Response to editor/reviewer comments and changes to manuscript:

Editor comment	**Author response**
The title should be changed to specify the source type (diaries)	We have modified the title accordingly.
The first reviewer requested stylistic edits throughout the text and clarification of the figures.	We have revised the manuscript, making use of Referee 1's detailed comments.
Both reviewers indicated that the manuscript should include more international context regarding weather diaries and methods for using them.	We have included more references to international usage of diaries for weather reconstruction throughout the manuscript.
Both reviewers requested that the conclusion be rewritten to emphasize the study's global methodological significance for historical climatology and not only its findings regarding past British climate. The last two points are particularly important in light of the international and comparative focus of this special issue.	We have extensively rewritten the conclusion.
Referee 1 comment	**Author response**
Thank you for the opportunity to review this manuscript, which presents a useful methodological consideration of the use of qualitative data from personal diaries in weather reconstruction. The authors have analysed a huge amount of qualitative data – for which they should be commended – and have analysed it rigorously. The study is novel and the methods (mostly) clearly outlined. The material covered is relevant to Climate of the Past. In short, there is certainly scope for the work to be published. While the science in the paper is sound, the presentation and written style detracts significantly from the quality of the data presented. There are many long and overly complex sentences, the writing is (in places) imprecise, and many figure captions are vague. The results are really strong but the conclusion, if anything, downplays them.	Response to Referee 1 (David Nash) We would like the thank the referee (David Nash) for a very thorough and thoughtful review of our paper, and for his constructive comments. We are happy that the referee recognises the value of the data analysed, the quality of the analysis, the strength of the results and the novelty of the study. We are happy to act on his suggested edits and additions.
I suggest that significant revision is needed before the manuscript could be considered suitable for an international readership. At a bare minimum, the authors should read over the full text carefully and tighten up the wording. They should split their longer sentences – e.g. lines 72-77, 133-135, 135-138, 140-143, 168-171, 181-184, 197-	In our revised manuscript we have paid close attention to the referee's concerns regarding sentence length, citations and grammatical inconsistencies. We have assessed every occurrence of the words 'that' and 'which' and hope that they are now used correctly. We have done the same for 'index' and 'indices'. We have checked all the citations.

200, 216-218, 281-284 (there are many others) – into multiple parts. This will greatly improve the readability of the manuscript. The authors also need to check for consistency in the use of 'which' and 'that' throughout the text – often this is incorrect. Section 4 onwards – check the use of the singular (index) and plural (indices) here, as the results sections are full of inconsistencies. "No single index system is universally used…" "…converted these to 7-degree indices…" "Additionally, an indexing approach based on…" "…each of which was given an index score…" Inconsistency in citations – there are places where the referencing software used in the manuscript goes awry and places parentheses around citations when the author name should be included in the text of the sentence.	
The title of the paper would be more accurate and informative if it included the words 'from private diaries'.	Accept – we have revised the title to reflect the sources and added a sentence to the Introduction (para 3) differentiating between private and personal diaries.
Section 2 – I appreciate that sources are cited throughout the results section, but it would be useful to refer the reader (perhaps at the end of the first paragraph) to the list of Archival Sources.	Accept - We have added the sentence 'Details of archival sources used in this reconstruction can be found at the beginning of the reference list' to the end of section 2, paragraph 1.
Figure 2 – caption could be more informative.	Accept - We have reviewed all our captions
Line 158-162 – this is a very long and confusing explanation of the standardisation process – consider fragmenting the sentence.	Accept - We have revised this sentence, and hope it is now clearer.
Figure 3 – the caption is very densely written and could be more informative.	Accept – we have rewritten this caption.
Line 176 – this is the second Section 4 in the manuscript.	Accept – corrected.
Figure 5 – I'm assuming that the blue line in 1b, 2b and 3b is the Trentham index series, as the caption doesn't explain this. Also, I may have missed it, but have you explained somewhere before the first mention of this figure how the index values for Trentham have been converted into mm rainfall?	Accept - We note some confusion around the conversion of the Trentham index series into mm of rainfall. We will clarify this in the appropriate figure captions (Figure 5 shows the raw index series plotted on a secondary axis, and Figure 8 shows the conversion to mm) and in the relevant section of the text (section 6.2).
Figure 6 – the distribution data at the bottom of the figure require appropriate axes and a little more explanation in the caption.	Accept - We have revised the caption and labelling of axes for figure 6 as suggested.

