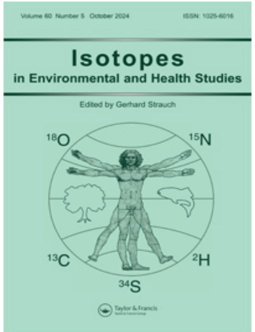

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ISOTOPES IN ENVIRONMENTAL AND HEALTH STUDIES
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Stable-isotope variability in daily precipitation: insights from a low-cost collector in SE England

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ABSTRACT

Precipitation stable-isotope data are often used in hydroclimatic, hydrological and hydrogeological investigations, with measurements typically undertaken on integrated monthly samples. However, daily sampling reveals overlooked aspects of controls on precipitation isotope values, including synoptic meteorological conditions. We present a one-year record of stable isotopes in daily precipitation during 2021, from a site in SE England close to Greater London. We find marked daily variability over the course of the year (−15.62 to +0.92 ‰ for $\delta^{18}O$, −108.7 to +2.9 ‰ for $\delta^{2}H$ and −6.5 to +23.1 ‰ for deuterium excess). Correlations with individual meteorological variables including precipitation amount, temperature and weather type are moderate to weak suggesting complex controls on the daily rainfall isotope values. The daily data are compared with three other daily datasets from England and, by conversion to monthly values, directly with data from three long-term collection stations across Britain and Ireland. The scale of variability in the daily data from our site is consistent with that seen in other English records despite them all coming from different time periods. The monthly data show broad consistency, although there are differences that also highlight geographical variability in precipitation values across the British Isles.

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Precipitation; stable isotopes; local meteoric water line (LMWL); Britain and Ireland

1. Introduction

Spatial and temporal variations in the stable-isotope composition of precipitation provide valuable insights into hydroclimatic processes. Such variations arise as a result of various isotopic fractionations that occur in the water cycle [1]. Precipitation stable-isotope data have been employed extensively in hydroclimatic, hydrological and hydrogeological investigations. For example, they have been used to study meteorological processes at a synoptic scale [2], to track moisture sources at a regional scale [3] and to examine decadal to interdecadal climate dynamics [4]. They make important contributions to

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studies of groundwater resources [5] and to catchment-scale hydrological [6] investigations. They provide baselines for interpreting isotope-based climate proxies in terrestrial archives such as lake sediments, speleothems and peat [7] and, finally, they contribute to the validation of general circulation models (GCMs) of climate that incorporate water isotope diagnostics [8].

The Global Network of Isotopes in Precipitation (GNIP) programme was established by the International Atomic Energy Agency (IAEA) and World Meteorological Organization (WMO) and commenced operation in 1961. The GNIP hosts a network of more than 1000 sites across 125 countries, at which precipitation is sampled and its isotopic composition measured. Most of these measurements relate to integrated monthly precipitation samples [9]. The oxygen ($^{18}O/^{16}O$) and hydrogen ($^{2}H/^{1}H$) isotope ratios of precipitation are usually presented in standard delta (δ) units expressed as parts per thousand or per mil (‰) deviations from the VSMOW (Vienna Standard Mean Ocean Water) standard, with $\delta‰\ \mathrm{VSMOW} = ((R_{\mathrm{sample}}/R_{\mathrm{standard}}) - 1) \times 1000)$, where $\delta = \delta^{18}O$ or $\delta^{2}H$ and $R = {}^{18}O/{}^{16}O$ or $^{2}H/^{1}H$. The $\delta^{2}H$ and $\delta^{18}O$ values of global precipitation form a best-fit line known as the Global Meteoric Water Line (GMWL), which was first presented by Craig [10] and described by the equation $\delta^{2}H = 8 \times \delta^{18}O + 10$. Subsequent studies based on a much larger dataset have shown that Craig's equation continues to provide a good approximation of the $\delta^{2}H$ and $\delta^{18}O$ relationship in global precipitation [11]. There are, however, regional variations in this relationship, which give rise to local meteoric water lines (LMWLs), and the exact form of these has climatic significance at regional and global scales [12,13]. A second-order parameter known as the deuterium excess [14], given by $d = \delta^{2}H - 8 \times \delta^{18}O$, is sensitive to conditions in the moisture-source region, especially relative humidity, as well as to subsequent changes within the air mass, particularly the contribution of recycled moisture and the evaporation of raindrops during rainfall [15,16]. Time series of precipitation stable-isotope data collected at intervals more frequently than monthly (e.g. daily or event-based) are less common, but are nonetheless valuable and have been used to investigate shorter-term controls on precipitation isotope values and relationships to meteorological variables at a synoptic scale.

In this paper, we present a daily precipitation isotope time series from Thames Ditton, a single site in Southeast England, for the year 2021 (Figure 1) collected using a low-cost precipitation collector. Daily and event-based records of precipitation are rare in mid-latitude regions [17] and additional time series are invaluable for understanding spatial patterns. First, we describe the construction, installation and testing of the precipitation collector used in this study. We then describe and evaluate the daily record from 2021, with particular emphasis on the controls on short-term variations in precipitation isotope values. Next, we compare the record from Thames Ditton with the few other published daily rainfall isotope records from the UK. Finally, we use our daily data to compute monthly values and compare these with monthly records for the year 2021 from other parts of Britain and Ireland in order to evaluate the nature of, and controls on, geographical patterns of precipitation isotopes across the British Isles.

For Britain and Ireland, monthly data are available from the GNIP [18] for seven sites, although only six of these sites cover at least one whole year and our discussion is limited to these six (Figure 1). A few other datasets are available for Britain and Ireland with monthly or sub-monthly sampling [19–22] although none is currently available

