Received: 13 February 2018 | Accepted: 22 October 2018
DOI: 10.1002/gdj3.63

DATA PAPER

WILEY Geoscience Data Journal RMetS

Meteorological measurements at Auchencorth Moss from 1995 to 2016

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Abstract

The Auchencorth Moss atmospheric observatory has being measuring meteorological parameters since 1995. The site was originally set-up to measure the deposition of sulphur dioxide at a site that represented the vegetation and climate typical of NW Europe, in relatively clean background air. It is one of the longest running flux monitoring sites in the region, over semi-natural vegetation, providing infrastructure and support for many measurement campaigns and continuous monitoring of air pollutants and greenhouse gases. The meteorological sensors that are used, data processing and quality reviewing procedures are described for a set of core measurements up to 2016. These core measurements are essential for the interpretation of the other atmospheric variables.

KEYWORDS
data assessment, meteorological data

1 | INTRODUCTION

Auchencorth Moss was first instrumented in 1995 due to its suitability for micrometeorological studies, specifically for sulphur dioxide (SO_2) deposition under the European funded LIFE Programme (Appendix A). The first meteorological measurements at the site were wind speed, wind direction, air temperature, total solar radiation, net radiation, soil temperature, soil heat flux, surface wetness, rainfall and dewpoint temperature. Measurements continued and have been enhanced with new sensors for many parameters, such as relative humidity, air pressure, direct and diffuse photosynthetically active radiation (PAR) and soil water content. The site was inspected by a representative of the UK Meteorological Office in 2013 and subsequently assigned the status of a regional station as part of the World Meteorological Organisation, Global Atmosphere Watch (WMO GAW, n.d.), in March 2014. This led to an enhancement of management systems and measurement protocols in line with GAW requirements. In 2016, integration into the pan-European Integrated

Dataset
Meteorological Measurements at Auchencorth Moss from 1995 to 2016
Identifier: http://catalogue.ceda.ac.uk/uuid/8e6cbb111cfd41a19c92aadcb2d040fd
Creator: M Coyle
Title: Auchencorth Moss Atmospheric Observatory (AU): Annual half-hourly meteorology since 1995, Near Edinburgh, UK
Publisher: Centre for Environmental Data Analysis (http://catalogue.ceda.ac.uk/record/party/1483/)
Publication year: 2017
Resource type: Dataset
Version: 1.0

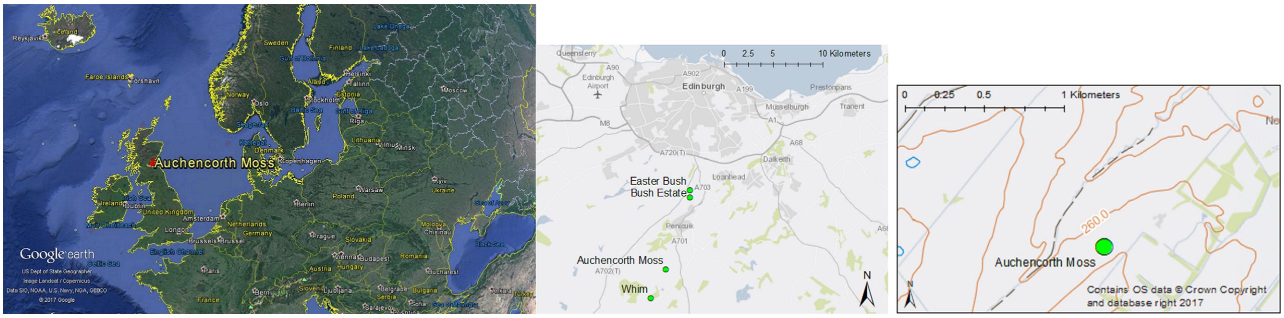

FIGURE 1 Location of the Auchencorth Moss measurement site

Carbon Observation System (ICOS, n.d.) research infrastructure was also initiated which has further enhanced operations and instrumentation at the site. Future meteorological data will be made available via these programs.

1.1 | Site description

Auchencorth Moss (55°47′32″N, 3°14′35″W, 267 m a.s.l.) is a low-lying peatland situated *ca*. 20 km south-west of Edinburgh (Scotland, UK) as shown in Figure 1. The site has an extensive fetch of open moorland in all directions except the easterly sector. The dominant wind direction is SW (Helfter *et al*., 2015; Figure 2). The vegetation consists of mixed grass species, heather and mosses (Sphagnum spp. and Polytrichum spp.). The site was drained for agricultural use over 100 years ago but since then the drains have naturally refilled and the site rewetted (Leith *et al*., 2014). The land is now mainly used for sheep grazing at a low stocking density of *ca*. 1/ha. The photographs in Figure 3 show the instrumentation and exposure of the site.

2 | DATA PRODUCTION AND DESCRIPTION

The sensors deployed at the site have been changed and expanded over its 25 years of operation; Table 1 lists which sensors are used and when. All the sensors have been logged using Campbell Scientific data loggers which have been periodically replaced, as shown in Table 1. The sensors were sampled at either 1, 5 or 10 s intervals and 15 or 30 min averages (or sums for rainfall) calculated and stored in the logger. The dataset described here has been through a range of assessments and adjustments to provide a time series that is consistent in terms of instrument calibrations or other changes, and as complete as possible. The following quality control steps are applied to every time series:

- Periods of known downtime are removed, such as servicing periods, instrument or power failures.

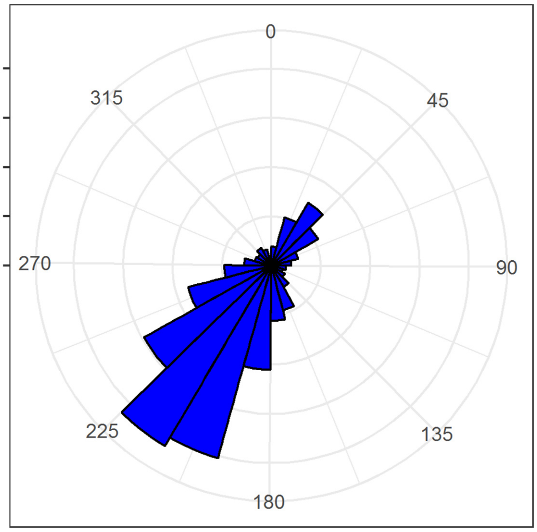

FIGURE 2 Windrose of the frequency of wind direction from 1995 to 2016

- A filter is applied using bounds appropriate to the parameter to exclude spurious data points; the data are plotted and examined visually to ensure they are random outliers and not part of consistent change in the parameter.
- The data are plotted alongside measurements of the same parameters from alternative instruments in-place at Auchencorth or at nearby sites also operated by CEH Edinburgh (Appendix B). If a consistent divergence is observed between the time series, conditions are examined in more detail, for example by looking at synoptic weather patterns, to ascertain whether the differences are likely to be real or caused by an instrument fault. If a problem can be clearly identified, the data are excluded.

