation (quality control on gas exchange/turbulence)
Photosynthetically active radiation	Licor	LI-190R	Environmental factor in gas exchange
Temperature and relative humidity	Vaisala	HMP155	Environmental factor in gas exchange; gas unit conversion
Soil Heat Flux sensor	Hukseflux	HFP01SC	Soil heat flux (quality control on gas exchange/turbulence)
Water Table Depth	Campbell Scientific	CS456	Environmental factor in gas exchange
Soil moisture and temperature	Campbell Scientific	CS650	Environmental factor in gas exchange
Average soil temperature	Campbell Scientific	TCAV-L	Environmental factor in gas exchange
Rain guage	EML	ARG314	Environmental factor in gas exchange
Phenocam	Stardot	CAM-SEC51R	Plant phenology

Balmoral, Glen Muick, Balmoral Estate - UK-BAM

This site was established in the summer of 2018 to obtain baseline data before the area will undergo restoration. Currently, the area within the fetch is still unrestored, but there are adjacent areas of land where there have been various gully surface bunding, gully reprofiling, and mulching efforts applied in phased work. The peatland has suffered from extensive erosion with many deep gullies and areas of bare peat. It is the highest elevation eddy-covariance flux tower in the UK, and scientifically important as it is currently in a sub-boreal climate region that is projected to move towards the more widespread oceanic climate characteristic of Scotland by 2080. At present, frost heave and periodic snowpacks still occur.

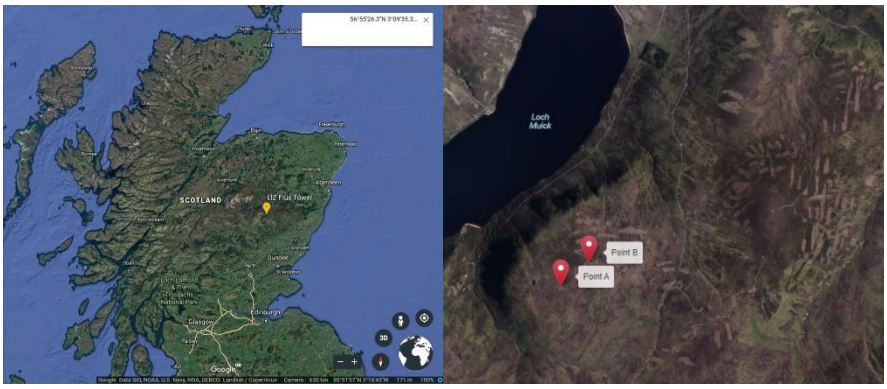

Figure 4 UK-BAM Location maps (A is the measurement mast and B the 4G relay tower)

The data from this site from 2018 to 2020 have already been utilized in two publications, Artz et al, 2022, and the major synthesis effort of Evans et al, 2021. The instrumentation is owned by JHI and was funded by Peatland ACTION.

UK-BAM Location, Land use and Topography

Grid Reference: NO29499 82005. Lat 56.923960, Lon -3.159811. Altitude (asl) 642 m

Figure 5 Balmoral tower and landscape, UK-BAM

This site is location on the plateau above Loch Muick in the Cairngorms National Park and part of the Balmoral Estate. The topography is reasonably good for eddy-covariance. Although the land drops of rapidly to the NW-W this is far enough outside the main fetch to have minimal effects, although there will be night-time drainage flows into the glen.

UK-BAM Instrumentation Summary

This is site is instrumented with a mix of equipment from Campbell Scientific© and LICOR. Table 3 lists the sensors with brief description of their function.

Table 3 UK-BAM Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger	Campbell Scientific	CR1000X	Store/analyse data
Modem	Proroute	H820 WRT -4G	Remote communication
Carbon dioxide and water vapour analyser	Licor	LI-7200	Gas exchange, humidity
Methane analyser	Licor	LI-7700	Gas exchange
3D Wind sensor	Gill	Windmaster Pro	Wind speed & direction; turbulence/gas exchange
4 component net radiometer	Apogee	SN500	Net radiation (quality control on gas exchange/turbulence)
Photosynthetically Active Radiation	Skype	SKP215	Environmental factor in gas exchange
Temperature and relative humidity	Rotronic	HC2S3	Environmental factor in gas exchange; gas unit conversion
Soil Heat Flux	Hukseflux	HFP01SC	Soil heat flux (quality control on gas exchange/turbulence)
Water Table Depth	Durck	PCDR 1830	Environmental factor in gas exchange
Soil moisture	Acclima	ACC-SEN-SDI	Environmental factor in gas exchange
Soil temperature	Hukseflux	STP01	Environmental factor in gas exchange
Barometric Pressure	Campbell Scientific	CS541	Backup and reference for gas analysers sensor; gas unit conversion
Rainfall	Campbell Scientific	SBS500	Environmental factor in gas exchange

Balruddery, Dundee - UK-BLR

This is the only non-peatland site in the network and provides data for projects assessing the carbon balance of agricultural systems. It was installed in spring 2021 to validate a model being used to run a phone app which allows farmers to estimate their farms carbon budget in real-time and assess the impact of management.

UK-BLR Location, Land use and Topography

Grid Ref: NO 30800 32778; Lat 56.482003, Lon -3.1251748. Alt 106 m asl.

It is located on a field which is part of the CSC (Centre for Sustainable Cropping) at Balruddery Farm near Dundee. The CSC fields are split into two management regimes, one conventional and the other low/no-tillage. The tower is located on the boundary of the two treatments and so measures gas exchange over either depending on wind direction. The field slopes to the south and is quite small, at the limit for application of eddy-covariance, but is relatively smooth without significant disruption to the fetch. The equipment is owned by JHI and the project, RETINA, was funded by the NERC.

Figure 6 Location of the Balruddery research farm and CSC


Figure 7 Balruddery tower and landscape

UK-BLR Instrumentation Summary

This site is instrumented with a mix of Campbell Scientific and LICOR sensors.

Table 4 UK-BLR Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger	Campbell Scientific	CR1000x	Store/analyse data
Modem	Proroute	M2M H685	Remote communication
Carbon dioxide and water vapour	Licor	LI-7200	Gas exchange, humidity
Sonic anemometer	Gill	Windsonic	Wind speed & direction; turbulence/gas exchange
Net radiometer	Kipp and Zonen	NR-LITE2	Net radiation (quality control on gas exchange/turbulence) -
Total global solar	Campbell Scientific	CS320	Environmental factor in gas exchange
Weather station	Campbell Scientific	MetSENS550-DS	Compact weather station: back-up wind speed/direction, air temperature, relative humidity, barometric pressure, rainfall and location
Soil moisture	Campbell Scientific	SoilVue	Environmental factor in gas exchange
Soil heat flux	Hukseflux	HFP01	Soil heat flux (quality control on gas exchange/turbulence)
Soil temperature	Campbell Scientific	TCAV	Environmental factor in gas exchange
Rainfall	EML	ARG314	Environmental factor in gas exchange

Cross Lochs, Forsinard, The Flow Country - UK-CLS

Cross Lochs was installed by UKCEH in 2008 and has operated since then with some breaks due to instrument problems until 2014. It was refurbished and brought back to full operation by JHI in 2016, when some of the major instruments were also exchanged for different models (requiring different data handling). It is located on the RSPB Forsinard Reserve within the Flow Country and represents what is likely to nearest example to a pristine blanket bog. The Flow Country as a whole represent the largest area of intact blanket bog in the world, although large parts have been modified by human activities. Its early (2008-2014) data have been published in Levy & Gray, 2015. Instrumentation on this system is a mix of ownership between UKCEH and JHI.

UK-CLS Location, Land use and Topography

Grid Reference: NC 85151 44251; Lat 58.371598, Lon -3.9651938; Altitude 207 m asl

The site is ideal for the application of eddy-covariance as it is fairly flat and extensive, other than the power supply and storage boxes, there is no disruption to the fetch in any wind direction. The peat is in near natural condition as there has been no extensive cutting or tree planting is this area, although there is some drainage due to the access tracks and ditches, and there is some unquantified grazing biomass offtake by deer.

Figure 8 Location of Cross Lochs, UK-CLS

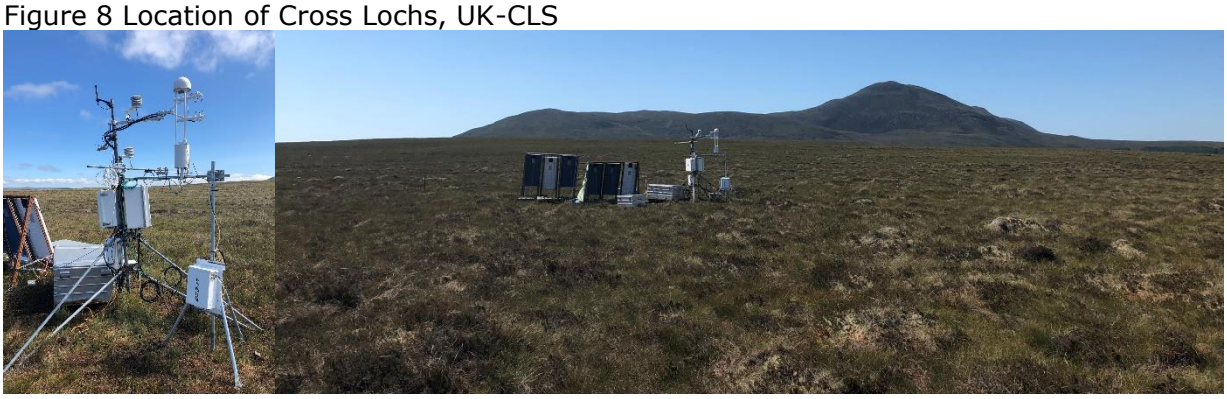

Figure 9 The tower and landscape around Cross Lochs

UK-CLS Instrumentation Summary

This site is mainly instrumented with Campbell Scientific supplied and manufactured instruments with the exception of the methane sensor.

Table 5 UK-CLS Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger(s)	Campbell Scientific	CR3000	Store/analyse data
Modem	Sierra Wireless	RV50X	Remote communication
Carbon dioxide and water vapour	Campbell Scientific	IRGASON	Gas exchange, humidity
Methane exchange	LICOR	LI-7700	Gas exchange
Sonic anemometer	Campbell Scientific	IRGASON	Wind speed & direction; turbulence/gas exchange
Net radiometer	Kipp&Zonen	NRLite2	Net radiation (quality control on gas exchange/turbulence)
Total global solar	Kipp&Zonen	CMP11	Environmental factor in gas exchange
Photosynthetically Active Radiation	Skye Instruments	SKP215	Environmental factor in gas exchange
Soil Moisture	Campbell Scientific	CS616	Environmental factor in gas exchange
Soil Temperature	Campbell Scientific	105T & TCAV	Environmental factor in gas exchange
Soil heat flux	Huskeflux	HFP01	Quality control on gas exchange/turbulence
Water Table Depth	Durck	PDCR 1830	Environmental factor in gas exchange
Air temperature & Relative Humidity	Campbell Scientific	CS215	Environmental factor in gas exchange; gas unit conversion
Rainfall	RM Young		Environmental factor in gas exchange
Surface Wetness	Campbell Scientific	237 Leaf Wetness Sensor	Environmental factor in gas exchange

Dyke, Forsinard, The Flow Country - UK-DKE

Dyke was installed in 2016 by UHI to monitor CO_2 exchange over a mature stand of commercial forestry prior to its harvesting and ongoing restoration of the peatland. The trees were felled in late 2017 and the tower was shortened and reinstalled at the original location in August 2018 before being moved to improve the fetch in 2019. Equipment is owned by UHI and was funded by Peatland ACTION.