Line 247 – do you really mean 'greater capacity for snowfall at Trentham'? 'A higher propensity for snowfall' might be better.	Accept - We have changed this sentence as suggested by the referee.
Line 250 – is 'medium' the best word here?	Accept
Figure 7 – I assume this is Trentham as the caption doesn't state this. And indices for what (in both the caption and axes labels)?	Accept - We have revised the axes labels and caption.
Figure 8 – again, how are the Trentham values converted into mm rainfall?	See section 6.2 paragraph 1
Line 303 – one example of the misuse of 'which' here – what you mean is '…(drop the comma) that might flag…'. For comparison, the use of 'which' in the next sentence is correct.	Accept - This sentence has been modified.
Lines 307-311 – I was going to ask exactly this, as a direct comparison of 'missing days' in diaries (and potentially vice versa) would be very instructive.	Agree – we have added a further comment to this section on probabilistic fittings, but recognise the limitation here is the data resolution during early instrumental records.
Line 357 – spelling 'tornadoes'.	Accept - This typographic error has been corrected.
Line 365-369 – confusing sentence. Line 375 – unclear what is meant by 'this' here. Line 381 – unclear what is meant by 'it' here.	Accept - edited
Lines 393-394 – I understand what you are trying to say, but this is a very UK-centric take on diaries. I could point you to numerous personal diaries from beyond the UK that are biased towards drought.	Accept - We acknowledge that lines 392-394 presents a UK centric perspective and have provided examples from S.Africa and Mexico to demonstrate this bias towards extremes is not specific to this region or study
Lines 413-418 – I understand the reason for including this paragraph, but it has the potential to seriously detract from the results of the study. Much better would be to state earlier (in the methodology): (i) that one person completed the analysis for all index series to improve consistency; (ii) that volunteers were involved in transcription but there was quality control.	Agree- we have rephrased and inserted in section 2, thank you for the comments provided here.
Section 8 – I want to end on a positive. The results of this study represent a huge amount of work and are potentially very interesting. However, the Conclusion seriously underplays the quality of the research and should be much stronger. This is an opportunity to point out the key findings of the paper and highlight which aspects of the methodology were most successful. To my knowledge, no one has conducted this volume of analyses of diary entries, so this is the opportunity to recommend a methodology	Agree - We have redrafted the conclusions. We feel the revised version provides a stronger conclusion, and thank the referee for his constructive comments.

to be used in future studies. This will elevate the manuscript from 'an interesting study' to a 'must-cite paper' for future researchers seeking to use diaries for climate reconstruction.	
Referee 2 comment	**Author response**
[Evaluation] This manuscript presents very interesting research on reconstruction of rainfall amount from several simultaneous diaries in the past. The methods used are appropriate and the conclusions derived from these and the interpretations are consistent and sound. I believe the paper will be of interest to the readership of this journal and would recommend it for acceptance after the minor revisions. I look forward to seeing it in print.	Response to referee 2 We would like the thank the referee for reviewing the paper, and for their useful and constructive comments. We are glad that they consider the content of the paper to be sound. We are happy to incorporate their suggestions into our revised manuscript and have made an effort to include more relevant non-European literature. We have added more detail where suggested in the methodology and revised our figure captions.
[Comment] I understand that this paper deals with past climate in UK, Europe. However, in Chapter 1, I believe that related past studies should be introduced not only European cases but also other parts of the world (I could find only one reference in China). As far as I know, rain day index could show more strong correlation rather with temperature than rainfall amount in several Asian countries. I would like to recommend that the authors take more information from related studies outside of Europe and reflect it in the context.	Accept – we accept the comment from the referee and throughout the manuscript have attempted to link more and provide context to practices outside of Europe.
[Minor comment] Page 6, line 107-116: Please state more detailed classification and weather descriptions especially for Approach A and C. At this moment readers need to get and read references to understand the methods in detail.	Accept- Further examples and explanation have been added to this section.
Figure 1: In Figure caption, please explain what circles and triangles in the map refer.	Accept – clarity added to the caption
Figure 2: In Figure caption, please provide detail explanations.	Accept – caption expanded

Marked-up Manuscript:

Evaluating the utility of qualitative ~~data~~ personal diaries in precipitation reconstruction in the eighteenth and nineteenth centuries.

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Evaluating the utility of qualitative ~~data —~~personal diaries in precipitation reconstruction in the eighteenth and nineteenth centuries.