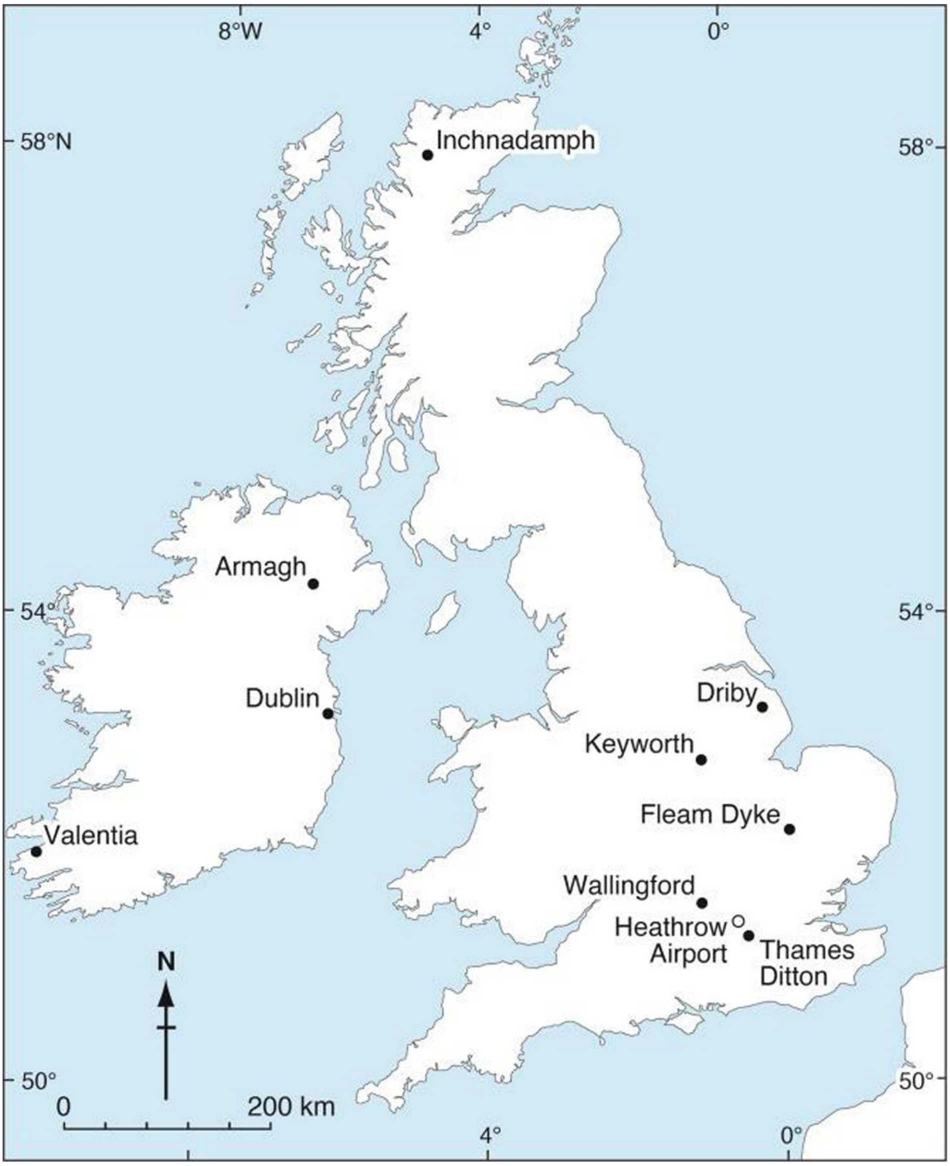

Figure 1. Location of precipitation collectors at Thames Ditton, SE England, and at other sites in Britain and Ireland discussed in text (filled circles). Ancillary meteorological data were obtained from the UKMO meteorological station at Heathrow Airport (open circle).

from GNIP. Spatial patterns of the isotopic composition of rainfall have been assessed for the British Isles as a whole using primarily monthly GNIP data [20], more locally using a range of data sources [21] and in snapshots of daily rainfall data across three individual months for Britain only [23]. Site-specific investigations into rainfall isotopes and their climatic and meteorological controls have been presented for daily [19] and event-based [22] time series. Finally, precipitation isotope data have been collected and used to support various palaeoclimatic [24,25] and hydrogeological [26] investigations in Britain and Ireland.

2. Methods

2.1. Precipitation sampler design

The sampling of precipitation for stable-isotope analysis requires a collector that minimizes subsequent evaporation to avoid isotope fractionation of the collected precipitation sample. This is especially important for monthly integrated sampling, where water remains in the collecting vessel for up to a month. However, evaporative effects may also be sufficient to alter the isotopic composition of daily integrated samples, especially during hot and dry weather. Various rainfall collector designs have been used to minimize evaporative effects (IAEA/GNIP, 2014). In this study, a modified version of a device employing tube dip-in with pressure equilibration was used, as described in detail by Gröning et al. [27] (further details are shown in the supplement). Although a version of this collector is available commercially, we constructed a similar device using components available in retail stores in the United Kingdom in order to minimize costs and because the availability of a commercial collector was precluded by covid-19 lockdown restrictions at the time of the study. This approach has been taken to build and successfully install similar collectors in South Africa [28] and northern India (J. Holmes and Y. Dixit, unpublished). The low cost of each individual collector may be a consideration when a large network of samplers is required in a study.

2.2. Precipitation collection

The precipitation collector was located in Thames Ditton, Surrey, UK (51.387367°, −0.325697°: 10 m a.s.l.) less than 1 km to the west of Greater London and 0.5 km due south of the River Thames (Figure 1). Precipitation was recovered from the collector once a day on the vast majority of rainy days, generally at 0800 GMT or 0800 BST during the UK daylight-saving period, and the total volume measured to the nearest 1 mL using a 50 mL measuring cylinder in order to estimate daily rainfall amount, in millimetres. Covid-19 lockdown restrictions in force in the UK at the time of the study meant that the water volume measurements could not be checked gravimetrically owing to the lack of access to a suitable balance. An aliquot of water was filtered through a 0.45 µm filter using a syringe filter, directly into a 5 mL Thermo^{TM} vial for analysis. For all days on which more than 5 mL of precipitation was collected, two samples were taken. On the two days in 2021 on which snow fell, the rainfall equivalent was estimated semi-quantitatively based on snow depth at a location close to the rain collector that was unaffected by snow drift.

2.3. Stable-isotope analysis

Precipitation samples were analysed on a Picarro L2130-i cavity ring-down spectrometer (CRDS) in the Bloomsbury Environmental Isotope Facility (BEIF) at the University College London (UCL), UK, for oxygen and hydrogen isotopes. Results were calibrated against laboratory standards (MinWat, AIW, NSW, NSO-J, NSO-H, NSO-A), which had been calibrated against IAEA international water standards VSMOW, GISP and SLAP. Nine replicate measurements were undertaken on each sample, with the results of the first three measurements discarded to exclude any potential memory effects and isotope values and standard deviations calculated from the remaining six. All injections yielded a water concentration of around 17,000 ppm. Analytical uncertainties determined from the replicate measurements and multiple analyses of standards were better than ±2.15 ‰ and ±0.18 ‰ for δ^2H and $\delta^{18}O$, respectively.