UK-DKE Location, Land use and Topography

Grid Ref Pre-restoration: NC 85113 50463; Lat 58.427254, Lon -3.969340; 156 m asl
Grid Ref Post-restoration: NC 85121 50454; Lat 58.427264, Lon -3.968809; 149 m asl

The site has a reasonably good topography for eddy-covariance in that the ground is fairly level, but the fetch is limited by a burn which runs along the S-SW side of the block and the rides (tracks) left for accessing the forest.

Figure 10 Location of the Dyke tower, UK-DKE

Figure 11 Dyke tower and landscape (top left original post-harvest installation on tall mast, relocated short tower top right and bottom)

UK-DKE Instrumentation Summary

This site is instrumented with a LICOR system of instruments.

Table 6 UK-DKE Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger(s)	Sutron	9210	Store/analyse data
Modem	Proroute	M2M H685	Remote communication
Enclosed-path carbon dioxide and water	Licor	LI-7200	Gas exchange, humidity
Open path methane	Licor	LI-7700	Gas exchange
Sonic anemometer	Gill	Windmaster Pro	Wind speed & direction; turbulence/gas exchange
Soil heat flux plate x3	Hukseflux	HFP01	Net radiation (quality control on gas exchange/turbulence)
Net radiometer	Kipp & Zonen	NR-Lite	Environmental factor in gas exchange
Air Temperature & Relative humidity	Vaisala	HMP155	Environmental factor in gas exchange
PAR	Licor	LI-190R	Environmental factor in gas exchange
Soil temperature x3	Licor	7900-180	Quality control on gas exchange/turbulence
Soil moisture x3	Delta-T	ML2	Environmental factor in gas exchange
Water level	Durck	PDCR 1830	Environmental factor in gas exchange; gas unit conversion
Rainguage	Texas Instruments	TR-525	Environmental factor in gas exchange

Dyke-FIRE, Forsinard, The Flow Country - UK-DKF

This site was set up in September 2019 following a wildfire that spread into the north of the reserve, coming with about 20 m of the Dyke tower. The instrumentation is owned by University of Glasgow and on loan to JHI. The fire did not materially penetrate the peat but did a lot of damage to the surface vegetation and burnt some of the brash still lying after the forestry had been harvested in 2017/2018. The tower is located on the edge of the harvested blocks, almost due north of the Dyke tower. It had originally been planned to mulch the brash on both sites and leave it in-situ but following the disruption caused by the covid pandemic this has been postponed and a different restoration technique may be used.

Figure 12 Wildfire impacts in proximity to the Dyke tower (top right)

UK-DKF Location, Land use and Topography

Grid Ref: NC 85049 50888; Lat 58.431141, Lon -3.9702661; Alt 168 m asl

As with Dyke, the site is not perfect for eddy-covariance as it slopes to the SW and there are distinct boundaries to the block, with a large wet area/pools of water in winter within the fetch.

Figure 13 Location of Dyke FIRE, UK-DKF


Figure 14 The FIRE tower and landscape

UK-DKF Instrumentation Summary

This site was originally instrumented with a full LICOR system but following the failure of the Sutron data logger in 2022, it was replaced with a Campbell Scientific logger.

Table 7 UK-DKF Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger	CampbellSci	CR1000X	Store/analyse data
Modem	Proroute	M2M H685	Remote communication
Enclosed-path carbon dioxide and water	Licor	LI-7200	Gas exchange, humidity
Open path methane	Licor	LI-7700	Gas exchange
Sonic anemometer	Gill	Windmaster Pro. 1561-LID-040/W	Wind speed & direction; turbulence/gas exchange
Net radiometer	Kipp & Zonen	NRLite	Net radiation (quality control on gas exchange/turbulence)
Temperature and humidity	Vaisala	HMP155	Environmental factor in gas exchange
PAR (Quantum)	Licor	Li-190R-AMV-5	Environmental factor in gas exchange
Global radiation	Licor	LI-200R-SMV-5	Environmental factor in gas exchange
Soil heat flux	Hukseflux	HFP01-SC	Quality control on gas exchange/turbulence
Water level	Campbell Scientific	CS456	Environmental factor in gas exchange
Rainguage	Texas Instruments	TR-525M	Environmental factor in gas exchange
Soil Water Content & Temperature	Stevens	HydroProbeII	Environmental factor in gas exchange; gas unit conversion

Elchies, Moray - UK-ECH

This site is on a block of secondary conifer plantation and so it has been through a cycle of commercial tree planting and harvest already. The new trees are still very young and at most about 1 m tall, allowing us to use a relatively short tower rather than the tall masts or scaffolding often needed for mature plantations. The instrumentation is owned by JHI and was funded by Peatland ACTION.

UK-ECH Location, Land use and Topography

Grid Ref: NJ21676 46918; Lat 57.505657, Lon -3.3087757; Alt 295 m asl

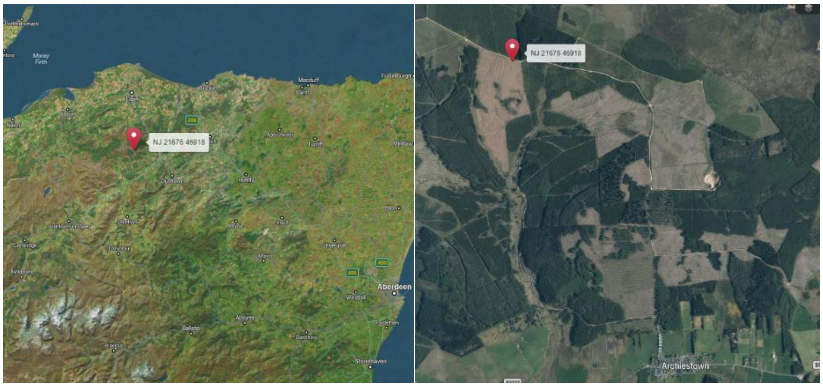

Figure 15 Location of Elchies, UK-ECH

Unfortunately the fetch at this site is slighty restricted, due to surrounding blocks of plantation, and we only measure in the S-SW wind sector. There are also some distruptions in that sector such as a block of mature birch trees to the SSW and the ground slopes away quite steeply from about 20 m away from the tower. With these restrictions and the rough surface we are assessing the best height for the instruments to capture the gas exchange without compromising data quality. It was installed at around 2.80 m above the surface, then moved to 3.5 m on 3/05/2021, and lowered slightly to 3.15 m on 31/08/2022.

UK-ECH Instrumentation Summary

The instrumentation installed at Elchies is a full Licor system, initially with an enclosed path LI-7200 CO_2/H_2O analyser. The system experienced some faults after installation and the LI-7200 had to be replaced with a LI7500DS open-path unit so it could be sent for repair.

Table 8 UK-ECH Instrumentation

Description	Manufacturer	Model	Additional Info.
Biomet Data Acquisition System	Licor	DAqM	Store/analyse data
Modem	Proroute	M2M H685	Remote communication
Enclosed path carbon dioxide and water	Licor	LI-7200RS	Gas exchange, humidity
Open path methane	Licor	LI-7700	Gas exchange
Sonic anemometer	Gill	Windmaster Pro	Wind speed & direction; turbulence/gas exchange
Net radiometer	Kipp & Zonen	CNR4	Net radiation (quality control on gas exchange/turbulence)
PAR	Licor	LI-190R	Environmental factor in gas exchange
Temperature and humidity	Vaisala	HMP155	Environmental factor in gas exchange; gas unit conversion
Soil moisture and temperature	Stevens	Hydraprobe	Environmental factor in gas exchange
Self-calibrating soil heat flux plate	Hukseflux	HFP01SC	Quality control on gas exchange/turbulence
Rainguage	Texas Electronics	TR-525M	Environmental factor in gas exchange

Girlsta, Shetland - UK-GST

This is the most northerly UK site, representing a cool maritime climate. The site is located near the hamlet of Girlsta. The peatland is heavily degraded with large, deep gullies and areas of bare peat or bedrock. There is nearby peatland restoration but not within the fetch of this system. The instrumentation is owned by JHI and was funded by Peatland ACTION.

UK-GST Location, Land use and Topography

Grid Ref: HU42191 49797; Lat 60.230296, Lon -1.240111; 32 m asl

The fetch at the site is limited by the topography as there is a rise along the WSW and a step-down drop to the east.

UK-GST Instrumentation Summary

This site is instrumented with a full Campbell Scientific system, but the IRGASON failed after a few months and is currently away for repair and has been replaced with a LICOR LI-7200DS.