Abstract. To date few studies have reconstructed weather from personal diaries (~~alternately called~~ also known as private diaries). In this paper, we consider different methods of indexing daily weather information, specifically precipitation, from eighteenth and nineteenth century personal diaries. We examine whether there is a significant correlation between indexed weather information and local instrumental records for the period, thereby assessing the potential of discursive materials in reconstructing precipitation series. We demonstrate the potential for the use of diaries that record weather incidentally rather than as the primary purpose, and the value and utility of diaries ~~which cover~~covering short periods when used alongside nearby contemporary diaries. We show that using multiple overlapping personal diaries can help to produce a more objective record of the weather, overcoming some of the challenges of working with qualitative data. This paper demonstrates indices derived from such qualitative sources can create valuable records of precipitation. There is the potential to repeat the methodology described here using earlier material, or material from further away from extant instrumental records, thereby addressing spatial and temporal gaps in current knowledge globally.

1 Introduction

There has been an increased recognition in recent years of the value of long-instrumental series spanning several centuries (Brönnimann et al., 2019; Dobrovolný et al., 2010; Todd et al., 2015), as they ~~which~~ can provide valuable information on both climate variability (Murphy et al., 2018)~~,~~ and sensitivities in ~~-~~early records and~~s~~ ~~/~~long-term reconstructions (Murphy et al., 2020). Long series also provide value through increased robustness in back casting in climate model testing (Talento et al., 2019), extreme event contextualisation (Todd et al., 2015; Wetter et al., 2014) and for examining social and cultural changes and modifications (Pfister et al., 2010). This increased recognition has ~~also~~ coincided with public science projects ~~which~~that have seen extensive archival materials transcribed and reanalysed through both national and international programmes and initiatives (e.g. ACRE) (Allan et al., 2016; Brohan et al., 2009).

Whilst the focus has been on identifying instrumental datasets, considerable information is stored within qualitative archival source materials (Strauss and Orlove, 2003). These, however, ~~, however they~~ ~~which are~~ can be more challenging to analyse using citizen science approaches. Such descriptive materials incorporate valuable information detailing not just the weather~~,~~ but also human interactions with the weather and wider environment, documenting ~~the~~ social, cultural and economic responses to past extremes. In addition, they may also offer insights and information on activities undertaken during ~~more~~ mundane intervening phases~~, periods during which important actions may be taken~~ that either exacerbate or mitigate the hazards and risks presented to communities during extremes.

There have been many studies globally of weather diaries, where the diary is predominantly if not solely ~~s i.e. daily records primarily~~ concerned with the weather~~, which can be found around the world~~ (for example Brázdil et al., 2019a; Domínguez-Castro et al., 2015; Druckenbrod et al., 2003; Gergis et al. 2012; Mikami, 2008; Sanderson, 2018; Walsh et al., 1999). An early example ~~being~~is the weather diary kept in 1337-1344 by William Merle in Oxford, England (Lawrence, 1972). O~~; with o~~ther diaries ~~. This weather, with the earliest such diary being kept in 1337–1344 (Lawrence, 1972), and~~ document~~ing~~ the weather ~~information has often been recorded~~ alongside related information, such as tides (Woodworth, 2006). To date few studies have reconstructed weather from personal diaries, where the weather is not the focus of the document, but rather noted as an aside (often daily). Where personal diaries have been considered authors have often chosen to ~~choosing instead~~ simply ~~to~~ extract and present this weather data as it appears in the diary (Adamson, 2015; Schove and Reynolds, 1973). However, ~~, T~~there are some exceptions to this. For example,~~, however, for example~~ Chen et al. (2020) ~~for example~~ analysed the weather from a ~~short section of a~~ fourteenth century ~~Chinese~~ private diary from Jiangsu Province, China; whilst ~~(~~Kelso & Vogel (2007) and Nash & Grab~~,~~ (2010) use diaries and correspondence from South ~~.~~Africa to examine rainfall and drought. ~~, but these have generally been limited in spatial and temporal coverage.~~ The depth and quality of descriptive materials have long been recognised within the historiographical and geographical disciplines (Oliver, 1958), but have to some extent been shunned within the physical sciences, though they have received increased recognition in recent years (Sangster et al., 2018). The sciences often present a preference for 'instrumental' information, because of concerns relating to quality, replicability and comparability of content within discursive materials; as ~~(~~Adamson~~,~~ (2015) notes, weather recording in personal diaries can

lack rigour, be sporadic and be affected by the identity, personality and beliefs of the writer. However, the potential of qualitative materials is considerable, and have been shown to offer good correlations, comparable to adjacent instrumental series (Macdonald et al., 2010) and have previously been used for filling gaps in instrumental rainfall data. The potential of such sources is considerable, presenting opportunities to extend further back in time and cover areas poorly represented by instrumental information.