2.1 | Instrument specific data processing

The surface soil heat flux (G) is calculated from the measurements of average soil temperature and average soil heat flux measured by two plates (SHF, see Appendix C for instrument setup), using the standard formula:

FIGURE 3 Photographs of the site instrumentation and fetch: (a) is the original set-up with one cabin and the met mast to the far left; (b) shows the new sensors and meteorology mast installed in front of the old mast in 2015 with the old tipping bucket to the left; (c) shows the new tipping bucket in a pit to reduce wind shear effects and (d) the current site set-up with three cabins; (e) too f show typical examples of the vegetation and fetch

$$C_s = B_d(C_d + \text{fSWC}.C_w)$$

$$\text{SC} = \Delta Ts.C_s.d/\Delta\text{time}$$
$$G = \text{SHF} + \text{SC}$$

C_s = heat capacity of moist soil; B_d = soil bulk density 100 kg/m^3; C_d = specific heat dry soil, 840 J kg^{-1} K^{-1}; fSWC = fractional soil water content, measured when available or 0.9; C_w = specific capacity heat of water, 4,190 J kg^{-1} K^{-1}; SC = storage correction; ΔTs = change in average soil temperature from start to end of measurement period (first and last 2 min); d = plate depth 0.2 m; Δtime = measurement period, 1,800 s; G = net surface soil heat flux; SHF = average measured soil heat flux at 0.2 m (Campbell Scientific, 2016a).

The wind speed at 10 m is estimated using turbulence measurements from the 3D sonic anemometers and wind speed measured by a 2D sonic located, all at 3 m height, as follows (Sutton *et al.*, 1993):

h = height (10 m)
z = sonic measurement height
L = Monin–Obukhov length = $\frac{-\rho_a C_p T_K u_*^3}{kgH}$
$u*$ = friction velocity = $\sqrt{|uw|}$
k = von Karman's constant, 0.41
z_0 = aerodynamic roughness length = $\exp\left(\ln(z) - \Psi_m(z) - k\frac{U}{u_*}\right)$
$\Psi_m(h)$ = aerodynamic correction for momentum at height, h:$\chi_{\text{unst}} = \left(1 - 16\frac{h}{L}\right)^{0.25}$
$L \geq 0$ then $\Psi_m(h) = \frac{-5.2h}{L}$
$L < 0$ then $\Psi_m(h) = 2\ln\left(\frac{1+\chi_{\text{unst}}}{2}\right) + \ln\left(\frac{1+\chi_{\text{unst}}{}^2}{2}\right) - 2\tan^{-1}(\chi_{\text{unst}}) + \frac{\pi}{2}$

$$U_{10\text{m}} = \frac{u_*}{k\left(\ln\left(\frac{h}{z_0}\right) - \Psi_m(h)\right)}$$

The NR-Lite net radiometer used from 2001 requires a correction for wind speed to be applied at speeds above 5 m/s (Campbell Scientific, 2016b):

$$R_{n\_c} = R_n(1.0 + A(u(1m))A = 0.021286,$$

where u(1 m) is calculated using the same equations as for 10 m, as above.

TABLE 1 Measured parameters and sensors

	1995	1999	2001	2002	2003	2005	2006	2007	2008	2010	2011	2013	2016
Campbell Scientific Data Logger	21X: 05/01/1995 - 02/11/2005					23X: 02/11/2005 - 09/07/2013						CR3000: 09/07/2013	
Temperature upper & lower (2.4 m & 0.5 m)	Campbell Scientific FW TCBR-3: 18/02/1995 - 07/03/2008								Fine gauge Type-E Made In-house[a]: 07/03/2008				
Relative Humidity (RH) at ~ 1.5 m	Campbell dewpoint hygrometer: 08/02/1995 - 26/06/1999					Vaisala HMP50: 05/11/2005							Rotronics HC2S3: 23/03/2016
Temperature from RH probe at ~1 m						Vaisala HMP50: 05/11/2005							Rotronics HC2S3: 23/03/2016
Pressure (Pa) at ~1.5 m							Vaisala PTB110: 22/05/2006 - 7/09/2006		Druck RPT410F: 24/01/2008				
Total Solar Radiation (St)	Skye SKS 1110: 18/02/1995												
Photosynthetically Active Radiation (PAR)					Skye SKP215: 18/09/2003								
Net Radiation (Rn)	REBS Q7.1-L: 18/02/1995 27/02/2001		Kipp-Zonen NR-Lite : 02/05/2001										
Soil Heat Flux (SHF)	REBS HFT3-L: 18/02/1995-24/02/2007							HuskeFlux HFP01: 24/02/2007 -					
Average Soil Temperature (Soil T)	Campbell Scientific TCAV (renewed in 2007): 18/02/1995												
Soil Water Content (SWC)												Campbell CS616 TDR probes: 10/07/2013	
3D Sonic Anemometer at ~3 m	Gill R3: 01/01/1995 - 31/12/2002			Gill Windmaster Pro: 26/04/2002 -									
2D Sonic Anemometer									Gill Wind Sonic 3 m: 30/07/2008 30/04/2010		27/04/2011		10 m: 22/06/2016

(Continues)

TABLE 1 (Continued)

	1995	1999	2001	2002	2003	2005	2006	2007	2008	2010	2011	2013	2016
Weather and Visibility										FD12P Vaisala PWS: 20/05/2010-15/08/2011		06/02/2013	
Rainfall (Rain)	ARG 100 Tipping Bucket: 18/02/1995 – 20/06/2007							Casella TBRG: 20/06/2007					
Soil Water Table Depth								Druck PCR 1830: 12/04/2007 at 50 cm					
Snow Depth													Campbell Scientific SR50A Sonic Ranging Sensor, from 2016

[a]The thermocouples are made in-house with very fine pre-made Type-E junctions from Omega (0.075mm Unsheathed Fine Diameter Thermocouples with Bead-Welded Junction, P/N CHCO-003). Comparison with the Campbell probes showed they gave virtually identical readings (unpublished data).

For modelling applications, complete time series are often requested so a set of core measurements will be gap-filled for this purpose and included in the CEDA database (ambient air temperature, barometric pressure, relative humidity, total solar radiation, rainfall, wind speed and direction) as described in a later paper. Evaporation of water vapour from the peat-bog will also be added to the database when it has been calculated from the measurements of water-vapour flux which are currently being assessed for quality.

3 | SUMMARY METEOROLOGY

The site's climate is typical of an exposed rural area in the lowlands of Scotland. The prevailing wind direction is south-westerly and wind speeds averaging 4 ± 0.1 m/s (Figure 2, Table 2), with occasional strong winds ~26 m/s, typically over the winter months. Temperatures average 7.5 ± 0.6°C with a minimum around −7°C although in some years it has been as low as −15°C and a maximum 30°C, with typical summer day time temperatures around 13°C. No temperatures below −10°C have been recorded since winter 2010–2011 (Figure 4, Table 2).

Total solar and photosynthetically active radiation show similar seasonal patterns with levels over 500 W/m^2 and 1,000 μmol m^{-2} s^{-1} respectively in the summer months. The time series do appear to show a slight decrease in levels which is likely due to degradation of the thermopile sensors. The sensors have been sent for calibration and this information will be added to the database when it is available. In contrast, the net radiation sensors appear stable but there is a step change in the measurement range when the REBS Q7 (Campbell Scientific, 1996) was replaced with a Kipp and Zonen NR-Lite in 2001 (minimum readings decreased from ~−92 to −175 W/m^2).