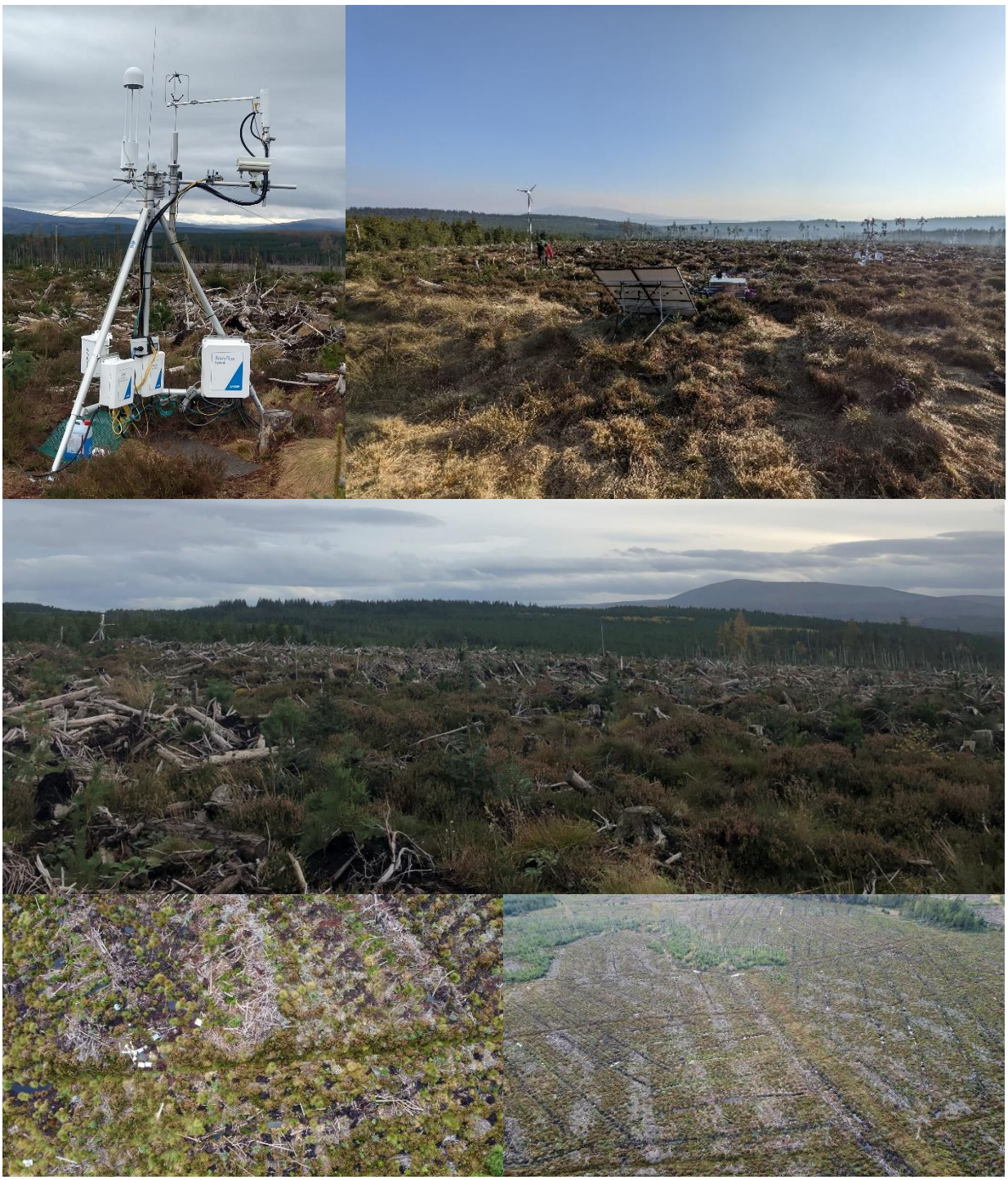

Figure 16 Elchies tower and landscape

Table 9 UK-GST Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger	Campbell Scientific	CR1000X & CR6	Store/analyse data
Modem	Sierra Wireless	RV50X	Remote communication
Open-path carbon dioxide and water vapour	Campbell Scientific	Irgason	Gas exchange, humidity
Methane	Licor	LI-7700	Gas exchange
2D sonic anemometer	Gill	Windsonic	Wind speed & direction; turbulence/gas exchange
Net radiometer	Apogee	SN500ss	Net radiation (quality control on gas exchange/turbulence)
Temperature and humidity	Rototronic	HC2A-S3	Environmental factor in gas exchange; gas unit conversion
Heat flux plates	Hukseflux	HFP01SC	Quality control on gas exchange/turbulence
Average soil temperature	Campbell Scientific	TCAV	Quality control on gas exchange/turbulence; Environmental factor in gas exchange
Soil water content and temperature	Campbell Scientific	CS650	Environmental factor in gas exchange
Soil water content	Campbell Scientific	CS655	Environmental factor in gas exchange
Rainguage	EML	ARG314	Environmental factor in gas exchange
Water depth	Campbell Scientific	CS456	Environmental factor in gas exchange

Figure 17 Location of the Girlsta tower

Figure 18 Girlsta tower and landscape

Lonielist, Forsinard, The Flow Country - UK-LNS

This site was setup in 2014 by JHI on the Forsinard RSPB Reserve. The area had been felled after a first rotation of conifers and rewetted in 2003/2004, with further reprofiling and furrow blocking in 2018. With a relatively long period since restoration started it represents a peatland in transition towards a near natural state. The instrumentation is owned by JHI and was funded by the RESAS.

UK-LNS Location, Land use and Topography

Grid Ref: NC96913 46089; Lat 58.391024, Lon -3.7650510. Alt 174 m. asl

Figure 19 The location of Lonielist, UK-LNS

The site is ideal for eddy-covariance with extensive fetch in all wind directions which is fairly level and homogenous. The only significant disruption comes from the access track which runs along the south side of the site.

Figure 20 Lonielist tower and landscape. Top middle is prior to resurfacing, with lots of small brash present while the top left is a year afterwards.

UK-LNS Instrumentation Summary

This site operates with a full LICOR system and has some additional sensors to most of the other sites, such as NDVI and more replicates of soil moisture and temperature.

Table 10 UK-LNS Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger(s)	Sutron	9210	Store/analyse data
Modem	Sierra Wireless	RV50X	Remote communication
Enclosed-path carbon dioxide and water	Licor	LI-7200	Gas exchange, humidity
Open path methane	Licor	LI-7700	Gas exchange
Sonic anemometer	Gill	HS	Wind speed & direction; turbulence/gas exchange
Soil heat flux plate	Hukseflux	HFP01	Environmental factor in gas exchange
Net radiometer	Kipp & Zonen	CNR2	Quality control on gas exchange/turbulence
Temperature and humidity	Vaisala	HMP155	Environmental factor in gas exchange; gas unit conversion
PAR	LICOR	LI-190R	Environmental factor in gas exchange
NDVI	Skye	SKR 1860ND SKR 1860D	Environmental factor in gas exchange
Soil moisture	Campbell Scientific	CS650	Environmental factor in gas exchange
Water level	Durck	PDCR 1830	Gas exchange
Rainguage	Texas Electronics	TR-525M	Wind speed & direction; turbulence/gas exchange

Talaheel, Forsinard, The Flow Country - UK-THE

This site on Forsinard was installed in 2013 by the University of St Andrews (instrumentation is now owned by the University of Exeter). It was previously another commercial tree plantation which was harvested in 1997, with the main drains rewetted in 1997/98. Further furrow blocking occurred in 2015 and the site is now near to a natural state, although the plantation ridges and furrows are still visible, and some trees have regenerated across the fetch.

UK-THE Location, Land use and Topography

Grid Ref: NC 95067 48816; Lat 58.415061, Lon -3.7978571; Alt 172 m asl

The site is another which meets the requirements for eddy-covariance quite well. There is an extensive fetch which is fairly homogenous, although a few trees are regenerating, but the ground is slightly sloped to the NW.

UK-THE Instrumentation Summary

This site is unusual in that it has a custom-built CO_2/H_2O analyser which is essentially a LI-7500 open-path instrument enclosed in a box with a fan to sample the air and flow it through the chamber.

It was constructed before the enclosed path instruments were available (Licor LI7200 and Campbell Scientific CPEC), the quality of gas exchange is measures appears to be equivalent to the newer commercial instruments (addendum to Hill *et al* 2017). The rest of the tower uses standard commercial instruments and a Campbell data logger.

Table 11 UK-THE Instrumentation

Description	Manufacturer	Model	Additional Info.
Datalogger	Campbell Scientific	CR3000	Store/analyse data
Modem	Proroute	M2M H685	Remote communication
Enclosed path CO_2/H_2O	Uni of St Andrews	Customised Licor LI7500	Gas exchange, humidity
3D Sonic anemometer	Gill	Windmaster	Wind speed & direction; turbulence/gas exchange
Soil heat flux	Hukseflux	HFP01	Quality control on gas exchange/turbulence
Net radiometer	Kipp and Zonnen	CNR-2	Quality control on gas exchange/turbulence
Temperature and humidity	Campbell Scientific	CS215	Environmental factor in gas exchange; gas unit conversion
PAR	Skye	SKP215	Environmental factor in gas exchange
NDVI	Skye	SKR 1860ND SKR 1860D	Environmental factor in gas exchange
Soil temperature	Campbell Scientific	TBC	Environmental factor in gas exchange
Soil moisture	TBC	TBC	Environmental factor in gas exchange
Water level	Durck	PDCR 1830	Environmental factor in gas exchange
Rainguage	EML	ARG100	Environmental factor in gas exchange

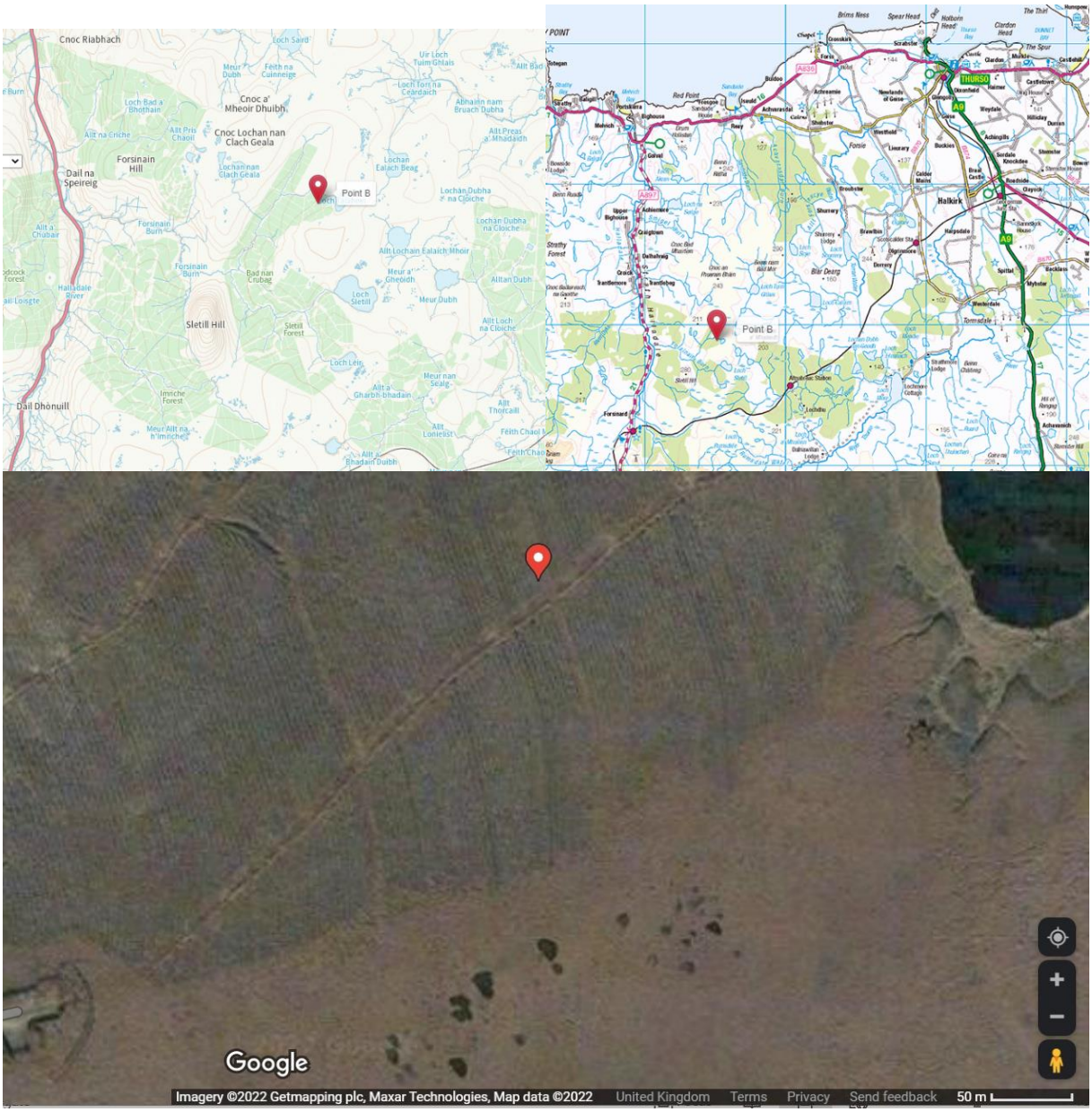

Figure 21 The location of Talaheel, UK-THE


Figure 22 The Talaheel tower and landscape

Affiliated Sites

There are four sites which are being affiliated with the network so their data can be utilized in analysis of peat GHG exchange across Scotland and the rest of the UK:

Auchencorth Moss (55°47'36" N, 3°14'41" W)

This site has been operated by UKCEH since 1995 although initially it measured other trace-gases, CO_2 exchanged was added in 2002. It is an ombrotrophic peatland, classified as a transitional raised lowland bog, peat depth varies considerably from only 20 cm to up to 3 m across the site. The fetch is idea for eddy covariance with an extensive flat and homogenous surface in the main wind sector. It is part of many national and international networks for studying and monitoring atmospheric processes and gas exchange such as GAW, ICOS, EMEP, AURN etc http://www.auchencorth.ceh.ac.uk/. The site has fairly shallow peat depth across much of the fetch and there is significant grazing biomass offtake by small mammals. In the UK GHG Inventory, it is classified as a modified, undrained, bog.

Racks Moss (55.043 °N, -3.513 °W)

The installation of this future site is being managed by CCC and UKCEH with support from FLS and Peatland ACTION. In 2018/2019 the need for more measurements over forested peat was identified, particularly over secondary plantations. However, forests pose the technical issue of measuring at height, particularly when including a CH_4 sensor which needs regular cleaning and servicing. UKCEH had a tall scaffolding tower in storage which would

allow safe, walk-up access to the top of the canopy and so they lead the project to identify and install a site. A suitable site was identified in Dumfries & Galloway on Racks Moss, near Dumfries and the CCC became project partners. Work on setting it up is progressing and plans are now going to the local council for approval, with the aim of completing installation is spring 2023.

Flanders Moss (56.135 ºN, -4.302 ºW)

This site is part of the EU-MERLIN (https://project-merlin.eu/, Mainstreaming Ecological Restoration of freshwater-related ecosystems in a Landscape context: INnovation, upscaling and transformation, led by UKCEH in the UK) and FORTH-ERA (University of Sterling, https://www.stir.ac.uk/about/scotlands-international-environment-centre/forth-environmental-resilience-array/) projects which aim to study, manage a monitor ecological restoration of different ecosystems across the Forth River catchment. A Licor system for measuring CO_2 and CH_4 is due for installation before the end of 2022.

Hare Moss

This site is also part of the EU-MERLIN project and is on the same area of bog as Auchencorth Moss. The area was drained historically and restoration is now planned to improve the condition of the peat. Several low cost/low tech methods are being employed, such as manual dipwells, and regular vegetation monitoring but they will also install a flux tower hopefully with funding from Peatland ACTION for the equipment.

Data Overview

The following figures show the meteorological and soil data obtained from each site, either as downloaded or from preliminary analysis. It should be noted that we are in the process of compiling the full data sets for each site and so some gaps and faults seen here will be filled and resolved. Where there are gaps in these compiled variables, they will be gap-filled as much as possible using either data from nearby sites or from meteorological models. For the final datasets all timeseries will be reviewed and any spurious data due to local events and faults removed. The CO_2 and CH_4 fluxes will be reported in future overviews after being recalculated using the standard procedures as defined by the Fluxnet (https://fluxnet.org/) and ICOS international monitoring networks (https://www.icos-cp.eu/). If conditions at the site are consistent with time the data logging will be setup to calculate the final fluxes in real-time where the software allows this.

Arnol, Lewis, UK-ARN

The time series for the Arnol site shows the good data coverage that has been obtained to date (Figure 23). The site has operated well, with all the variables are within the expected range and few loses. The soil water content shows significant variation between the locations, one on a hummock of peat, one in a hollow and one in an intermediate location,

illustrating the importance of replicating measurements of some parameters in this complex environment. The water table depth[3] shows that it took a week or so for the dipwell to reach equilibrium with the surrounding peat and fill with water. Unfortunately, the rainfall was not recorded due to a programming fault but this period will be filled with measurements from a nearby weather station, or standard model outputs if these cannot be obtained.

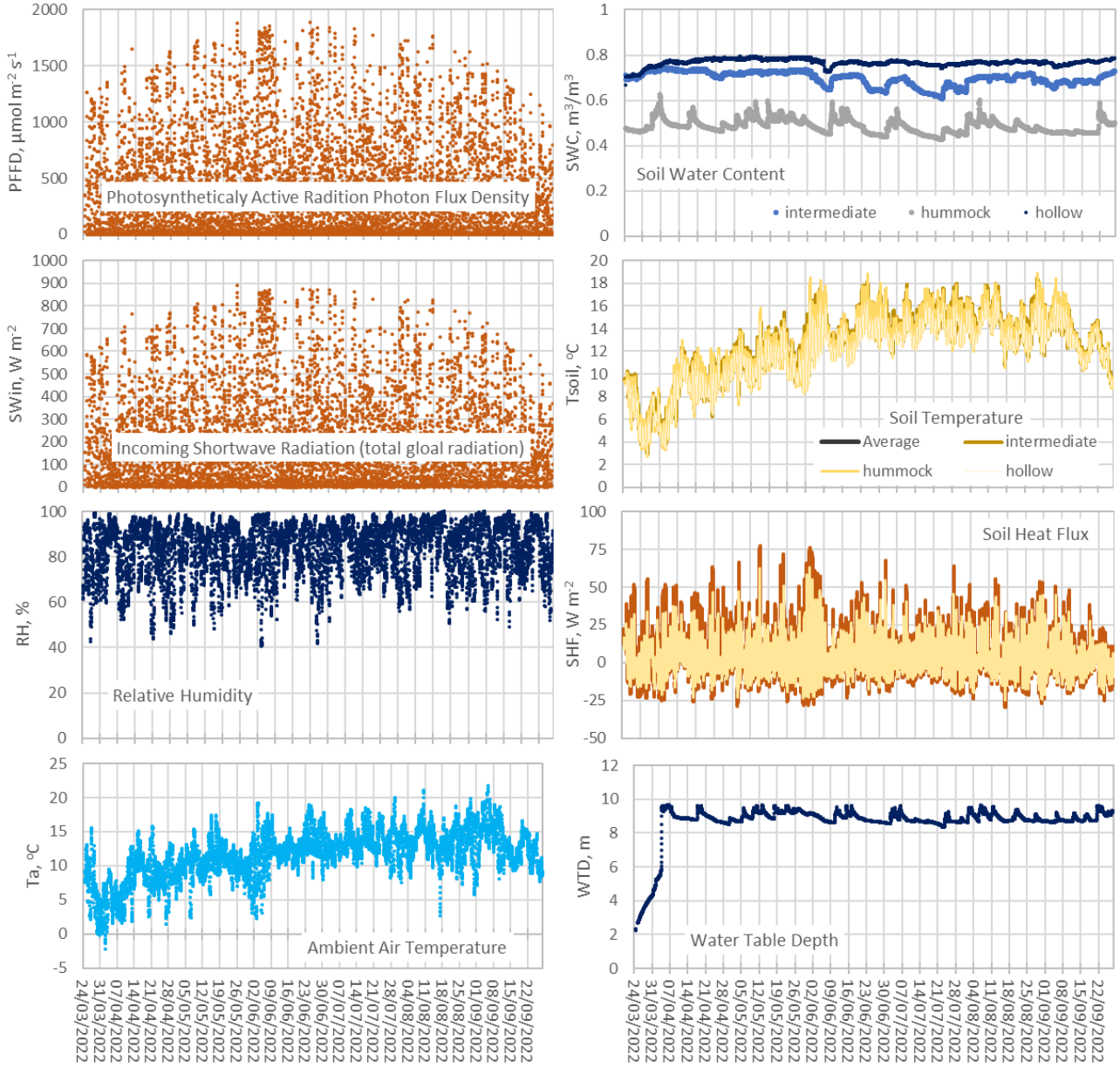

Figure 23 Time series of meteorological and soil variables observed at Arnol since installation.

[3] Water table depth is reported as m or cm below the surface, so larger numbers mean less water in the column. There are also a number of further standalone water table loggers within the footprint.

Balmoral, Cairngorms, UK-BAM

For the Balmoral site the impact of the instrument, logging and power supply issues are clearly seen in the time series. However, the meteorological data can be gap filled with other data and we hope to recover more raw data, Figure 24.