2.4. Ancillary meteorological data and other precipitation isotope time series

Meteorological data were used to support the initial evaluation of the stable-isotope time series from Thames Ditton. Daily precipitation amount, in millimetres, was calculated from the volume of rainwater collected in the rain collector each day. Daily mean temperature was computed from hourly air temperature values measured at the UK Met Office (UKMO) observation station at London Heathrow Airport (Met Office, 2006), which lies about 13 km NNW of Thames Ditton (Figure 1) and is the nearest station with recordings for 2021. We used the daily rainfall isotope data to determine monthly values weighted by rainfall amount for comparison with monthly data from other sites in Britain and Ireland. We compared the isotope data from Thames Ditton to Lamb weather types (LWTs) [29,30] to investigate the relationship between synoptic meteorology and precipitation isotope values, as in previous studies [19,22]. Daily LWTs for 2021 were obtained from https://crudata.uea.ac.uk/cru/data/lwt/. Precipitation isotope data from other sites in Britain and Ireland were used to compare with the record from Thames Ditton. These data were obtained from GNIP (from Valentia in Ireland and Armagh, Inchnadamph, Fleam Dyke, Keyworth and Wallingford in the United Kingdom: [18]) and Baldini et al. [22] (Dublin) for monthly records as well as from Heathcote and Lloyd [19] (raw data obtained from [31]) and Darling and Talbot [20] for daily data from Lincolnshire and Oxfordshire, respectively (Figure 1). The monthly values for Fleam Dyke in GNIP were originally reported in Darling and Bath [26] and calculated from daily data for the period November 1979–March 1981. For comparisons, we used only monthly and daily time series with at least one year of record. LMWLs were constructed for each site using the method of precipitation amount-weighted least-squares regression (PWLSR) [32].

3. Results and discussion

A total of 151 precipitation events were recorded at Thames Ditton from 1 January to 31 December 2021. Of these, samples from 148 events were analysed for oxygen and hydrogen isotopes: three samples were lost before analysis could be undertaken. The precipitation isotope values range from −15.62 to +0.92 ‰ (for $\delta^{18}O$) and −108.7 ‰ to +2.9 ‰ (for δ^2H). The daily precipitation *d*-value ranges from −6.5 to +23.1 ‰ (Figure 2).

The δ^2H and $\delta^{18}O$ values were used to compute an LMWL for Thames Ditton ($\delta^2H = 7.7 \pm 0.1 \times \delta^{18}O + 6.3 \pm 0.9$) (Figure 3). This lies close to the GMWL [10] given by $\delta^2H = 8 \times \delta^{18}O + 10$, but with lower slope and intercept. There is a moderate correlation between the isotope values (shown for $\delta^{18}O$) and daily temperature (Figure 4A), and a weak correlation between $\delta^{18}O$ and daily precipitation amount (Figure 4B). The correlation between $\delta^{18}O$ and the square-root transformed daily precipitation amount (Figure 4C) is also weak, although stronger than that for the untransformed data. Finally, there is a moderate negative correlation between *d*-excess and $\delta^{18}O$ (Figure 4D). Observations agree well with previous studies that show moderate to weak dependence of rainfall isotope composition on

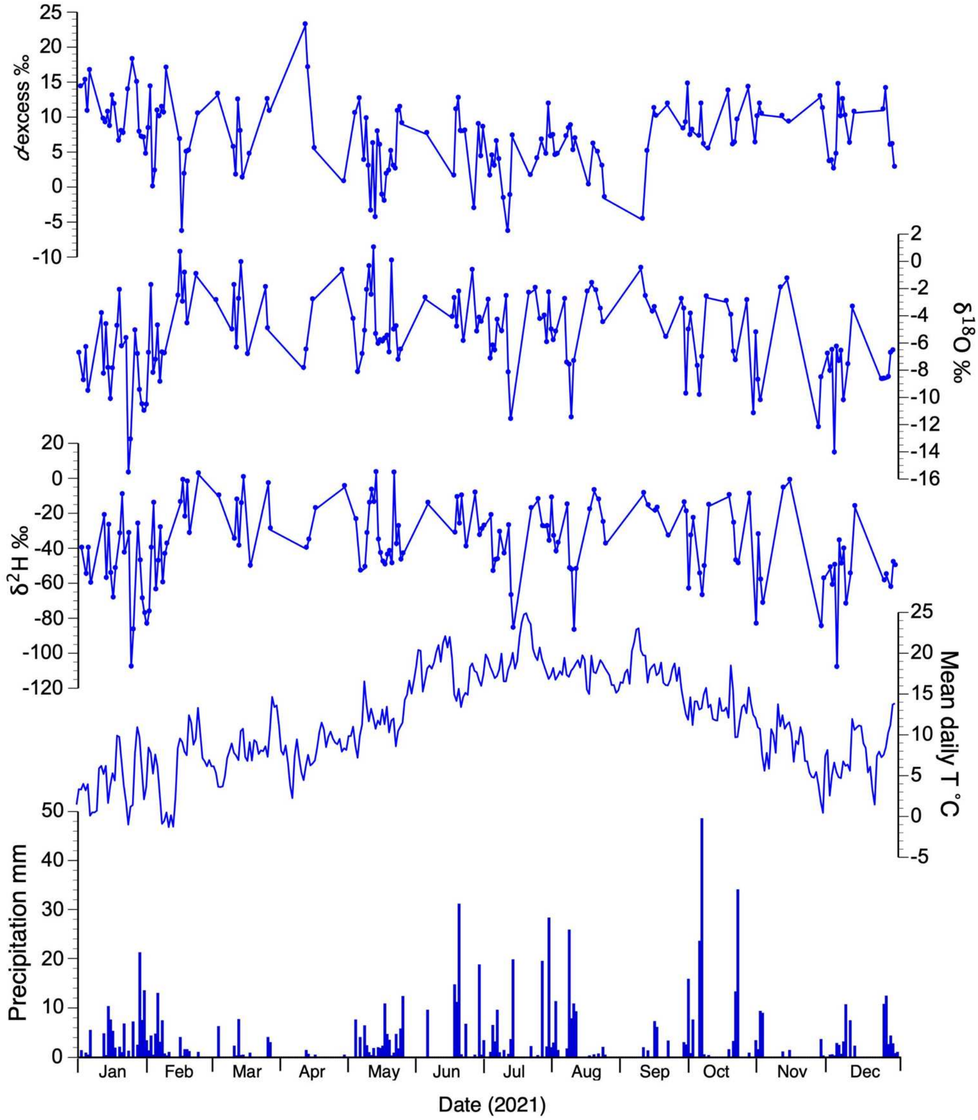

Figure 2. Daily precipitation isotope data and rainfall amounts from Thames Ditton. Daily mean daily temperatures are from the UKMO station at Heathrow Airport (Figure 1). (https://data.ceda.ac.uk/badc/ukmo-midas/data).

temperature for daily or event-based time series from British and Irish sites [19,20,22,23]. The positive correlation between the isotopic composition and air temperature is controlled primarily by the fraction of vapour that is removed from the air mass, which increases with decreasing temperature: the moisture-holding capacity of air is lower at colder temperatures and condensation of water vapour and its subsequent removal as precipitation leads to progressive loss of heavy isotopes by a Rayleigh distillation process [14]. The negative correlation with rainfall amount – the so-called amount effect – arises from the loss of heavy isotopes with increasing rainfall amount, also by a