The soil heat flux and temperature measurements show a decline in the range of observed values over the first 3–4 years of operation which may be due to the sensors taking a long period to bed-in or the build-up of the vegetation and peat layer above them. Regular measurements of the vegetation above the installation were not made but when the sensors were replaced in 2006, it was noted that they appeared to be 4–5 cm further below the moss layer than when initially installed. Soil water content measurements began in 2013 and also show a change in the range of seasonal variation which is believed to be due to the sensors bedding in, as any air gaps around the probes would cause low readings when the soil is dry.

The tipping bucket measures ~1,000 mm of rainfall every year which is slightly more than other stations in the region. For example, Edinburgh receives ~850 mm a year, but the local topography tends to enhance the local rainfall. In March 2016, a second Casella tipping bucket rain gauge was installed in a pit to reduce wind shear effects on the amount of water collected (http://www.case

TABLE 2 Annual summary statistics for each parameter (with the exception of the relative humidity measurements the data review procedure only resulted in the exclusion of a very small percentage of the data, less than 1% on average, so the %DC values are very close to the raw data capture)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Upper temperature (°C)																						
Average	8.3	6.9	7.7	7.7	8.2	5.0	7.1	7.7	8.4	8.1	8.0	8.3	8.1	7.7	8.2	7.3	8.9	7.0	7.9	8.2	7.4	7.4
Median	8.8	6.9	7.4	7.9	8.5	5.3	7.4	7.5	8.5	8.2	8.0	8.2	8.2	7.7	8.2	7.3	9.2	6.8	7.9	7.8	7.4	7.2
Max	26.7	24.0	24.9	24.1	25.4	16.4	23.6	23.4	29.0	24.2	27.8	26.9	21.4	23.9	27.2	24.7	24.5	24.6	29.3	26.3	26.7	26.4
Min	−12.6	−7.2	−5.1	−7.4	−6.0	−10.3	−10.7	−6.5	−7.7	−5.6	−9.4	−9.3	−9.2	−7.7	−8.2	−10.8	−6.9	−7.7	−8.4	−3.9	−6.5	−7.2
Stdev	6.13	5.57	5.15	4.73	5.24	4.05	5.56	4.58	5.86	5.05	5.45	5.85	4.66	5.27	5.34	6.19	4.54	5.04	6.19	4.92	4.89	5.27
%DC	86.8	96.2	95.7	96.5	80.1	25.6	99.8	95.0	86.1	91.1	96.4	90.3	97.2	99.8	100.0	100.0	95.6	100.0	99.7	98.7	100.0	100.0
Lower temperature (°C)																						
Average	8.1	6.8	7.6	7.5	7.5	4.7	7.0	7.5	8.2	8.0	7.9	8.1	8.1	7.6	7.9	6.8	8.4	7.0	7.7	8.0	7.3	7.3
Median	8.6	6.7	7.3	7.5	7.6	5.1	7.2	7.3	8.3	8.0	7.8	7.7	8.0	7.6	7.8	6.5	8.5	6.8	7.4	7.6	7.2	7.1
Max	28.3	25.0	25.9	25.5	26.9	16.3	25.0	25.5	29.8	25.2	30.5	31.0	26.7	26.9	28.8	31.0	28.4	26.4	31.0	27.6	28.2	28.0
Min	−15.2	−8.7	−6.2	−8.9	−9.8	−11.7	−9.1	−9.0	−9.6	−7.6	−11.5	−10.4	−10.5	−9.1	−12.0	−14.6	−10.9	−9.2	−9.5	−6.2	−8.0	−8.5
Stdev	6.58	5.87	5.45	5.09	5.81	4.28	5.87	4.93	6.25	5.31	5.84	6.24	5.25	5.70	6.00	7.34	5.40	5.42	6.51	5.28	5.24	5.64
%DC	86.8	97.3	95.9	99.7	87.6	25.6	99.8	95.0	86.2	95.2	95.8	95.5	99.9	99.6	96.9	100.0	98.1	100.0	96.4	98.8	100.0	100.0
Temperature RHT probe (°C)																						
Average											4.1	8.9	7.9	7.3	7.6	6.6	8.5	6.9	5.2			8.7
Median											4.5	8.5	7.9	7.3	7.7	6.6	9.0	6.6	4.2			8.8
Max											12.7	28.5	22.1	23.2	27.5	24.6	24.6	23.3	24.5			26.7
Min											−8.7	−8.2	−9.7	−8.4	−9.0	−12.0	−8.9	−8.3	−8.0			−7.2
Stdev											3.70	5.82	4.75	5.34	5.59	6.57	4.84	5.04	5.56			4.99
%DC											15.6	95.5	100.0	99.6	99.9	99.5	85.2	100.0	51.9			64.5
Soil temperature (°C)																						
Average	8.8	7.2	7.9	7.6	7.4	7.1	6.9	7.1	7.2	7.4	7.7	8.7	8.2	7.6	7.9	7.5	8.2	6.9	6.6	6.5	6.9	7.2
Median	9.2	7.0	7.2	7.0	7.8	6.6	7.1	6.1	6.6	7.0	7.5	9.2	8.7	7.1	7.8	6.9	8.2	6.0	6.1	6.1	6.8	6.5
Max	19.7	15.8	16.5	13.9	13.6	13.2	13.7	13.4	13.6	14.7	15.1	14.6	13.7	14.2	14.2	13.4	12.1	12.7	13.1	12.4	12.5	13.8
Min	0.3	0.4	1.7	2.5	1.7	2.3	1.0	1.3	0.9	1.5	1.4	2.6	1.4	1.8	2.1	1.9	3.4	1.8	1.3	1.6	1.4	1.0
Stdev	4.51	4.24	3.57	3.05	3.32	2.96	3.71	2.98	3.48	3.02	3.34	3.33	3.18	3.49	3.11	3.35	2.24	2.86	3.44	2.99	2.85	3.36
%DC	86.8	99.8	95.5	100.0	98.8	99.7	99.7	95.0	83.0	97.4	98.7	76.4	93.4	99.5	99.9	100.0	99.0	100.0	100.0	98.2	98.9	99.8
Total solar radiation (W/m^2)																						
Average	110.8	92.9	86.2	81.8	88.0	89.6	88.1	80.6	96.7	82.8	89.0	94.4	87.8	84.8	92.8	92.2	86.6	83.5	93.3	87.6	94.7	88.3
Median	8.7	1.1	0.0	0.9	0.0	0.4	0.8	0.0	0.0	0.0	0.8	0.0	0.0	1.4	1.9	1.8	0.5	1.0	2.4	0.0	0.0	1.6
Max	874	944	867	962	877	915	877	904	920	878	871	1,080	928	871	905	901.0	965	873	835	913	923	894
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stdev	178.91	162.30	155.86	145.94	153.81	156.88	153.11	143.10	162.23	146.23	155.13	172.89	151.80	145.64	158.96	154.51	150.02	145.81	159.31	152.55	159.82	152.61
%DC	86.8	100.0	97.1	100.0	99.6	100.0	99.8	97.1	99.2	98.2	99.6	98.0	99.9	99.5	100.0	100.0	99.3	100.0	100.0	98.7	99.2	99.8
PAR (µmol m^{-2} s^{-1})																						
Average										175.3	187.2	175.3	169.9	160.0	182.8	187.7	172.8	161.2	182.5	162.9	180.1	151.2
Median										0.4	2.3	0.4	0.4	2.2	3.6	4.1	1.1	2.1	3.0	2.6	0.0	2.3
Max										1,774	1,791	2,070	1,747	1,684	1,730	1,845	1,772	1,678	1,725	1,759	1,783	1,569
Min										0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.0	0.0	0.0