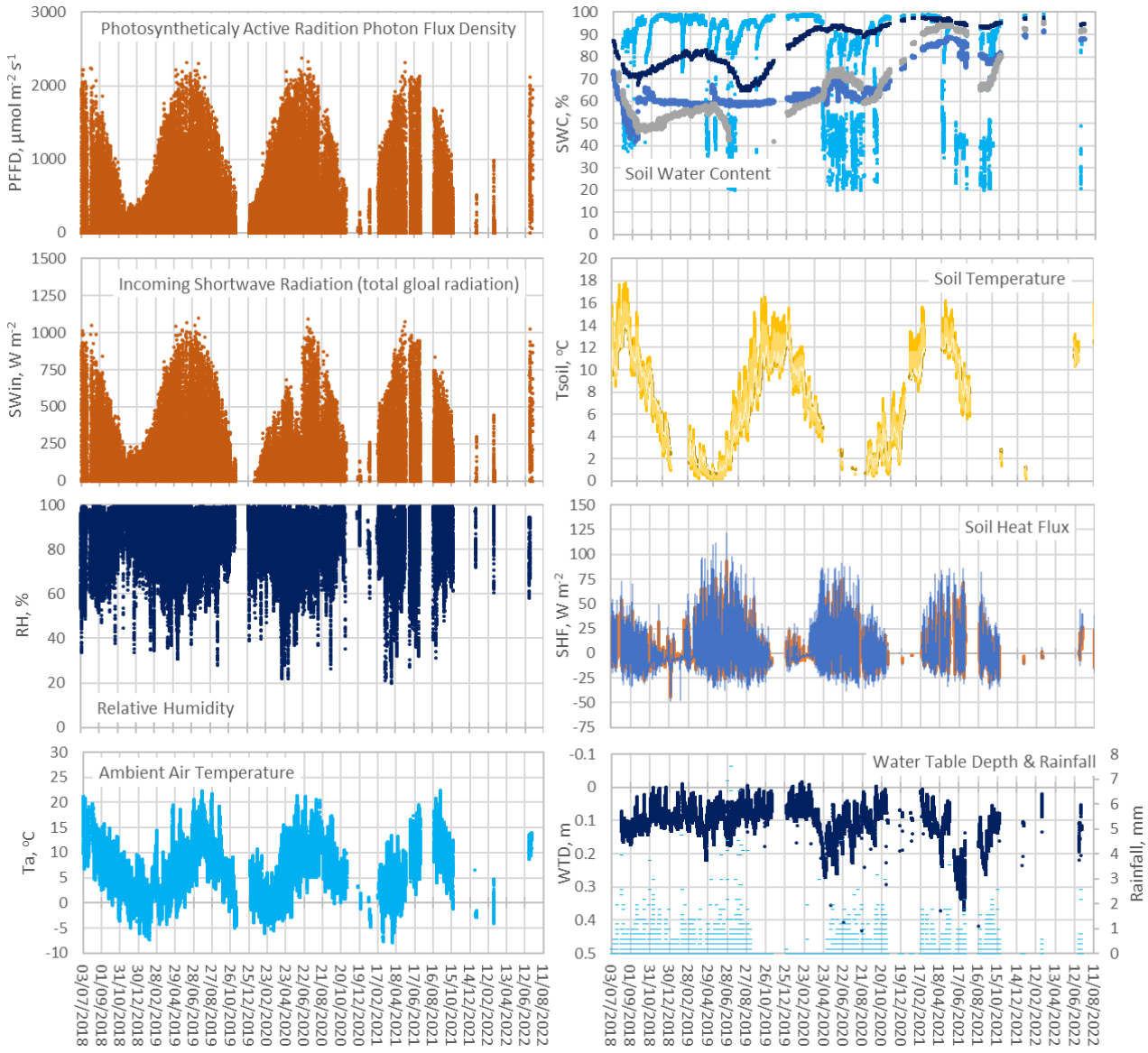

Figure 24 Time series of meteorological and soil variables observed at Balmoral since installation. There are also a number of further standalone water table loggers within the footprint and wider surrounding area, as well as other hydrological monitoring.

Balruddery, Dundee, UK-BLR

The Balruddery data are not plotted here as the site has not been managed as part of the network, it was setup to provide data to a model and phone app. Although some data have been logged, they have not been collated or processed as yet.

Cross Lochs Forsinard, UK-CLS

The measurements at Cross Lochs started in 2008 but data from when JHI took over running the site are reported here, Figure 25. There were some bugs in the data logging program which led to losses of some parameters at the start of the time series, but these will be filled by correcting the logged data and gap filling. The water table depth appears to have been above the top of the dipwell for much of 2017-2019 but the site records and data need reviewed to check the correct sensor depth was used to calculate the distance to the water table. Some parameters have been gap filled up to 2018 while the latest data is as recorded.

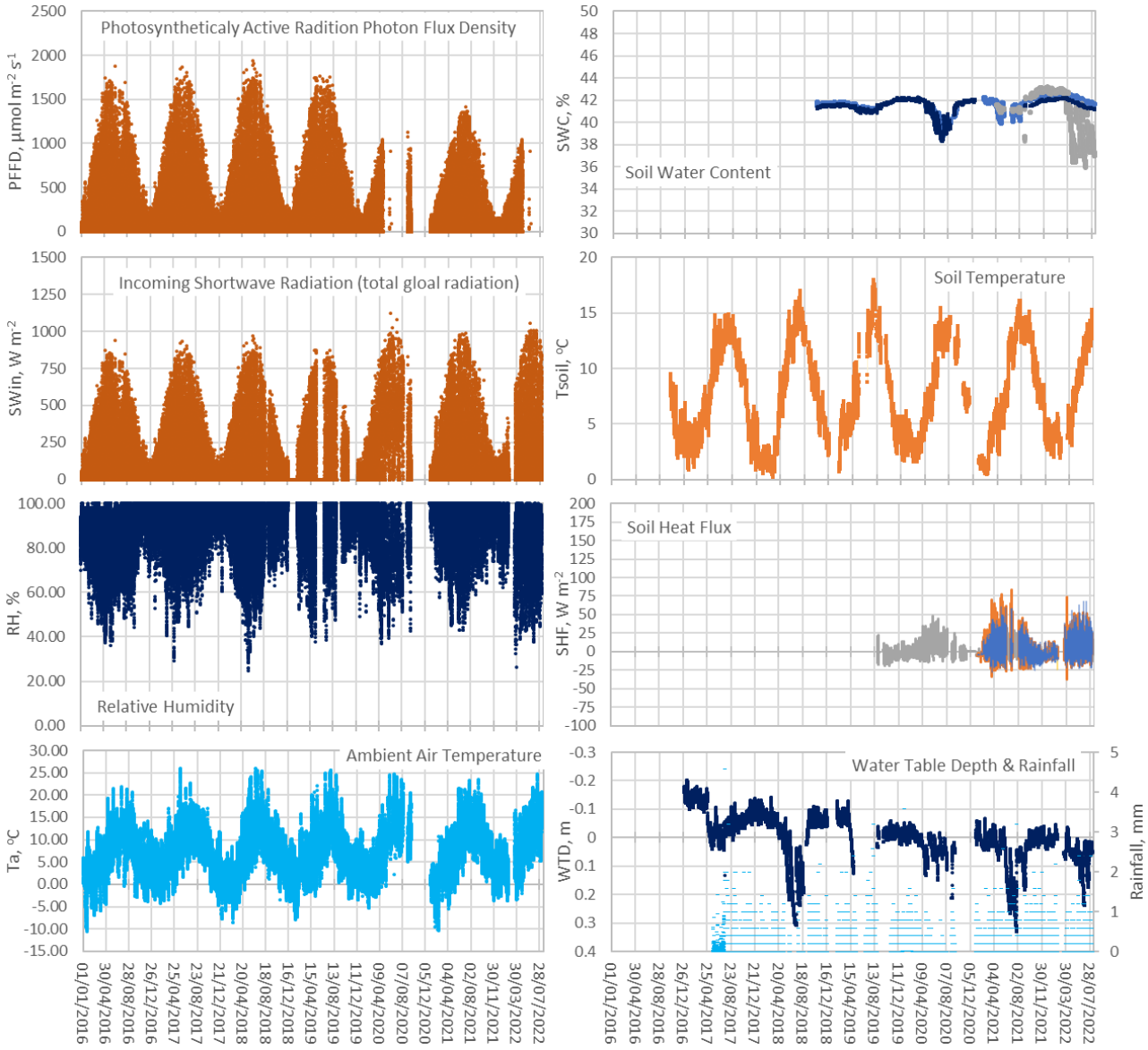

Figure 25 Time series of meteorological and soil variables observed at Cross Lochs since 2016. There are also a number of further standalone water table loggers on the other side of the footprint.

Dyke, Forsinard, UK-DKE

The instruments at this site were removed before the trees were harvested and the meteorological data reflects this, Figure 26. The solar radiation remains the same as the sensor is always exposed while the soil heat flux and temperature both show increased variation without the trees in place, as the ground surface is now exposed to solar heating. The data also show that the soil was a lot drier with the trees in place. While it appears that the water table has dropped, the data require review to ascertain if this is a true measurement or caused by a change in sensor and programming. Other time series need reviewing and more data will hopefully be added to the historical data in due course. The relative humidity and temperature sensor has developed an intermittent fault which will be resolved at the next site visit.

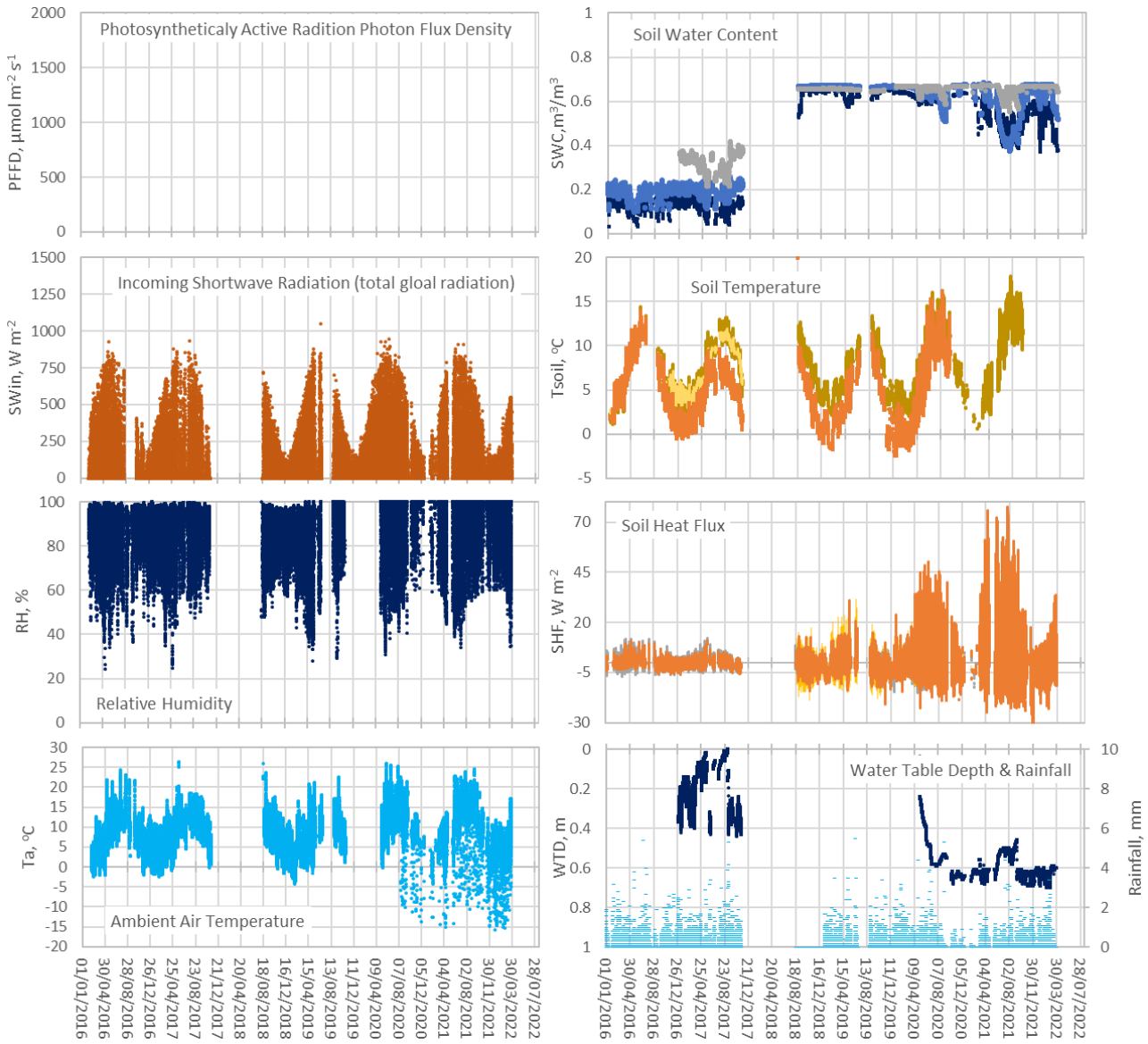

Figure 26 Time series of meteorological and soil variables observed at Dyke since 2016.