The series presented in this paper correspond to time periods when two diarists are writing from similar locations, and therefore offers the opportunity to test whether having multiple diarists recording simultaneously can between them produce a more objective record of the weather. Using multiple overlapping personal diaries may help to counteract ~~the~~ potential biases ~~of~~within personal diaries and therefore provide a more reliable weather record. This differs from previous studies ~~that~~, which have often focused on either a single diary (Lawrence, 1972; Sanderson, 2018) or used multiple diaries for the purpose of extending the temporal timeframe (Walsh et al., 1999). We consider different methods of indexing daily weather, examine whether there is a significant correlation between indexed weather information and local instrumental records for the period, thereby assessing the potential of discursive materials in reconstructing weather series.

2. Qualitative Historical Materials

Over seventy years of daily qualitative weather data between 1770 and 1865 for the UK were identified from diaries, letters and similar sources at the Staffordshire Record Office, with a wide spatial and temporal extent (details of archival sources used in this reconstruction can be found at the beginning of the reference list). The longest near continuous (daily) series in the materials collected were for Scotland 1790-1794, London 1794-1795 and 1797-1801, and Trentham in Staffordshire mid-1816-1865 (Figure 1). T~~, t~~he majority of the daily weather data were~~as~~~~which are~~ derived from personal diaries. These ~~were not principally weather diaries, as they~~ do not formally record daily weather, but rather ~~a record of~~describe daily life, ~~reflecting personal recollections and thoughts of the individual from the day, which~~ incidentally referring to the weather (~~(~~particularly precipitation~~)) daily (personal diaries with incidental weather recording)~~. ~~Further details of archival sources used in this reconstruction can be found at the beginning of the reference list.~~

The data ~~collected and used within this study~~analysed ~~here~~consists of 27,794 records (20,657 for Trentham, and 2,379 using three different indexing methods for London). The transcription of the materials was untaken by a small group of volunteers working alongside the authors at the Staffordshire Record Office, with careful quality control ~~(Harvey-Fishenden et al., 2019)~~. The classification and analysis of the index series was untaken by a single individual (AH-F). Previous studies that have applied indices have often used two or more researchers to provide some assessment of accuracy of classification (e.g. Nash et al., 2016); however it would be impractical to have two (or more) researchers look at this volume of material. In considering daily qualitative data the effect of any occasional errors in classification are minimal when aggregated to monthly timeframes. ~~The type of data in this study reduces the effect of occasional errors in the application of indices to the daily records, since having~~

~~daily weather recording means that many records contribute to the monthly values. Methods used limit the impact of such errors occurring.~~