(Continues)

TABLE 2 (Continued)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Stdev										303.53	321.88	329.65	286.50	274.03	311.92	313.58	298.10	280.41	311.73	283.76	305.85	260.22
%DC										98.2	99.6	98.0	98.0	99.8	100.0	100.0	99.3	100.0	100.0	98.8	99.2	99.9
SHF (W/m^2)																						
Average	−0.4	−1.0	−0.1	−0.2	−0.1	−0.2	−0.3	−0.1	0.6	−0.5	0.7	−0.4	−0.3	0.0	−0.1	−0.6	0.0	−0.5	−0.3	−0.1	0.1	0.1
Median	−1.6	−2.0	−0.5	−0.3	−0.1	−0.5	−0.4	0.0	0.8	−0.5	0.6	−1.1	−0.3	−0.1	0.1	−0.8	0.2	−0.5	−0.5	−0.1	0.0	0.0
Max	49.1	50.1	31.6	17.1	15.9	14.3	15.5	15.4	14.7	17.2	19.0	42.8	12.8	15.6	12.8	13.2	10.0	12.6	11.5	11.4	15.9	16.9
Min	−25.2	−26.7	−19.2	−15.5	−14.9	−29.6	−10.8	−9.9	−15.8	−18.5	−17.1	−25.0	−19.6	−16.6	−12.4	−14.9	−16.2	−8.0	−12.7	−10.7	−14.2	−17.5
Stdev	8.94	6.14	5.16	4.27	4.02	3.45	3.62	3.28	4.15	3.99	4.17	3.83	3.47	4.03	3.19	3.21	2.70	3.01	3.37	2.95	3.27	3.42
%DC	77.8	89.4	90.7	97.6	97.0	98.0	98.3	94.7	94.8	91.0	84.9	91.0	90.3	96.5	99.1	99.1	98.8	99.8	99.3	98.4	99.9	99.9
Net radiation (W/m^2)																						
Average	59	44	44	43	37	46	27	22	34	27	29	32	26	24	30	29	27	24	26	27	28	28
Median	−1	−2	−1	−1	−2	−2	−5	−8	−7	−5	−5	−6	−7	−7	−7	−5	−8	−6	−7	−7	−8	−6
Max	575	582	551	644	578	585	549	578	625	572	557	682	569	568	565	571	606	547	530	597	562	569
Min	−113	−73	−66	−96	−175	−88	−176	−115	−193	−241	−88	−137	−168	−133	−86	−165	−293	−174	−222	−192	−260	−258
Stdev	123.6	104.6	100.5	96.5	95.0	105.6	94.6	90.5	104.4	93.2	99.8	109.0	94.3	90.8	100.6	95.5	96.3	91.0	97.0	93.0	97.9	95.0
%DC	79.0	99.7	89.6	89.3	98.9	100.0	82.1	95.0	86.2	97.4	98.7	95.5	99.8	99.6	99.8	100.0	99.0	100.0	100.0	98.7	98.9	99.8
Pressure (hPa)																						
Average												988	982	979	978	981	980	980	981	978	981	982
Median												990	983	980	979	982	980	981	983	980	981	983
Max												998	1,008	1,010	1,008	1,007	1,009	1,008	1,007	1,006	1,007	1,007
Min												965	940	930	938	928	934	936	944	925	933	935
Stdev												7.5	12.0	12.7	13.4	11.2	11.2	12.1	11.2	12.5	11.8	11.2
%DC												6.6	93.6	99.8	100.0	100.0	99.0	100.0	94.4	91.0	95.6	84.3
Soil water content (%)																						
Average																			75	77	77	77
Median																			76	77	78	78
Max																			83	79	79	79
Min																			66	68	75	75
Stdev																			2.9	2.4	1.1	1.1
%DC																			47.7	98.8	98.7	99.7
Wind speed measured (3D sonic, m/s)																						
Average	4.4	4.2	4.2	4.7	4.5	4.3	4.0	3.9	3.9	4.4	4.2	4.1	4.2	4.2	4.3	3.9	4.4	4.2	4.4	4.1	4.6	3.9
Median	3.8	3.7	3.5	4.3	3.9	3.8	3.7	3.4	3.3	4.0	3.8	3.7	3.8	3.6	3.9	3.4	3.8	3.8	4.0	3.6	4.1	3.5
Max	16.4	19.3	16.1	22.8	26.5	16.9	17.8	20.2	15.0	16.1	23.2	19.4	16.6	16.3	17.8	18.4	17.5	21.2	19.4	14.1	17.3	14.9
Min	0.0	0.2	0.2	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Stdev	2.71	2.42	2.80	2.69	2.79	2.77	2.35	2.52	2.48	2.59	2.44	2.50	2.50	2.78	2.58	2.46	2.84	2.56	2.55	2.51	2.75	2.43
%DC	90.6	99.0	99.4	98.6	88.9	98.0	94.9	96.1	89.9	91.3	79.9	75.6	91.6	94.1	92.2	95.0	84.3	84.6	92.4	90.6	91.5	93.9
Wind speed at 10 m (m/s)																						
Average	6.2	6.7	6.3	6.5	6.7	6.6	5.8	6.1	6.7	6.7	6.8	6.1	6.4	6.2	6.2	5.5	6.9	6.0	6.5	6.6	5.3	5.4
Median	5.5	6.4	5.6	6.0	6.4	6.1	5.4	5.7	6.2	6.4	6.2	5.7	6.0	5.9	5.9	5.2	6.5	5.6	6.2	6.3	4.9	5.0
Max	19.0	16.7	17.2	16.5	15.9	16.2	17.9	23.6	20.0	15.6	22.1	15.9	19.8	22.1	14.9	14.4	20.7	17.4	14.7	16.2	19.8	19.8

(Continues)