Dyke-FIRE, Forsinard, UK-DKF

The meteorological measurements at this site ran well for the first two years but at the end of 2021 the data logger failed, Figure 27. It took some time to construct a replacement unit. The magnitude of the soil heat flux at both Dyke and Dyke-FIRE are very similar, as the only difference between these sites is that the brash left in place at the FIRE site and some surface vegetation was burned in the wildfire, while Dyke remained untouched.

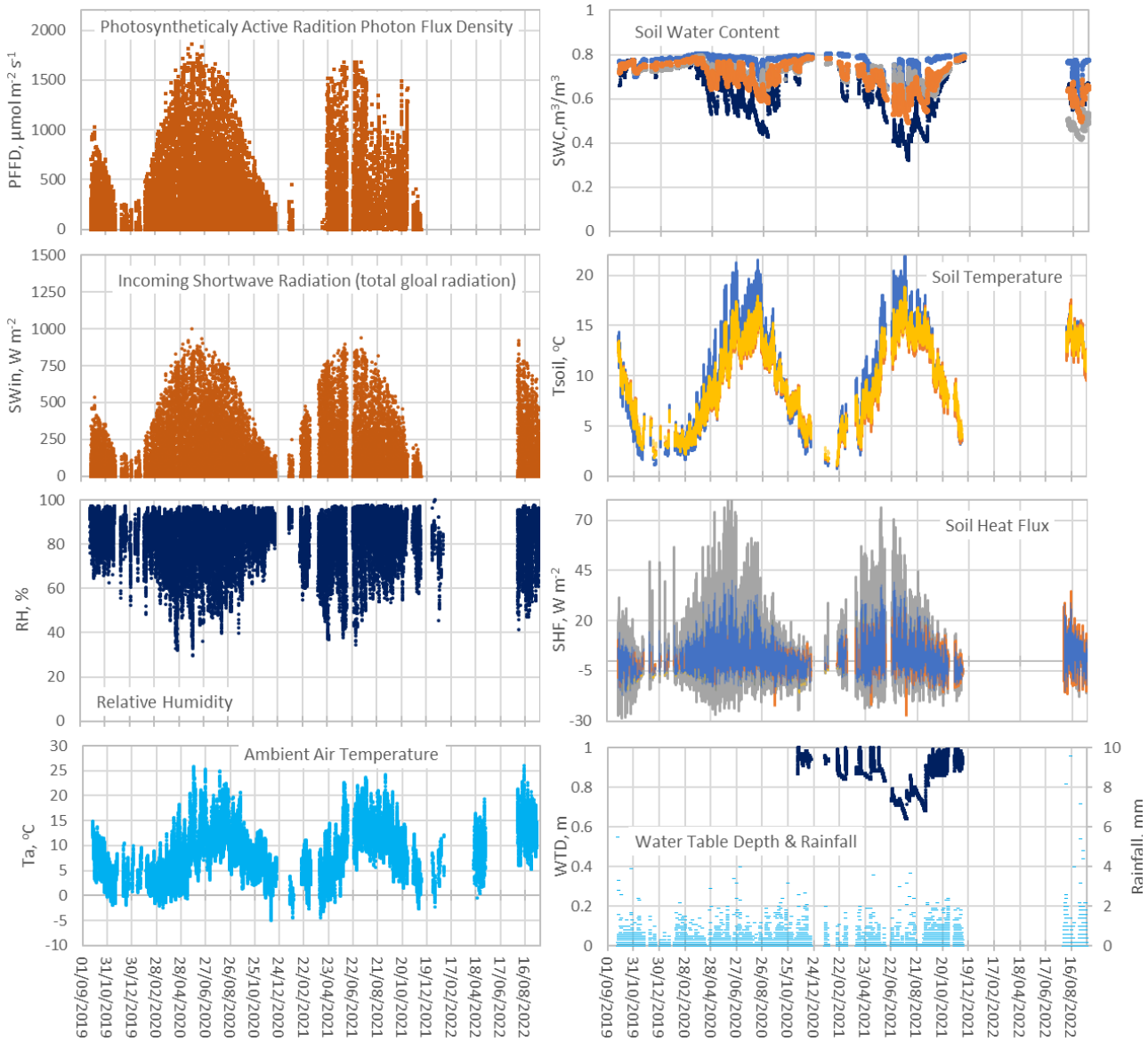

Figure 27 Time series of meteorological and soil variables observed at Dyke-FIRE since installation. The water table depth data require review.

Elchies, Moray, UK-ECH

The meteorological sensors at Elchies have operated well since installation, with most gaps due to power failures rather than sensors, Figure 28. The water table depth is recorded for the whole period but that latter portion requires recalculating with the correct installation depth and so is not shown.

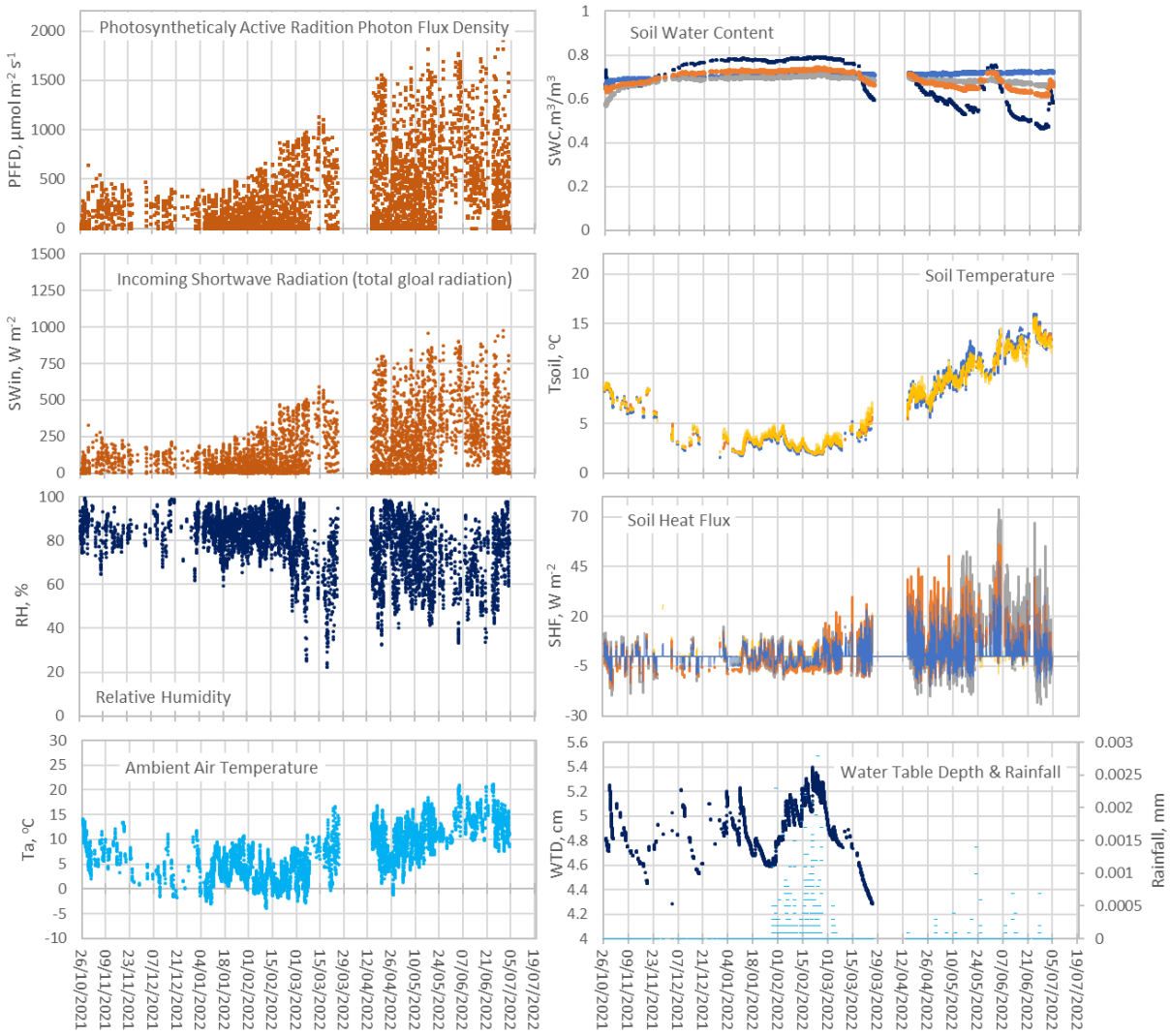

Figure 28 Time series of meteorological and soil variables observed at Elchies since installation. There are also a number of further standalone water table loggers within the footprint.

Girlsta, Shetland, UK-GST

The time series collated for Girlsta to date is shown in Figure 29. As described in more detail in the following section, this site experienced several technical issues despite initially operating very well and so there are currently several gaps in the meteorological data Further

review of the data we have will increase the data capture and give us what's needed to examine the CO_2 and CH_4 exchange over this eroded peat bog.