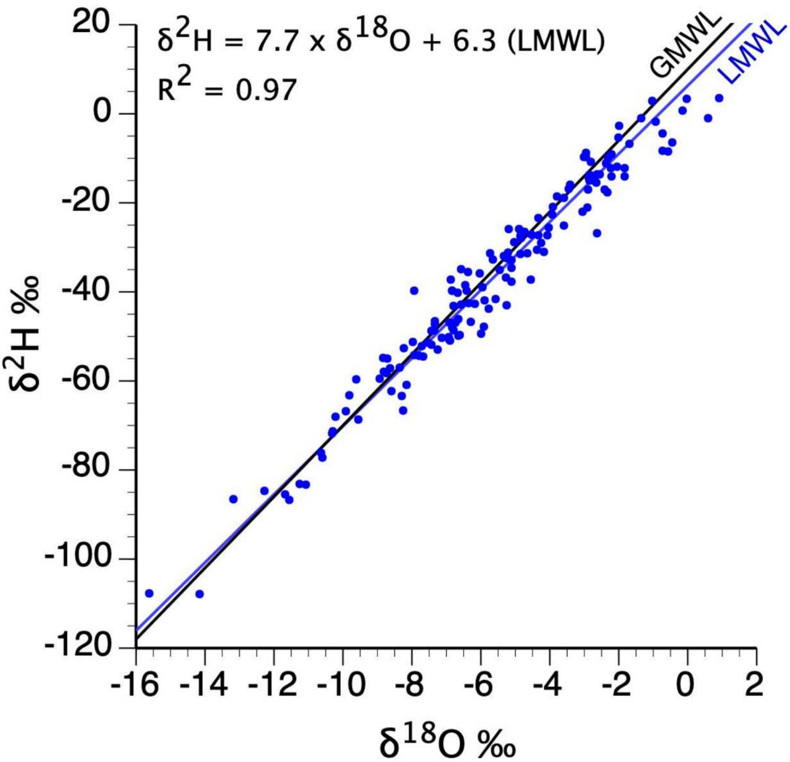

Figure 3. Daily δ^2H v δ^{18}O for all precipitation samples collected at Thames Ditton in 2021. The regression line was computed using precipitation amount-weighted least-squares regression (PWLSR: [32]) and forms a local meteoric water line (LMWL) for Thames Ditton, 2021 (blue line). The Global Meteoric Water Line (GMWL: $\delta^2\text{H} = 8 \times \delta^{18}\text{O} + 10$) [10] is also shown (black line).

process of Rayleigh distillation [14]. Tyler et al. [23] noted a slightly stronger relationship with the square root of rainfall amount, which accords with our findings and other studies [22] and has been attributed to non-linearity in the stable-isotope amount effect [33]. The deuterium excess is controlled by a complex range of factors relating to conditions at the vapour source as well as processes occurring along moisture transport pathways and during rainfall itself. The negative correlation between δ^{18}O and *d*-excess in our record could therefore be determined by several processes. Rainfall with elevated δ^{18}O values is associated with lower *d*-excess values, which could be source-related (lower fractionation at source, arising from higher relative humidity) [15] or some evaporative loss of raindrops below the cloud base under warmer conditions [16].

Monthly precipitation isotope values, including weighted monthly values, were computed from the daily isotope data and daily precipitation amounts (Figure 5) and largely reflect the moderate to weak correlations seen in the daily data: stronger correlations between stable-isotope values, temperature and rainfall amount are generally seen for longer time series in which the monthly values are averages of data from multiple years, or even decades in some cases [11].

Rainfall isotope values are determined for nine of the twenty-six LWTs, as well as for the 'unclassified' group. These categories individually make up more than 4 % of annual

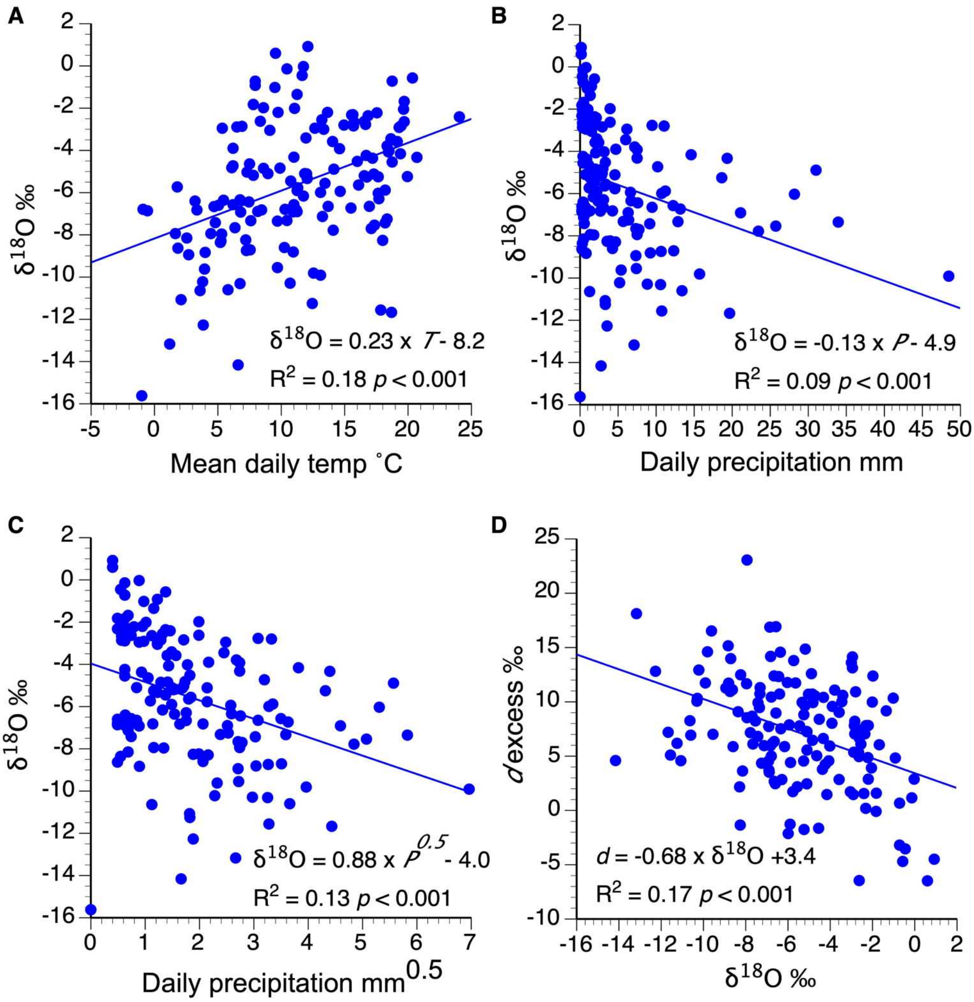

Figure 4. Oxygen-isotope values for daily precipitation from Thames Ditton versus (A) mean daily temperature (B) precipitation and (C) square root of daily precipitation amount (D) *d*-excess versus oxygen-isotope values for daily precipitation from Thames Ditton. In the equations, *P* refers to precipitation amount and *T* refers to temperature.