TABLE 2 (Continued)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Min	0.4	0.3	0.8	0.9	0.8	1.2	0.4	0.6	1.1	0.7	1.0	0.9	0.8	0.9	0.9	1.5	0.4	0.3	0.6	0.5	0.2	0.2
Stdev	2.84	2.69	2.84	2.59	2.61	2.68	2.45	2.84	2.66	2.50	2.90	2.37	2.61	2.66	2.49	2.12	2.95	2.54	2.49	2.66	2.73	2.76
%DC	65.4	46.6	54.4	66.6	50.3	50.0	64.0	57.0	46.9	54.4	60.0	43.4	59.8	52.0	36.2	5.5	45.8	53.4	53.0	38.8	78.4	74.6
Visibility (m)																						
Average																24,291	25,012		23,944	21,900	24,624	23,094
Median																22,906	24,317		22,890	21,497	24,341	22,671
Max																50,000	50,000		49,961	49,880	50,000	49,958
Min																93	59		64	64	62	65
Stdev																15745.4	15122.7		13304.6	12223.6	12729.1	13002.7
%DC																25.3	55.3	0.0	51.4	54.8	57.5	92.1
Rainfall (mm)																						
Total	732	828	1,016	1,366	936	1,123	843	905	774	1,169	896	785	984	1,210	989	684	1,099	1,321	830	952	1,116	886
Total scaled	843	828	1,060	1,366	947	1,123	884	952	787	1,200	1,084	1,128	1,175	1,214	1,029	1,058	1,111	1,321	831	963	1,130	888
Max	8	9	7	6	5	7	7	5	6	7	5	5	6	8	24	7	13	19	12	7	6	9
%DC	86.8	100.0	95.9	100.0	98.8	100.0	95.4	95.0	98.3	97.4	82.7	69.6	83.7	99.7	96.0	64.6	99.0	100.0	99.9	98.9	98.8	99.8

llasolutions.com/uk/en/products/met/met-environmental/products/tbrg.aspx, Figure 3), as specified by the WMO. The old and new gauge gave very similar totals, 775 and 778 mm respectively from 22nd March to 31st December 2016, when scaled for data capture. From 2017, data from the new gauge will be reported and the old gauge decommissioned.

The Vaisala FD12P Present Weather Sensor records weather and visibility, as well as estimating precipitation amounts, by measuring the amount of infrared light scattered at an angle of 33°. It also includes a heated capacitive sensor to detect surface water. The precipitation amount is estimated by scaling the optical intensity while the type of precipitation is inferred using air temperature, optical intensity and capacitive signal. Its estimates of rainfall amounts do not agree well with the tipping buckets and, although they detect precipitation at the same times, data capture was relatively low for the FD12P in most years due to data communication and logging issues. The 'present weather' and 'past weather' codes are included in the database, where they represent the most frequently recorded weather type over the last 15 min and one hour respectively. The FD12P can report either WMO or National Weather Service (NWS) codes, in this case the WMO 4,680 codes are recorded (Appendix D).

On hourly, daily or weekly time scales, the soil water content and water table depth mirror the rainfall pattern as would be expected. On several occasions, the water table was measured as being above the surface level and these coincide with periods of heavy or persistent rain. In reality, this was due to the nature of the vegetation and soil; the site was not flooded although the peat and surface vegetation were waterlogged and pools of standing water appeared in some places.

The relative humidity measurements obtained from the Vaisala HMP50 probes show some inconsistencies over the years. Initially, in 2006, the sensor regularly measured over 100% humidity. After the sensor was replaced in 2007, the maximum was less than 95% but gradually increased up to 2010, when it was again replaced. Measurements then appeared quite consistent until the end of 2013 when the system developed a logging fault and measurements below 73% were not recorded properly (in 2015 this cut-off increased to 78%). In 2016, a new sensor and serviced data logger were installed and measurements returned to a more normal range. From 23/03/2016, measurements from the Rotronics HC2S3 are reported in the database and the HMP50 was logged alongside it until 2017. Comparison of the two show they were very closely matched, giving an average of 87%, and maximum 100%, although their minima were slightly different with the Rotronics reading 29% and the Vaisala 27%. Despite the uncertainty on the measured values for some periods, all the data are included in the database because the measurements correlate well with those from the other sites, giving an indication of variations

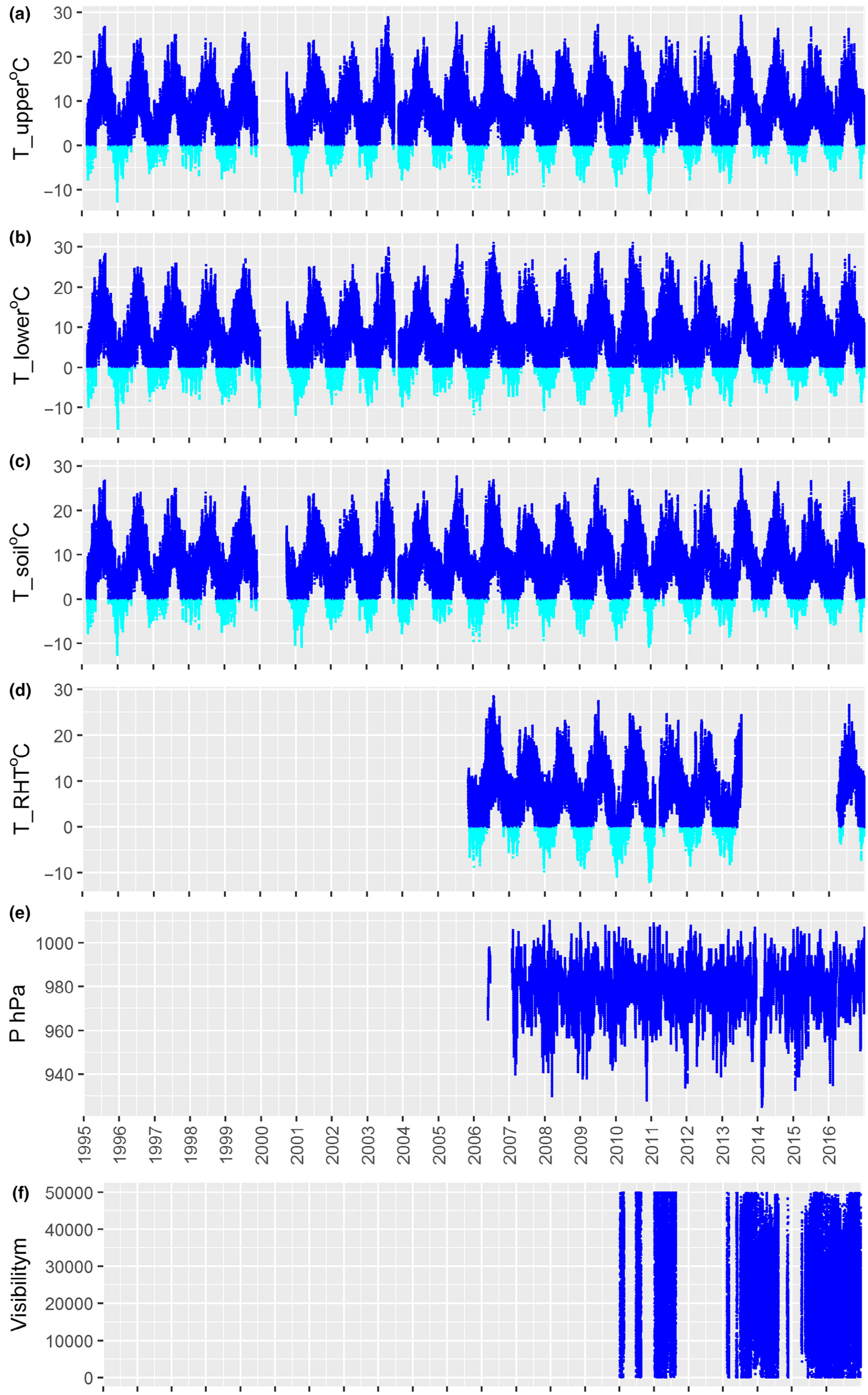

FIGURE 4 Time series of the half-hourly data after quality control, for: (a) upper air temperature; (b) lower air temperature; c) average soil temperature; (d) temperature measured by the RHT probe; (e) barometric pressure; (f) visibility; (g) total solar radiation; (h) photosynthetically active radiation; (i) net radiation; (j) soil heat flux; (k) measured windspeed; (l) windspeed at 10 m; (m) average soil water content; (n) rainfall; (o) soil water depth; (p) relative humidity from the RHT probe. (positive values are plotted in blue and negative values in cyan-blue)