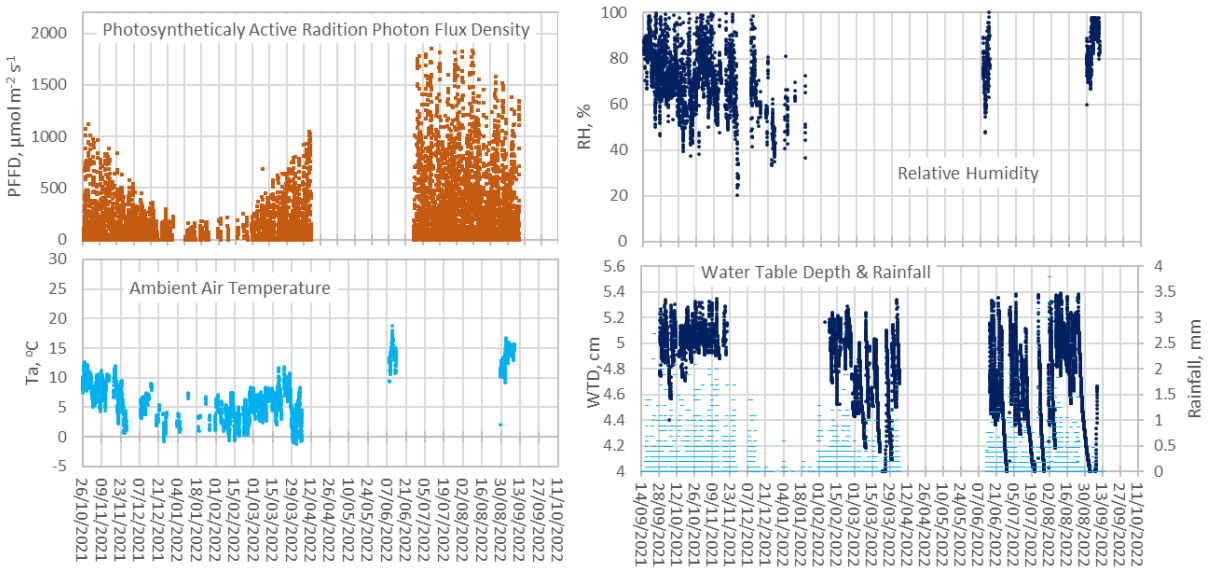

Figure 29 Time series of meteorological and soil variables observed at Girlsta since installation. There are also a number of further standalone water table loggers within the footprint.

Lonielist, Forsinard, UK-LNS

Lonielist is plotted in Figure 30, this is one of the longer running sites and it has good data coverage in many years. The time series do show some outstanding issues such as the intermittent low readings from the relative humdiity and temperature probe, as well as missing periods in the soil climate. As already noted some this data will be recovered and procedures are being put in place to detect and resolve faults more promptly as the full network is established.

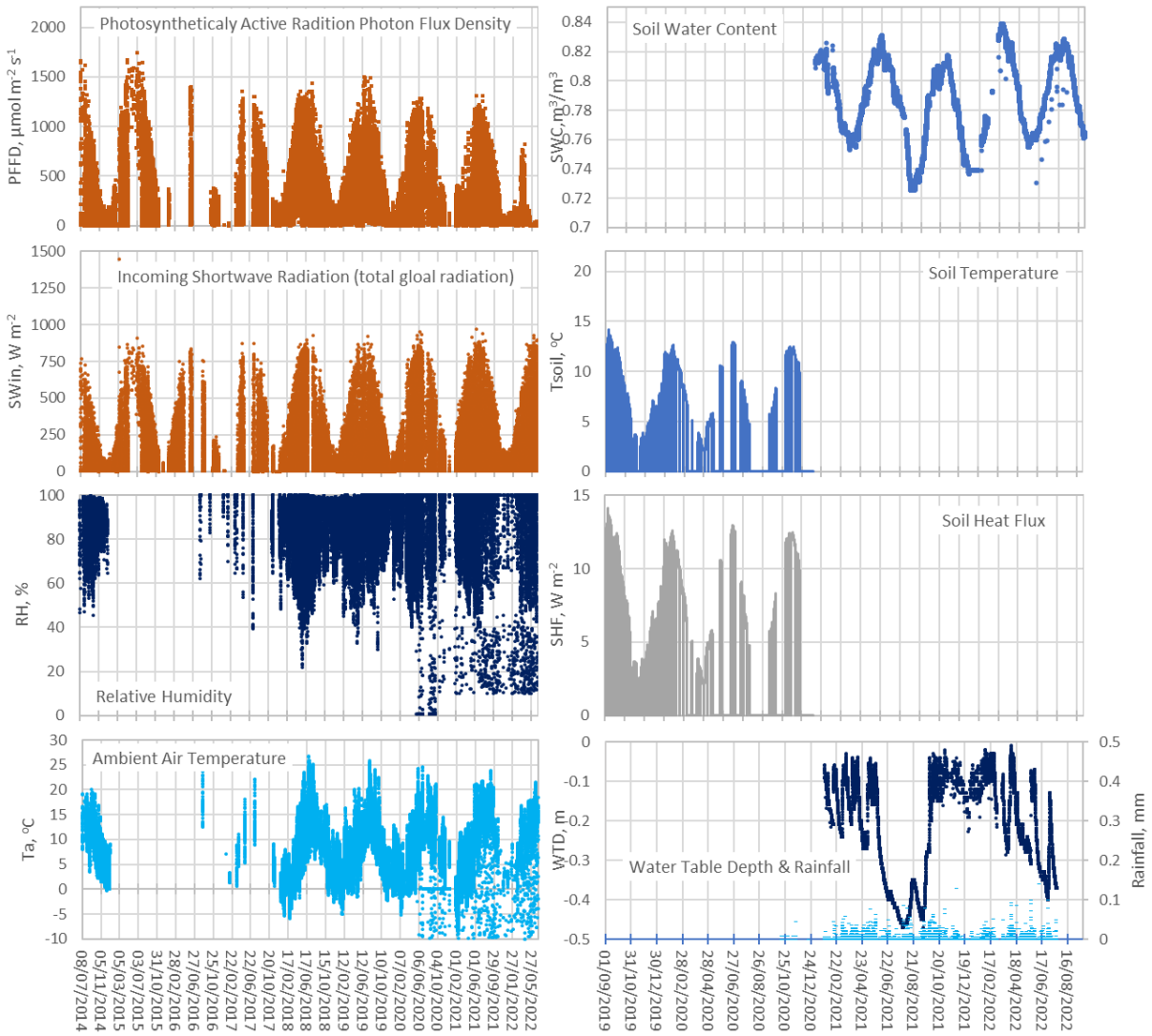

Figure 30 Time series of meteorological and soil variables observed at Lonielist since installation. There are also a number of further standalone water table loggers within the wider area.

Talaheel, Forsinard, UK-THE

The final set of time series plots is shown in Figure 31 for Talaheel, which is another long running site. As with the others there are gaps in some parameters but with further collation and review some of this will be recovered and gapfilled.

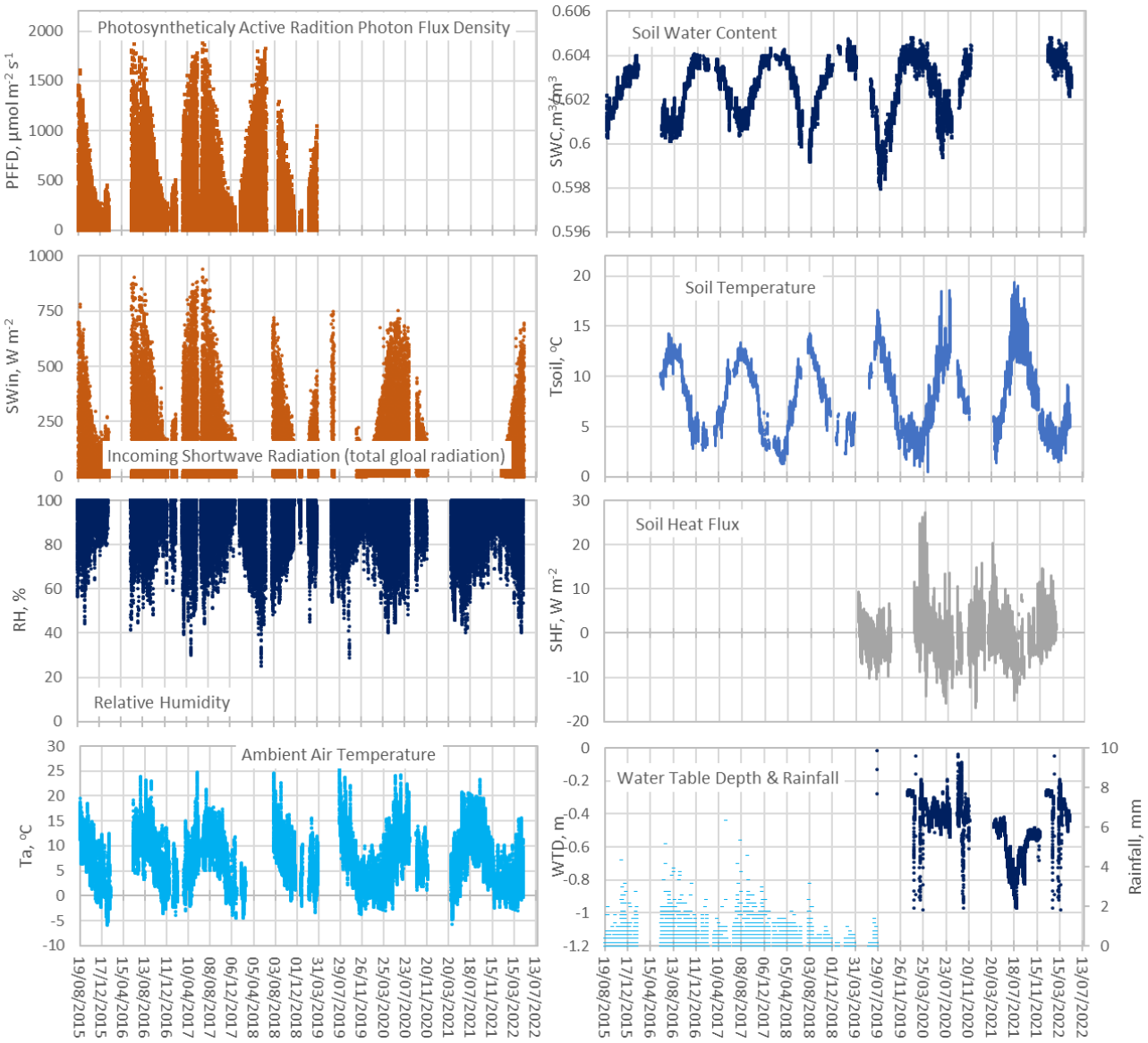

Figure 31 Time series of meteorological and soil variables observed at Talaheel since installation. There are also a number of further standalone water table loggers within the wider area.

Site Operations - Hardware and Infrastructure

The sites are designed to operate continuously without intervention other than regular inspections and maintenance. They all have telemetry[4], to allow the data to be retrieved in real-time and the instruments checked remotely. The following tasks are undertaken to keep things operating smoothly:

- Regular site visits to: clean the methane sensor, top up its washer fluid; copy data from local storage; check all equipment is operating and secure (at least monthly) – this is done by a local site operator where the site is too far from Aberdeen
- Remote checks on the instruments and battery power
- 6-monthly site service visits to: calibrate CO_2 and CH_4; swap out any sensors that need calibration/service offsite.

The data can be considered as two streams, the fast eddy-covariance data and the slower meteorological variables, as indicated in Table 11. The former is essential to being able to calculate the gas exchange while the latter aid quality control and interpretation on the drivers of the gas exchange. Not all sites measure the full suite of slow variables shown.