rainfall. Weather type might reasonably be expected to exert control on precipitation isotope values, since the vapour source, air-mass trajectory, temperature and rainfall characteristics (including rainfall amount and whether frontal or convective) vary with LWT [30]. Low individual values are associated with E (Easterly), N (Northerly) and CN (Cyclonic Northerly) types and high values with SW (Southwesterly) and A (Anticyclonic), probably reflecting the origin and transport path of air masses associated with type, but there is also wide variability in isotope values for each LWT as well (shown for $\delta^{18}O$ in Figure 6). The bulk of rainfall (>35 %) is associated with type C (Cyclonic) weather type. There is no clear pattern of *d*-excess variation with LWT (Figure 6). Previous studies of British and Irish rainfall and LWTs have also found, unsurprisingly, that the bulk of precipitation is associated with Type C [19,22] and that wide variability in isotope values is

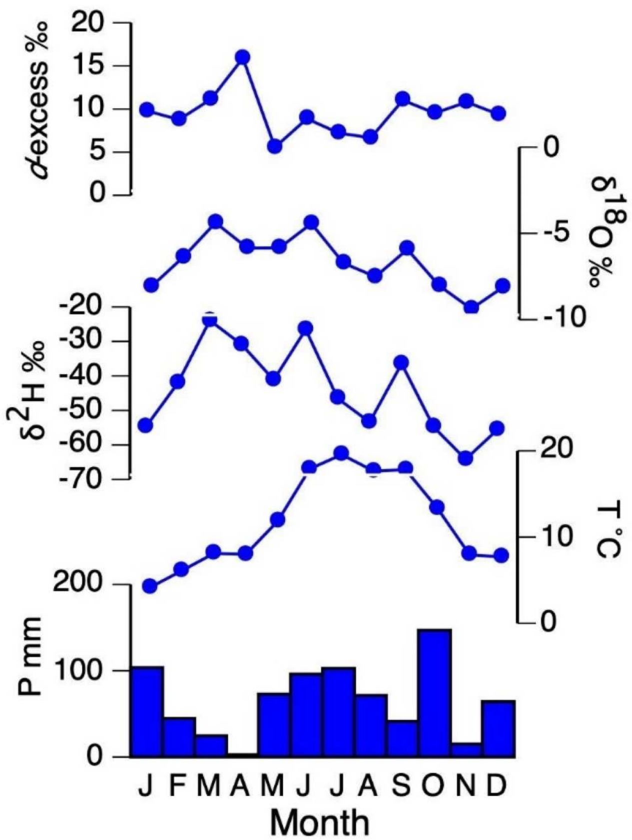

Figure 5. Monthly weighted δ^2H, δ^{18}O and *d*-excess, and total precipitation (P), for Thames Ditton, 2021, computed from the daily values as described in the text. Monthly mean temperature values (T) are from Heathrow Airport (https://data.ceda.ac.uk/badc/ukmo-midas/data).

associated with each type. However, at Thames Ditton, isotopic variability is less marked within the C type than at other sites for which the relationship has been investigated, namely Driby [19] and Dublin [22], and no amount of effect is apparent within any individual weather type or weather-type grouping (data not shown) (cf. at Dublin: [22]). The broad grouping of LWTs noted for Driby does not exactly agree with variations seen at Thames Ditton, although the ^{18}O-enrichment associated with A and SW types is consistent with the Driby data. The fact that the data series from Dublin, Driby and Thames Ditton do not coincide in time may explain some of the differences in detail in the relationship between isotope values and weather type although Tyler et al [23] noted spatial patterns in the relationship across Britain, and so some of the difference between sites noted here may be a reflection of such patterns.

None of the daily records from other sites overlap in time with the Thames Ditton record. As a result, inter-site comparisons of the daily records are limited to the general characteristics of the time series. Despite this, we note that the large variability day-to-day in isotope values (shown for δ^{18}O in Figure 7) is consistent with that seen in the other daily records. Moreover, the range in the isotope values (including *d*-excess if a single outlier from Driby is excluded) is remarkably similar between sites (Table 1).

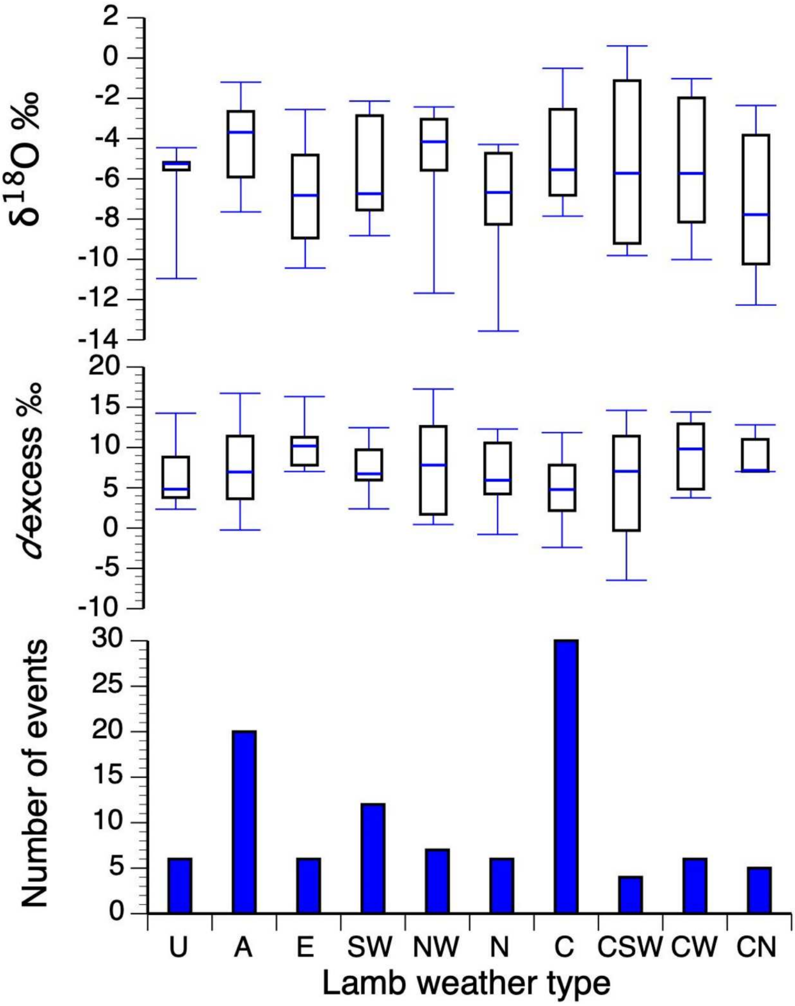

Figure 6. Variation in the isotopic composition of Thames Ditton daily rainfall with Lamb weather type (LWT) for each of the types that is associated with >4 % of total annual precipitation (U – unclassified; A – anticyclonic; E – easterly; SW – southwesterly; NW – northwesterly; N – northerly; C – cyclonic; CSW – cyclonic southwesterly; CW – cyclonic westerly; CN – cyclonic northerly) [29,30].