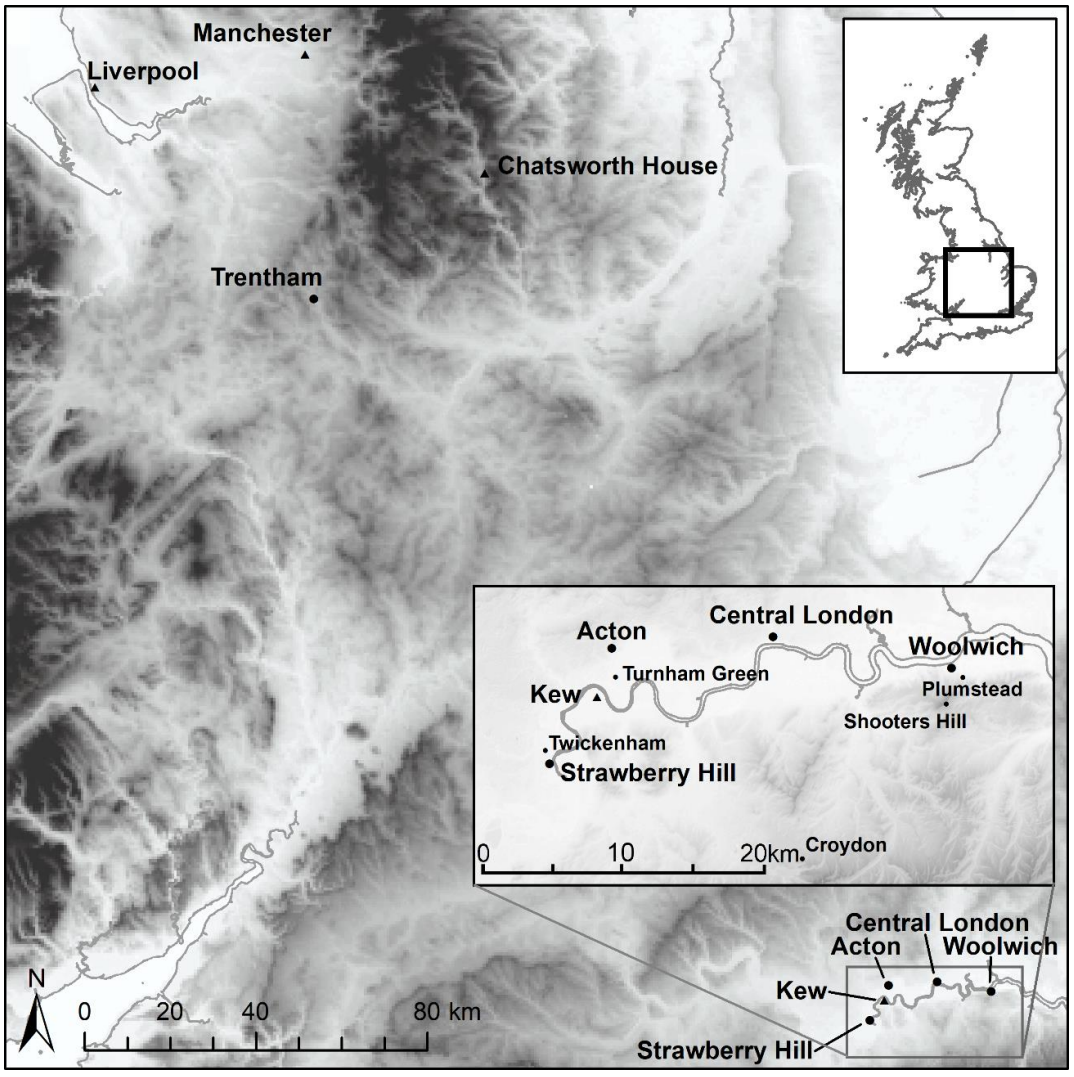


Figure 1. Location of ~~sites~~ rainfall records used within this study in Staffordshire and London (instrumental rainfall series marked with a triangle, locations of large numbers of non-instrumental records marked with a large circle, small numbers with a small circle). ~~(B~~b~~ackground map data from Digimap, © Crown copyright and database rights 2019 Ordnance Survey (100025252)) ~~Instrumental rainfall stations marked with a triangle, locations of large numbers of non-instrumental records marked with a large circle, small numbers with a small circle.~~

For the London series, diaries belonging to the author~~,~~ Elizabeth Hervey (1749-1820)~~,~~ provided many of the daily weather records. Hervey owned a house at Acton, in modern Greater London (Figure 1), and rented a house in Central London, but

travelled extensively and many of her diaries relate to her travels, in the UK and throughout Western Europe. She records the weather daily alongside a detailed account of her day, her health, and descriptions of the places she visits. A daily entry can run over several pages and the weather is often referenced multiple times during the day, interspersed with other information. The detailed weather descriptions recorded by HerveyThe detailed accounts of the weather provided by Hervey are particularly noteworthynotable as an early female weather recorder, withthere are few comparable female weather recorders in the late eighteenth century;. (Nnotable exceptions arebeing Margaret Mackenzie's temperature series (1780-1805) from Delvine, Scotland (Wheeler, 1994) and Constantia Orlebar's weather book (1786-1808) from Ecton, Northamptonshire (Manley, 1955)). The diaries of Richard Wilkes Unett also contribute to the London series.

For the Staffordshire (Trentham) series the major sources were from the Marquis of Stafford's Trentham Estate in Staffordshire. The majority of the information came fromse included the Trentham Farm reports monthly farm reports which which provide these daily reports daily include daily weather descriptions (predominantly concerning precipitation) from 1816 onwards , with temperatures recordings from 1821, and from a memoranda book belonging to the Agent for the Trentham Estate, William Lewis. In addition to sections on the weather, tThe farm reports were produced monthly and had sections on the weather and reportscontain reportsdetails from different employees on the estate, such as the gamekeeper, which help to contextualise the weather information. Daily entries in Lewis's memoranda book are relatively short (several to a page) but recollect the weather and its impact on Lewis's activities, and those of the wider estate. Letters between Lewis and his superior, James Loch were also consulted, as were diaries and letters from the wider North Staffordshire area for comparison, however these offered a less complete coverage.