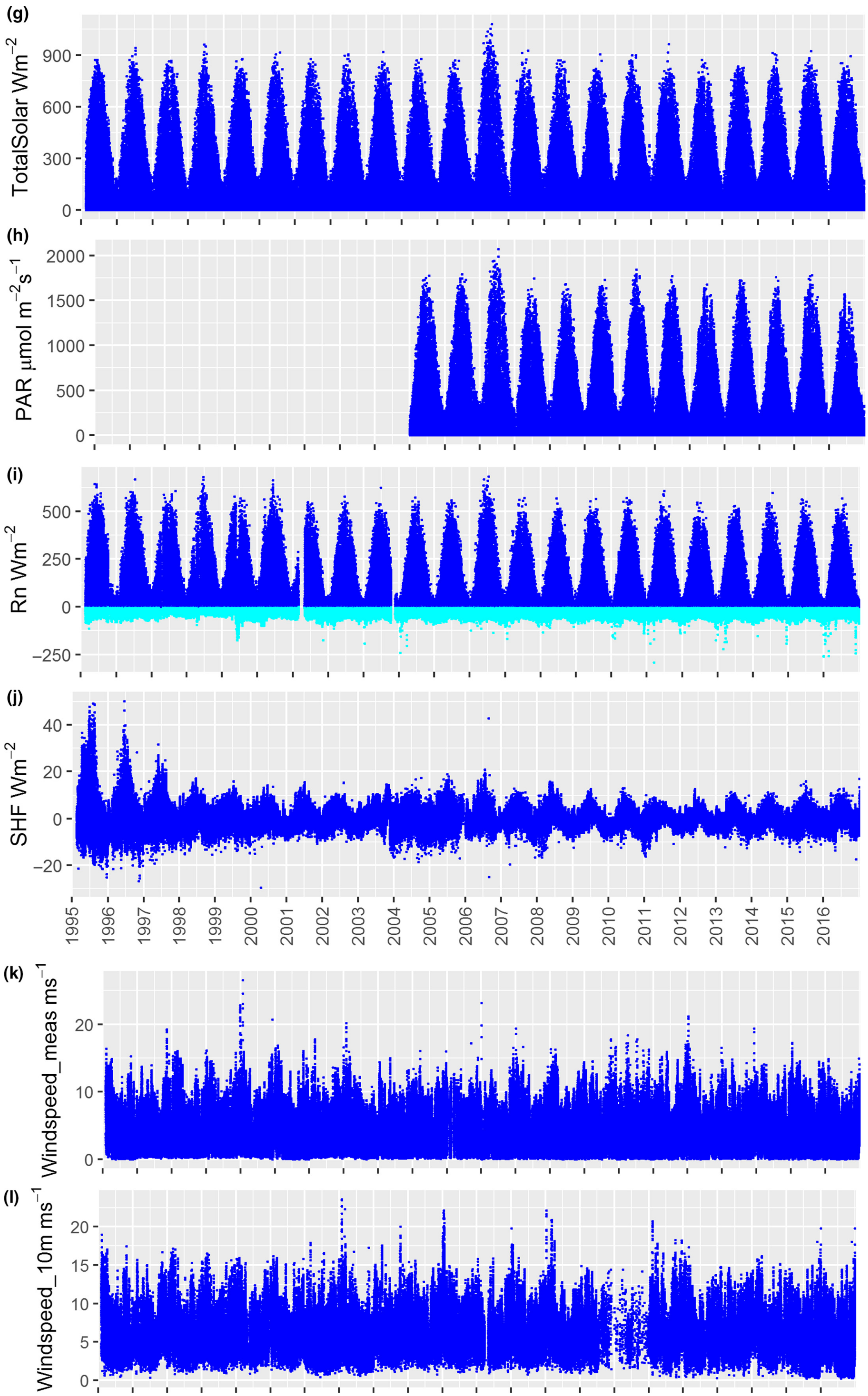

FIGURE 4 Continued

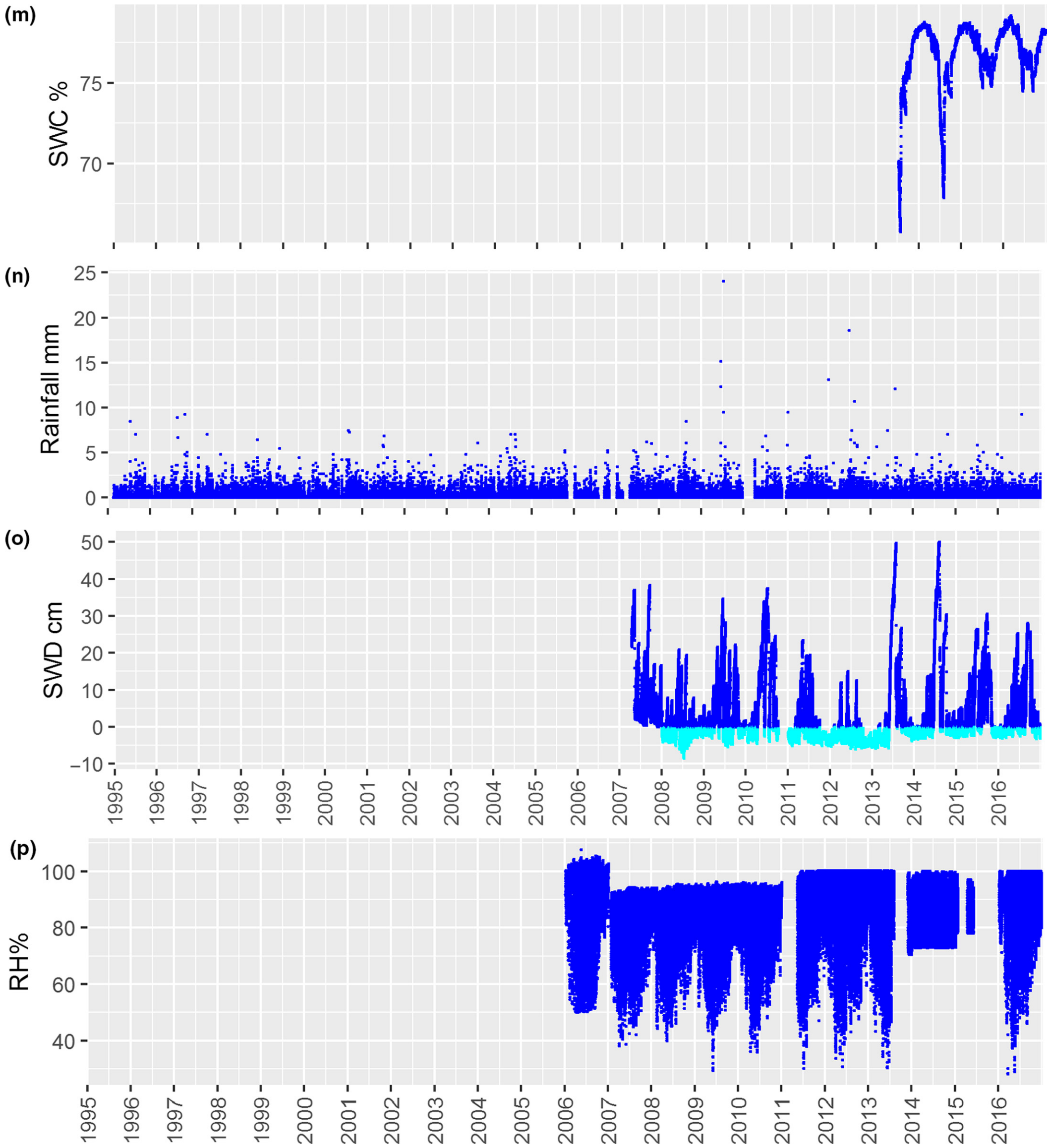

FIGURE 4 Continued.