Five named storms impacted the UK in 2021 (Table 2) although despite the fact that each led to precipitation at Thames Ditton, very intense rainfall and large rainfall amounts were only associated with three of these. Storms Darcy (February) and Barra (December) are noteworthy for ^{18}O-depleted rain and large rainfall amounts. Storm Arwen (November) was associated with a smaller rainfall total and lower peak intensity than other storms. At Thames Ditton, short intervals of very intense rainfall were observed on the day of Storm Arwen, even though the intensity of these individual intervals was not measured. It is possible that the peak intensity at Thames Ditton was much higher than measured at Heathrow Airport (quoted in Table 2), and if this were the case, it could explain the very negative δ^{18}O and δ^{2}H values on the 27th of that month. However, more frequent (hourly or even sub-hourly) sampling of rainfall would have been required

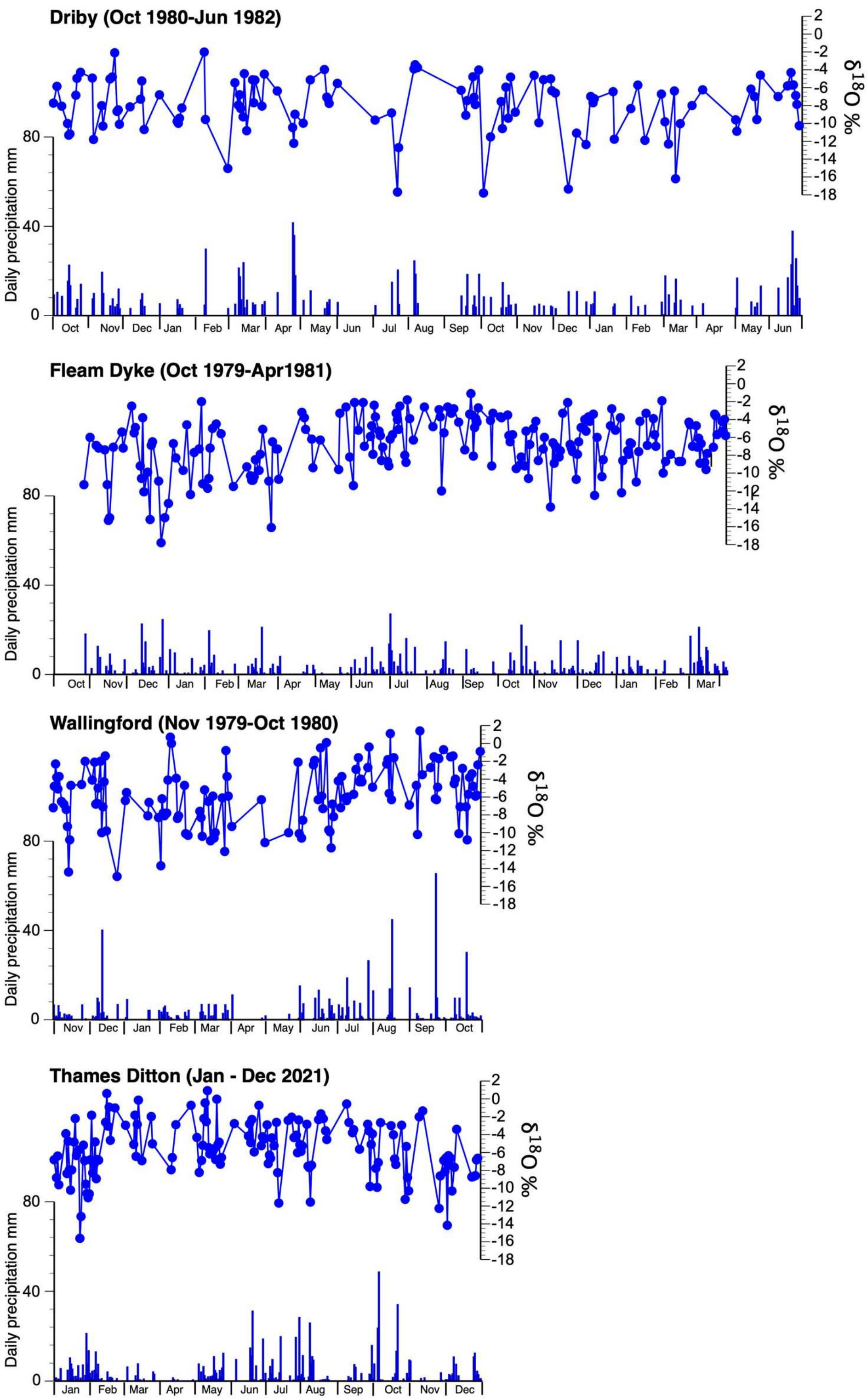

Figure 7. Time series of daily precipitation from Thames Ditton and other sites in England. For data sources, see text.

Table 1. Summary data for daily precipitation isotope time series discussed in this paper. Weighted values are weighted by rainfall amount.

	Thames Ditton			Driby			Fleam Dyke[a]			Wallingford[b]		
	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	*d*-excess (‰)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	*d*-excess (‰)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	*d*-excess (‰)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	*d*-excess (‰)
Date range	1 January 2021–31 December 2021			30 October 1980–28 June 1982[c]			26 October 1979–2 April 1981			2 November 1979–28 October 1980		
Mean	−5.62	−37.7	7.2	−7.99	−56.0	8.2	-6.89	-45.0	9.2	-5.76	-	-
SD	3.09	23.0	8.7	3.07	26.7	9.4	3.15	24.5	7.9	3.39	-	-
Weighted mean	−6.87	−46.3	5.1	−8.34	−42.9	5.7	-3.30	-57.3	9.3	-6.78	-	-
Max	0.92	2.9	23.1	−2.01	−14.6	37.3	-1.10	0.0	37.4	1.40	-	-
Min	−15.62	−108.7	−6.5	−17.80	−140.3	−44.4	-17.80	-136.0	1.8	-14.90	-	-
Range	16.54	111.52	29.54	15.79	125.70	81.70	16.70	136.00	35.60	16.30	-	-

[a]Weighted values determined only for days on which rainfall amount was measured.
[b]No hydrogen-isotope data.
[c]Hydrogen isotopes not determined for samples after 29 Dec 1981 and some values missing from earlier part of interval.

Table 2. Summary information for 2021 named storms. Rainfall intensity values are from met office station at Heathrow Airport (∼13 km from study site). All other data are from the Thames Ditton rain collector.