Table 12 Fast and slow data streams

Fast (sampled at 10 – 20 Hz)	Slow (sampling *ca* 1-10s, averaged 30 min)
Wind speed Wind direction Air temperature (from sonic or other sensor) CO_2 concentration H_2O concentration CH_4 concentration Barometric pressure Relative humidity (from H_2O or another sensor)	Net radiation Incoming total global radiation Photosynthetically active radiation (global and diffuse) Air temperature Relative humidity Soil heat flux Soil water content Soil temperature Rainfall Water table depth Barometric pressure NDVI (normalized difference vegetation index)

Table 1, in the Executive Summary, gives the data capture achieved for each stream, although the individual parameters may vary due to specific issues with a sensor, a full review of each site and sensor will follow in future reports.

Arnol, Isle of Lewis - UK-ARN

The installation went very well with the key components operating well. There have been two issues with this site:

- The tipping bucket rainfall sensor was flooded after the first heavy rainfall and the sensor appears to have been damaged
- The blades came off the wind turbine after only around a week's service (see notes on Girlsta and Elchies also)

[4] Telemetry at the Balmoral site is still being set up, as it required a secondary mast to relay the data. This is now installed but not yet fully operational.

Balmoral, Glen Muick, Balmoral Estate - UK-BAM

The site at Balmoral was installed in July 2018 and operated smoothly until a series of faults reduced its capabilities and, in conjunction with the covid pandemic, lead to data losses:

- January 2019 the modem couldn't maintain the 4G connection to allow remote communications, eventually it was clear that the signal strength had degraded in the region and the site was no longer seeing any networks
- May 2019 the phenocam (networked camera that takes daily shots of the vegetation) stopped working
- November 2019 intermittent blocks of corrupted data in the fast data files
- January 2020 net radiation sensor faulty replaced June 2020
- August 2020 Li7700 CH_4 sensor installed
- September 2020 two additional solar panels with new charge regulator installed to help run through the winter.
- November 2020 gaps in the data occurring with corrupted files and the system powering down – suspected the backup battery in the logging box which was replaced
- December 2020 – June 2021 continuing power issues, various fixes tried, strange smell noted at the end of June
- July 2021 power issue resolved as batteries were found to be fused and overheating – system shut down and all batteries disconnected
- August 2021 new batteries installed
- September 2021 still finding some corrupted data and CH_4 not logging
- October 2021 – Aug 2022 various fixes attempted to get the CH_4 logging
- August 2022 data logger removed and replaced with a newer model, all instrumentation running smoothly

The site still does not have telemetry to improve its operation but a Wi-Fi bridge is being installed from the hilltop above the site and should be operational late autumn 2022. All other sensors other than a phenocam are operational and logging correctly.

Balruddery, Dundee - UK-BLR

This site was installed in June 2021 with the aim of the data being automatically uploaded to an app being developed to help farmers and other land managers assess the carbon balance of their land and the effect of any interventions they make. As the priority was not obtaining data for answering any questions about CO_2 exchange of the current crop directly, it was not managed with this goal in mind and so there are some gaps in the time series. The only technical issue with the equipment has been that the wrong batteries were purchased and do not maintain charge over the autumn and winter when shorter day lengths

reduce solar input. The batteries will be replaced before winter 2022 and the site operation scheduled enhanced to improve data quality and capture.

Cross Loch, Forsinard, The Flow Country - UK-CLS

The site has operated well overall with no major failures apart from the long gap between UKCEH discontinuing maintenance in 2014 and reinstallation by JHI in 2016. New solar panels and batteries have been installed in 2021/2022 and the dataloggers will be replaced with a new model to replace the current obsolete ones in due course.

Dyke, Forsinard, The Flow Country - UK-DKE

The site has suffered from several issues which limited the data capture achieved:

- The Licor system on the original tower had logging and power faults which lead to large amounts of data not being recorded fully.
- When initially reinstalled the equipment was too high up to measure over an appropriate fetch and was likely impacted by the burn that runs along the edge of the block.
- The installation of the short mast occurred just before the start of the covid pandemic, when it developed faults with the sonic anemometer and data logging, they took some time to resolve because of travel restrictions.

Dyke-FIRE, Forsinard, The Flow Country - UK-DKF

On the 13th of May 2019 a wildfire started near Melvich to the north of the Forsinard reserve and spread south over the following days. At its furthest southerly extent it came onto the reserve, coming within 10s of meters of the Dyke tower and burning the brash left from harvesting the forest, although it did not significantly penetrate the peat. As a result, a NERC urgency grant was awarded to a consortium of the James Hutton Institute, The University of Glasgow, UHI-ERI and the RSPB to install another flux tower over the burnt area and obtain data to compare the regeneration of the unburnt Dyke area and this burnt area (now known as Dyke-FIRE). The tower was installed in September 2019 and initially operated well but some issues developed with the sonic anemometer, then the power supply and CO_2/H_2O analyser. As with all the sites, covid restrictions made maintenance and repair difficult at times. It is now operating a full suite of sensors.

Elchies, Moray - UK-ECH

This site was part of funding from Peat Action in 2018/2019 to add three new towers to the network, covering secondary plantation and degraded peat in different climatic condition. It proved difficult to find suitable forestry sites as tall trees require either a mast or scaffolding tower, with associated health and safety considerations, and many plantations are on complex topography, making eddy-covariance difficult to apply. A site was identified in 2020

and equipment was installed in October 2021 after agreement with Forest and Land Scotland. It initially operated well but issues developed with the power supply and data logging. The Li-7200 gas analyser was replaced with a Li7500 in August 2022 and the site is now running smoothly.

Girlsta, Shetland - UK-GST

As with many sites it operated well at first but then developed some technical problems:

- The solar panel frame came apart and one panel was damaged
- The blades came off the wind turbine twice
- The IRGASON developed a fault
- Some meteorological sensors failed

The IRGASON was replaced with a LI7500 in June 2022 and all the meteorology sensors are now operating as of September, with the exception of the net radiometer.

Lonielist, Forsinard, The Flow Country - UK-LNS

In general, it has operated well with minimal data loses, with the main outages being due to the power supply failing over the winter months. The batteries, fuel cell and wind turbine have been refurbished and so the site should run more consistently over the winter.

Talaheel, Forsinard, The Flow Country - UK-THE

The site has generally operated smoothly but in 2018/2019 the sonic anemometer failed and was replaced with an instrument from UKCEH in June 2019. The only other major issue being power outages and some meteorological instrument faults. The batteries were replaced in 2021 and new solar panels are ready for installation in 2023.

Overview

As described in the introduction, The James Hutton Institute began working with eddy-covariance systems with the installation of the Lonielist tower on Forsinard, which has led to the GHG team now managing a network of 10 towers with 3 more and an autochamber system to be added in the coming months. The team has expanded from 0.9 FTE in the form of 2 scientists mainly managing, maintaining, and analysing the sites and data, to a current group of 7 individuals (4.65 FTE) with technical support, a dedicated GHG data analyst, and further support for data collation and analysis of ancillary environmental data, over the last four years. Further expansion with another 1 FTE field technical support role is intended to start soon, to support the additional 3 sites as mentioned above. In addition, the NERC funding also adds capacity that is funded within some of the partner institutions, for remote site maintenance and further joint data analysis capacity. With these resources we should obtain a valuable dataset for use in academic research as well as supporting the continued

development of higher Tier methods to calculate national scale inventories of carbon emissions for Scotland and the UK and, ultimately, sent the baseline for more targeted policy development for peatland management in order to reach Scotland's net zero targets. However there is a legacy of issues to be resolved as we setup rigorous procedures to ensure the smooth operation of the network. Over the coming few months the following tasks will progress:

- Harmonising data acquisition and archiving with the UKCEH network of towers across the rest of the UK. This will involve sharing routines for automatically processing and quality checking data as it is retrieved from the sites in real-time.
- Harmonising instruments and logging across sites, there are a variety of systems in operation which adds to the complexities of managing them
- Ensuring remote communications are stable and fast enough to allow real-time data downloads, checking operations and troubleshooting
- Bringing the data archiving and analysis up to date at all sites, including an assessment of the site's fetch and setup to ensure the best quality eddy-covariance measurements we can obtain
- Setting up rigorous and auditable site management recording using the IAuditor software package
- Creating a database of site and equipment information, including instrument tracking records, calibration data, site condition and any management events. This will allow any outputs to be efficiently and consistently generated.
- Setting up a schedule for calibration and maintenance of all sensors, identifying tasks that can be done by local site operators or the technical staff from the GHG Fluxes group. With the aim of making a visit every 6-12 months for full calibration and servicing of the eddy-covariance sensors.

In terms of each site's data quality, infrastructure and instrumentation, the following tasks are in hand or planned for the coming months:

Arnol, Isle of Lewis - UK-ARN

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Site visit for maintenance and calibration

Balmoral, Glen Muick, Balmoral Estate – UK-BAM

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Update the logging program to calculate preliminary flux data automatically
- Install new control boxes for the off-grid power at the main mast and the 4G relay mast

- Fully insulate the battery box and reinstall the Efoy methanol fuel-cell

Balruddery, Dundee – UK-BLR

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Integrate the real-time data stream with the carbon management application
- Install new batteries and consider backup power generation for the winter months

Cross Loch, Forsinard, The Flow Country - UK-CLS

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Update the dataloggers from Campbell Scientific CR3000 to a CR1000x
- Update the off-grid power system with battery box insulation, new controls and new solar panels

Dyke, Forsinard, The Flow Country - UK-DKE

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Update the off-grid power system with battery box insulation, new controls and new solar panels

Dyke-Fire, Forsinard, The Flow Country - UK-DKF

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Update the off-grid power system with battery box insulation
- Fix the relative humidity/temperature probe

Elchies, Moray - UK-ECH

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Replace the modem to fix the communications issue

Girlsta, Shetland - UK-GST

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Site visit to reinstall the IRGASON CO_2/H_2O sensor, fix the net radiation sensor, install a fuel cell and perform a regular service and calibration

Lonielist, Forsinard, The Flow Country - UK-LNS

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed

- Resolve communication issue to allow remote data retrieval

Talaheel, Forsinard, The Flow Country - UK-THE

- Review the fetch and eddy-covariance spectra to check data quality and make modifications to the installation if needed
- Update the datalogger from a Campbell Scientific CR3000 to a CR1000x
- Replace or repair faulty radiation sensor
- Service the IRGA
- Update the off-grid power system with battery box insulation, new controls and new solar panels

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A further three eddy covariance-based systems and one autochamber-based system have recently been purchased via a CAPEX grant from Scottish Government and are to be installed when the equipment has arrived in full. There are major delays at present with the delivery of e.g., the gas analysers, due to global chip and other component shortages. Once installed, these stations will receive support under the Underpinning National Capacity JHI-UNC-F3.5 (2022-2027).

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