at least. The actual values for the periods below should be treated with caution:

02/01/2006 13:30 – 01/01/2011 00:00
27/11/2013 17:00 – 01/06/2015 22:00

In the gap-filled dataset, these periods will be removed and replaced with adjusted data from the other sites.

4 | PAST, CURRENT AND POTENTIAL FUTURE USES OF THE DATA

As noted in the introduction, the site was first instrumented in 1995 to study the deposition of the pollutants SO_2, NH_3, O_3 and NOx. The location was chosen for several reasons:

- Extensive uniform fetch over the prevailing wind direction, making it ideal for flux measurements using the gradient and eddy-covariance techniques.
- Relatively clean air with low or background concentrations of the key pollutants, particularly in the main wind sector.
- Representative of the climate throughout North Western Europe, that is, moderately high rainfall and low temperature regime.
- Vegetation representative of open moorland found in large areas of the United Kingdom, Ireland, north-western France and parts of Scandinavia.
- Mains power available at an accessible location where infrastructure could be established.

Several papers came out of this first period from 1995 to 2001, that enhanced the understanding of the processes controlling SO_2, NH_3 and O_3 deposition, many of which are related to meteorological conditions.

In subsequent years, additional instruments for other pollutants and trace gases were added, such as particulates, carbon dioxide and methane, for which the meteorological data were also essential to allow interpretation of the measurements and production of many other publications. The site has proved very useful in the study of greenhouse gases as it represents a significant ecosystem type for NW Europe.

A full list of published papers that have used Auchencorth data can be found at http://www.auchencorth.ceh.ac.uk/biblio.

The site is one of a few rare examples of long-term flux measurements over any ecosystem, comparable to sites such as Hyytiälä in Finland and others in the Fluxnet database, http://fluxnet.fluxdata.org/.

At present, the meteorological measurements continue to be an essential adjunct to all the pollutant and trace-gas measurements, allowing researchers to make full use of the results and enhance our understanding of the land–atmosphere interaction and atmospheric chemistry. The long time series has the potential for many studies into the changes in the pollution climate and interactions between factors such as SO_2 to NH_3 ratios or climate and greenhouse gases, as well as the climate itself.

The infrastructure at the site is well established and has gradually improved so that it can now accommodate teams of scientists for intensive field campaigns or the addition of longer term measurements where the supporting resources are also available. It is an ideal location for the study of European clean, background air and exchange processes over peaty moorland.

5 | DATASET LOCATION AND FORMAT

The data are stored by the Centre for Environmental Data Analysis (CEDA, http://www.ceda.ac.uk/) in BADC CSV format, as annual files containing all variables. It is publicly available under the licence: http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.
When using these data, you must cite them correctly using the citation given on the CEDA Data Catalogue record.

Annual updates will be made, with a year's new data being added as soon as it has been fully quality controlled and checked.

ACKNOWLEDGEMENTS

The measurements presented in this paper which underpin the air quality and greenhouse gas (GHG) observations at the GAW Regional Site and EMEP Supersite (The European Monitoring and Evaluation Programme (EMEP), http://www.emep.int/) at Auchencorth Moss were supported by the UK Natural Environment Research Council national capability funding under the CEH Atmospheric Chemistry and Effects Science Area (Award reference ceh020011). Several other organisations and projects that have provided support over the years are listed in Appendix B. The authors are grateful to the local landowners for providing access to the site (A.C Stoddart & Sons, Halls Farm and Springfield Farm, www.springfieldmeats.co.uk, www.springfieldfarmlivery.co.uk, www.lazylawn.co.uk/scotland.html). We would also like to thank our summer CAREERWISE student, Anjumol Babu, who spent her placement with us reviewing the source data files and compiling them for assessment.

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REFERENCES

Campbell Scientific. (1996) Instruction Manual: Q-7.1 Net Radiometer, Revision 5/96. Available at: https://s.campbellsci.com/documents/us/manuals/q-7-1.pdf

Campbell Scientific. (2016a) Instruction Manual: Model HFP01 Soil Heat Flux Plate, Revision: 10/16. Available at: https://s.campbellsci.com/documents/eu/manuals/hfp01sc.pdf

Campbell Scientific. (2016b) Instruction Manual: NR-LITE2 Net Radiometer, Revision: 5/16. Available at: https://s.campbellsci.com/documents/us/manuals/nr-lite2.pdf

Helfter, C., Campbell, C., Dinsmore, K.J., Drewer, J., Coyle, M., Anderson, M *et al*. (2015) Drivers of long-term variability in CO 2 net ecosystem exchange in a temperate peatland. *Biogeosciences*, *12*(6), 1799–1811.

ICOS. (n.d.) Available at: https://www.icos-cp.eu/

Leith, F.I., Garnett, M.H., Dinsmore, K.J., Billett, M.F. and Heal, K.V. (2014) Source and age of dissolved and gaseous carbon in a peatland-riparian-stream continuum: A dual isotope (^{14}C and ^{13}C) analysis. *Biogeochemistry*, *119*, 415–433. https://doi.org/10.1007/s10533-014-9977-y

Sutton, M.A., Flower, D. and Moncriefe, J.B. (1993) The exchange of atmospheric ammonia with vegetated surfaces I: unfertilized vegetation. *Quarterly Journal of the Royal Meteorological Society*, *119* (513), 1023–1045.

WMO GAW. (n.d.) Available at: https://www.wmo.int/pages/prog/arep/gaw/measurements.html

How to cite this article: Coyle M, Cape JN, Flechard C, et al. Meteorological measurements at Auchencorth Moss from 1995 to 2016. *Geosci Data J*. 2018;00:1–14. https://doi.org/10.1002/gdj3.63

APPENDIX A

FUNDING SOURCES AND RESEARCH PROJECTS AT AUCHENCORTH MOSS.