Storm	Dates	Max rainfall intensity[a] (mm h^{-1})	Collection date	Total rain (mm)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	*d*-excess (‰)
Christoph	19–22 January	3.0	19/01/2021	2.0	−4.8	−32.3	6.5
			20/01/2021	0.9	−2.2	−9.8	7.8
			21/01/2021	6.7	−6.3	−43.2	7.5
Darcy	6–8 February	4.0	06/02/2021	3.0	−4.8	−28.6	9.9
			07/02/2021	7.3	−8.9	−60.3	11.3
Evert	30 July	1.8	30/07/2021	1.9	−2.4	−11.8	7.1
Arwen	26–27 November	3.2	27/11/2021	3.6	−12.3	−85.3	12.8
Barra	7–8 December	7.4	07/12/2021	3.1	−6.7	−40.9	12.4
			08/12/2021	10.6	−10.3	−72.4	10.1

[a]From Heathrow Airport hourly rainfall data.

to substantiate this. More generally, the low isotope values associated with storm rainfall may suggest an amount effect [34], although the daily sampling employed here is insufficient to substantiate this. We also note that these values have relatively high *d*-excess (although not the highest of the entire year), which may be related to specific conditions at the original vapour source and/or to air mass trajectory. Such a relationship could be investigated further using air-mass trajectory modelling [22] although this is beyond the scope of the present study.

To compare the Thames Ditton data directly with records from other sites, we first look at those sites that also have data for 2021: this exercise is limited to the three GNIP sites with monthly data for 2021 (Valentia, Armagh and Wallingford), which we then compare with calculated monthly data for Thames Ditton. Secondly, we look more generally at spatial patterns across Britain and Ireland by assessing data for all sites that have at least a full year of data (either monthly or daily: $n = 9$) and focussing on mean isotope values and the regressions of $\delta^{18}O$ and $\delta^{2}H$, i.e. the LMWLs (Table 3). The interpretations from this second exercise are presented with the caveat that the time series do not all cover the same period.

For 2021 (Figure 8), values from all sites show characteristic seasonal patterns, with greater heavy-isotope depletion during the colder season (January to March and October to December) than warmer season (April to September) as is commonly seen in European sites. This is a seasonal manifestation of the temperature effect discussed above. There is close agreement between data from Wallingford and Thames Ditton, which is unsurprising given their proximity (the two sites are ∼60 km apart). The month of August was an exception however, with markedly more ^{18}O- and ^{2}H-depleted values at Thames Ditton than Wallingford ($\delta^{18}O = -7.51$ and −4.11 ‰, $\delta^{2}H = -53.1$ and −29.1 ‰, respectively). The largest discrepancy in daily rainfall amount between the two stations occurred over the 24 h period ending 0800 BST on 9 August, when Thames Ditton recorded 10.7 mm, but Wallingford only 2.4 mm, i.e. less than a quarter of the amount. The Thames Ditton rainfall on these dates was notably ^{18}O and ^{2}H-depleted, with $\delta^{18}O = -11.56$ ‰ and $\delta^{2}H = -87.4$ ‰. Although the corresponding values for Wallingford remain unknown since only monthly data are recorded at this station, it is possible that the intense, heavy-isotope depleted rainfall at Thames Ditton on 8 and 9 August accounts for a large proportion of the divergence in $\delta^{18}O$ and $\delta^{2}H$

Table 3. Summary climatological and isotope variables for each site considered in this paper, along with statistics for oxygen versus hydrogen-isotopes regression using precipitation amount-weighted least-squares regression (PWLSR: a = slope and b = intercept) portrayed in Figure 9. Weighted values are weighted by rainfall amount.

			Mean annual temperature (°C)	Annual precipitation (mm)	$\delta^{18}O_{weighted}$ (‰)	$\delta^{2}H_{weighted}$ (‰)	*d*-excess$_{weighted}$ (‰)	PWLSR		
								a	b	r^2
Thames Ditton	2021	Daily	11.7	785.6	−6.92	−46.6	8.7	7.65	6.32	0.97
Wallingford	1979–2022	Monthly	10.6	604.1	−7.27	−49.4	8.8	7.36	4.14	0.95
Keyworth	1985–1996	Monthly	10.0	NR	−7.97	−54.3	9.4	7.40	4.74	0.96
Driby	1980–1982	Daily	NR	587.0	−8.45	−59.2	8.4	7.62	5.13	0.91
Dublin	2003–2005	Monthly	11.3	691.8	−6.80	−47.5	NR	7.30	2.07	0.97
Valentia	1960–2022	Monthly	10.8	1525.8	−5.45	−35.1	8.5	6.94	2.77	0.90
Armagh	2012–2021	Monthly	9.9	840.9	−8.09	−55.5	9.9	7.51	5.33	0.96
Fleam Dyke	1980–1983	Monthly	NR	593.3	−7.49	−50.4	9.5	7.52	5.95	0.95
Inchnadamph	2003–2005	Monthly	7.8	2520.0	−6.28	−48.2	2.0	7.18	−2.79	0.95

Note: NR not reported.

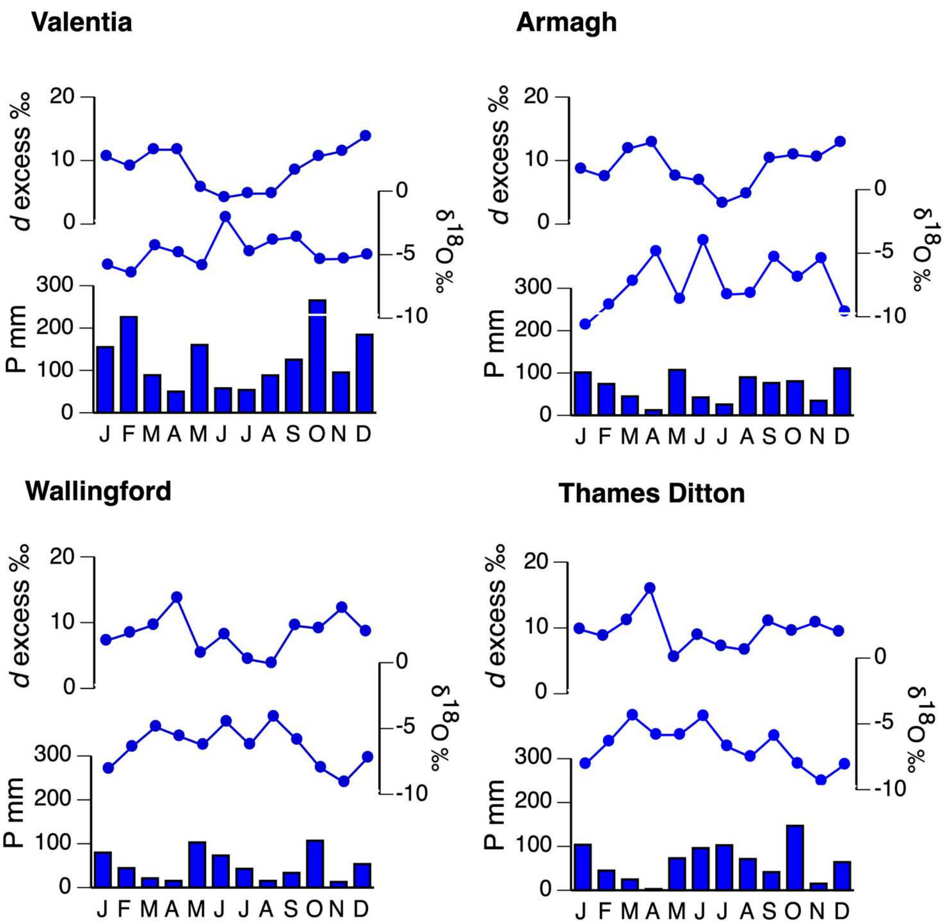

Figure 8. Monthly rainfall (P), $\delta^{18}O$ and *d*-excess for sites in Britain and Ireland for 2021. Data for Thames Ditton are from this study: data for other sites are from GNIP database.

values between the two stations for the month of August as a whole. This suggests that local factors can have a significant impact on isotopic characteristics of rainfall in individual months, particularly in the summer when convective precipitation events dominate. The other two sites with monthly data for 2021 (Valentia and Armagh), both of which are in Ireland, show broadly similar seasonal patterns, although differences between each of these sites and between them and the two sites in England, also highlight the significance of spatial variations in isotope values of monthly rainfall (the distances between Wallingford and Thames Ditton and between Valentia and Armagh are ~60 and 370 km, respectively).

Comparison of the data from all of the nine sites (Table 3) allows further insight into regional patterns. Based on weighted annual means, Valentia and Inchnadamph show rainfall that is least ^{18}O- and ^{2}H-depleted; both sites are closer than all others to the Atlantic coast and have therefore been subjected to less rainout (Figure 1). Sites in southern England become progressively more heavy-isotope depleted from west to east, consistent with a continental effect even over such a short distance,

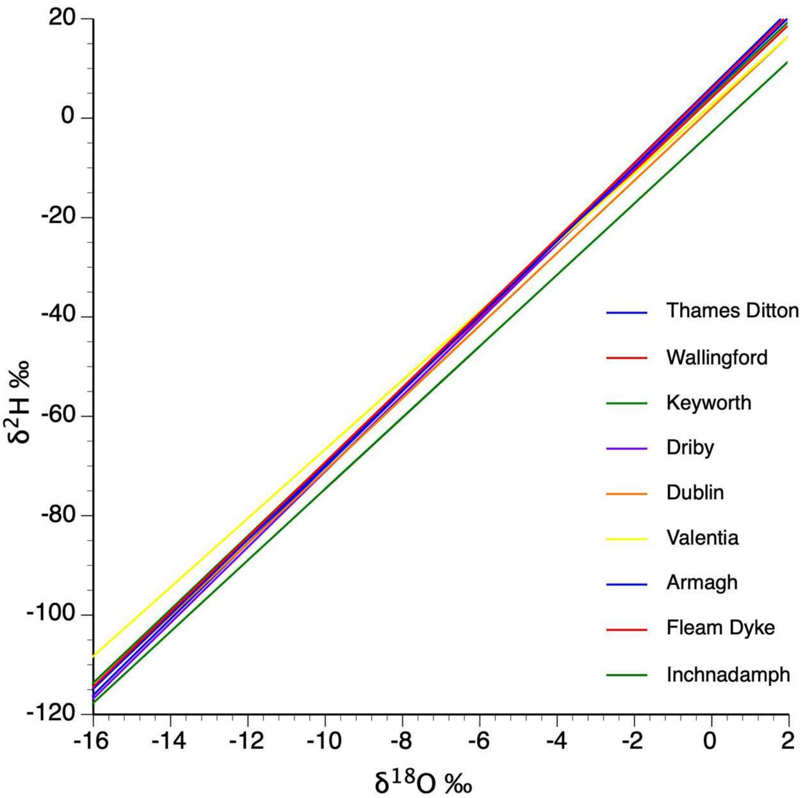

Figure 9. Local meteoric water lines (LMWLs) computed using precipitation amount-weighted least-squares regression (PWLSR) for sites referred to in text. Regression statistics are in Table 3.

with Driby, in the east of England, showing the lowest values. Dublin, on the east coast of Ireland, lies intermediate between Valentia on the extreme west and the southern England sites. Armagh, which is in Northern Ireland, also shows considerable ^{18}O and ^{2}H depletion, likely a reflection of its northerly *and* inland location. LMWLs for all nine sites (Figure 9) show considerable similarity, although Valentia (the most westerly site: Figure 1) and Inchnadamph have slightly lower slopes than the other sites (Table 3). Lécuyer et al. [13] have shown, albeit from a larger set of data with a much greater geographical spread over Europe, that regression line slopes increase with longitude (i.e. with distance from the North Atlantic Ocean) and propose two processes to explain the lowest slopes in the most westerly parts of Europe. First, the advection of recycled water vapour from the nearby Atlantic Ocean (termed the 'Atlantic Side Effect') and second, the evaporation of raindrops below the cloud base as they fall through warm, low-humidity air. The second process is less likely to be applicable to the British Isles, given high relative humidity. However, an Atlantic Side Effect is consistent with the geographical variations in LMWL slopes that we report here and the lower slopes of LMWLs for Valentia and Inchnadamph compared with those for the other sites can be explained by the proximity of these two sites to the Atlantic Ocean and greater influence of recycled North Atlantic moisture as a result.

4. Conclusions

We have compiled a one-year daily record of the oxygen- and hydrogen-isotope composition of rainfall from Thames Ditton, in SE England, using a home-constructed collector of proven design. Daily values of rainfall isotope composition varied markedly, consistent with other daily and event-based time series from Britain and Ireland and with similar ranges. Complex controls on the isotope values from Thames Ditton, including circulation type, temperature and rainfall amount are also consistent with previous studies and we find no strong correlations with single meteorological variables of temperature or rainfall amount. Comparison with data from eight other sites across Britain and Ireland shows that the values from Thames Ditton are consistent with geographical patterns, although local factors can lead to marked differences between sites that are quite close (<100 km apart in some cases). Our data have implications for the interpretation of palaeoclimate archives, water resources and understanding of climate dynamics over the British Isles. The understanding of spatial variations in precipitation isotope values and their controls can benefit from the employment of networks of samplers over large geographical areas [23]. In situations where funding is limited, the use of the collector design described here may allow such sampling networks to be established at low cost.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Precipitation isotope data are available from the GNIP database (https://www.iaea.org/services/networks/gnip).

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