1995 – ongoing CEH core support funding for basic infrastructure and site management

1995 – ongoing Funding for Defra (UK Department for Environment, Food, and Rural Affairs) projects (eg Acid deposition; Pollutant Deposition Processes)

1995 – 1998 LIFE Project: EC DG XI – Project number 7221010 Development of a deposition monitoring method for Europe; rivm.openrepository.com/rivm/bitstream/10029/10432/1/722108015.pdf

2003 – 2008 CARBOEUROPE: Integrated Project CarboEurope-IP Assessment of the European Terrestrial Carbon Balance; www.carboeurope.org

2006 – 2011 NITROEUROPE – a project for integrated European research into the nitrogen cycle. NitroEurope was part of the EU's Sixth Framework Programme for Research and Technological Development; www.nitroeurope.eu

2011 – 2015: ÉCLAIRE: Effects of Climate Change on Air Pollution and Response Strategies for European Ecosystems, funded by the EU's Seventh Framework Programme for Research and Technological Development (FP7); www.eclaire-fp7.eu

2011 – 2015 ACTRIS – Aerosols, Clouds and Trace Gases Research Infrastructure Network: This project integrated the existing research infrastructures (EUSAAR, EARLINET, CLOUDNET, and a new trace gases network component) into a single coordinated framework. The project was funded within the EC 7th Framework Programme under "Research Infrastructures for Atmospheric Research"; fp7.actris.eu

INTERNATIONAL NETWORKS

2006 – ongoing EMEP: the main objective of the EMEP programme (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe) is to regularly provide governments and subsidiary bodies under the LRTAP Convention with qualified scientific information to support the development and further evaluation of the international protocols on emission reductions negotiated within the Convention; emep.int

2014 – ongoing WMO GAW Regional Site: The Global Atmosphere Watch (GAW) programme of WMO is a partnership involving the Members of WMO, contributing networks and collaborating organizations and bodies which provides reliable scientific data and information on the chemical composition of the atmosphere, its natural and anthropogenic change, and helps to improve the understanding of interactions between the atmosphere, the oceans and the biosphere; www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html

2017 – ongoing ICOS Ecosystem Site; Integrated Carbon Observation System, Pan-European research infrastructure which provides harmonised and high precision scientific data on carbon cycle and greenhouse gas budget and perturbations; www.icos-ri.eu

UK MONITORING NETWORKS (UK-AIR.DEFRA.GOV.UK):

Acid Gas and Aerosol Network (AGANET) from 1996

Automatic Hydrocarbon Monitoring Network from 2006

Automatic Urban and Rural Network (AURN) from 2006

Heavy Metals Network from 2003

MARGA Network from 2006

National Ammonia Monitoring Network from 1997

PAH Andersen from 2007

PAH Deposition from 2009

PAH Digitel (solid phase) from 2008

Particulates from 2011

TEKRAN (Mercury) Network from 2006

Tomps from 2008

UK Black Carbon Network from 2006

Weekly rainfall (LOW) from 2006

APPENDIX B

AUXILIARY SITES AND INSTRUMENTATION USED FOR QUALITY CONTROL.

Whim Bog 3.267°E, 55.767°N

The measurements at Whim Bog have been ongoing since 2002 as part of a project to assess the impacts of wet- and dry-deposited nitrogen on a heather moorland. The following parameters are measured and stored every 15 min using similar sensors and a data logger to those at Auchencorth:

Windspeed and direction, Air Temperature, Relative Humidity, Total Solar Radiation, Net Radiation, Tipping Bucket Rainfall, Soil Temperature, Water Table Depth, Soil Moisture, Photosynthetically Active Radiation.

Easter Bush 3.206°E, 55.865°N

This site was set-up in 2001 to measure trace-gas fluxes as well C and N cycles over a managed grassland. The following parameters are measured and stored using similar sensors and a data logger to those at Auchencorth:

Wind speed and direction, Upper and Lower Temperature, Humidity Temperature Probe – temperature, Humidity Temperature Probe – Relative Humidity, Total Solar Radiation, Net Radiation, Photosynthetically Active Radiation, Barometric Pressure, Soil Heat Flux, Average Soil Temperature, Tipping Bucket Rainfall.

Bush Cabin 3.206°E, 55.862°N

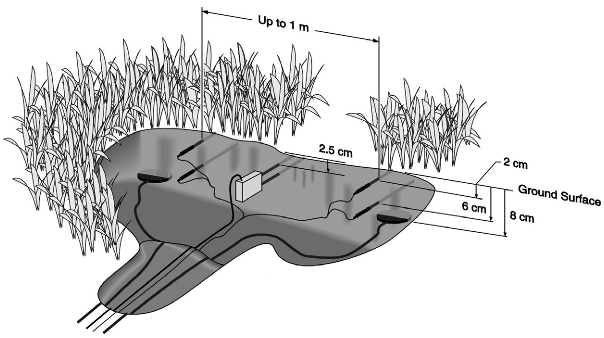
This site has been in operation since the late 1970's near the CEH research station, and meteorological data are available from 1988. It again uses similar instruments to the other sites and Campbell Scientific 21X data loggers:

Wind speed and direction, Air Temperature, Humidity Temperature Probe – temperature, Humidity Temperature Probe – Relative Humidity, Total Solar Radiation, Photosynthetically Active Radiation, Barometric Pressure, Tipping Bucket Rainfall.

APPENDIX C

SOIL CLIMATE MEASUREMENT SETUP

The soil climate plot was installed according to the Campbell Scientific manual: https://s.campbellsci.com/documents/eu/manuals/hfp01sc.pdf



The four soil temperature averaging probes are installed to measure the average temperature between the two plates that measure soil heat flux.

APPENDIX D

WMO 4680/4677 WEATHER CODES, RECORDED BY THE VAISALA FD12P PRESENT WEATHER SENSOR

0	Clear
4	Haze or smoke, or dust in suspension in the air visibility equal to or greater than 1 km.
5	Haze or smoke, or dust in suspension in the air visibility less than 1 km.
10	Fog
20	Mist
21	Precipitation
22	Drizzle (not freezing) or snow grains
23	Rain (Not freezing)
24	Snow
25	Freezing rain or freezing drizzle
30	Fog
31	Fog or ice fog, in patches.
32	Fog or ice fog, has become thinner during the past hour.
33	Fog or ice fog, not applicable change during the past hour.
34	Fog or ice fog, has begun or become thicker during the past hour.
40	Precipitation
41	Precipitation, slight or moderate
42	Precipitation, heavy
50	Drizzle
51	Drizzle, Not freezing, slight
52	Drizzle, Not freezing, moderate
53	Drizzle, Not freezing, heavy
54	Drizzle, freezing, light
55	Drizzle, freezing, moderate
56	Drizzle, freezing, heavy
60	Rain
61	Rain, light
62	Rain, moderate
63	Rain, heavy
64	Rain, freezing, light
65	Rain, freezing, moderate
66	Rain, freezing, heavy
67	Rain, (or drizzle) and snow, light
68	Rain, (or drizzle) and snow, moderate or heavy
70	Snow
71	Snow, light
72	Snow, moderate
73	Snow, heavy
74	Ice pellets, light
75	Ice pellets, moderate
76	Ice pellets, heavy
77	Snow grains (from WMO 4677)
78	Ice crystals (from WMO 4677)
80	Showers or Intermittent Precipitation
81	Rain Showers, light
82	Rain Showers, moderate
83	Rain Showers, heavy
84	Rain showers, violent (>32 mm/hr)
85	Snow Showers, light
86	Snow Showers, moderate
87	Snow Showers, heavy
89	Showers of hail, with or without rain or rain and snow mixed, not associated with thunder (from WMO 4677)

(Continues)