The Scotland series, which will not be analysed here simply because of the geographical distance from the other two series. It consists mainly they are mostly consist of diary entries made covered by a single diarist, Richard Wilkes Unett (1765-1815), but offers future interesting opportunities for further analysis alongside the records of Margret MacKenzie of Delvine, Perthshire (Wheeler, 1994). Unett travelled extensively with the military, with records according to his current posting. Although originally from Staffordshire, much of his diary material records life in Scotland or London. He kept a daily journal recording brief notes about his daily activities, the weather, his health and the state of his garden. Interestingly, a small section of journal with weather reports was kept by his father Thomas Unett also survives, but only for June of 1774 (SRO D3610/4). Unett's diary entries are generally short and factual, with information relating to the weather easy to identify and extract.

Two sections of collected data were selected for further analysisanalysis:s. Those from London (1797-1801) and North Staffordshire (1816-1865). These series which contain overlapping accounts from different sources, and permit an assessment of how many weather records are needed per month for the greatest reliability. The shorter series for London was used to test different types of indices and the Trentham series was used to evaluate how well the most successful indexices systems from the London tests could be used over a longer time periodperiod.

3. Indices and Instrumental Rainfall Data

No single indexices system is universally used with daily weather datawhen converting qualitative weather information into quantitative data, although often most use either a 5 or 7-point scale, such as that used by (Nash et al., (2016) is utilised. Indices to date are generally not used for daily weather data, although Brázdil et al. (2019b) calculated daily monthly days of rainfall for a set of weather diaries and converted these to a 7-degree indices index using a regular distribution of ranked monthly totals (assigning the highest and lowest 8.3% of values an index value of 3 or -3, and assigning a further 16.6% of values to each of intermediate index numbersclasses, as suggested by Pfister (1992)).. Since these indicesthis type of index reliesy on the concept of 'normal', theseey can beindicesey are difficult to apply to daily weather data, particularly when working with subjective personal accounts. Within this study overlapping daily weather data from different sources awere studied, so for a given year there may be >700 statements. The indexices therefore neededss to be easy to apply, to quantify daily rainfall, and be able to be and a system which quantifies daily rainfall and/or temperature is needed, which can be averaged for months with greater/fewer records. The system applied by Macdonald et al. (2010) uses an indexices from 0 (no rain, hot/drought) to 5 (very wet, storm), this approach was selected for testing (Approach index A). Each record in the London series was given a value from 0-5 following this method. For example, the 6th May 1797, described by Hervey as 'Horrid weather, almost perpetual hail and heavy hail storms' (D6584/C/74) was assigned a value of 5, while the 11th April 1799 'it has been showery all day' (D6584/C/85) was assigned a value of 3. The 9th July 1801 described by Richard Wilkes Unett as 'A very hot summers day' (D3610/12/3) was assigned a value of 0. Additionally, an indexice based on days of rainfall per month was considered, as used by several previous studies is also considered (for example Ayre et al., 2015; Brázdil et al., 2019b; Lee and MacKenzie, 2010). Two versions of this index are tested; one which that assigned each day a value of 0 for no rain, very light rain or fog or, and a value of 1 forto any any considerable rainfall (index B) and a second which that introduced nuance, aiming to capture the heaviness of the rainfall (index C). Index C assigns a value of(i.e. by assigning a value of 0 to no precipitation, 0.25 to very light rain or heavy fog, 0.5 to showers or light rain and 1 to heavy rain) (index C). For example, usingFor index method B, each record in the London series was given a value of 0 for no rainfall/ very light rain/ occasional showers, and a value of 1 for anything from showers to heavy rain.the 6th May 1797 and the 11th April 1799 would be assigned a value of 1, and the 9th July 1801 a value of 0. These indicesis wereas then reassessed using the more nuanced methodindex C, to better quantify the rain where possible. Using classification index C for the three events detailed above, 6th May 1797 is assigned a value of 1, 11th April 1799 a value of 0.5 and 9th July 1801 a value of 0. This gave three classification systems of indices for consideration with the weather records from London, systemsindex: A (after Macdonald et al., 2010); index B (based on days of rainfall) and index C (based on days of rainfall with consideration of heaviness of rainfall). There was insufficient data for London (only 56 months) to test the impact of converting into a 7-degree classification following the methodology of Brázdil et al. (2019b).. .

It is important to verify the data, through comparison of indices and instrumental rainfall wherever possible (Brázdil et al., 2018). Fortunately, analysed and homogenised precipitation series covering the period of the diaries are available from sites with ~50km of the London diary locations.

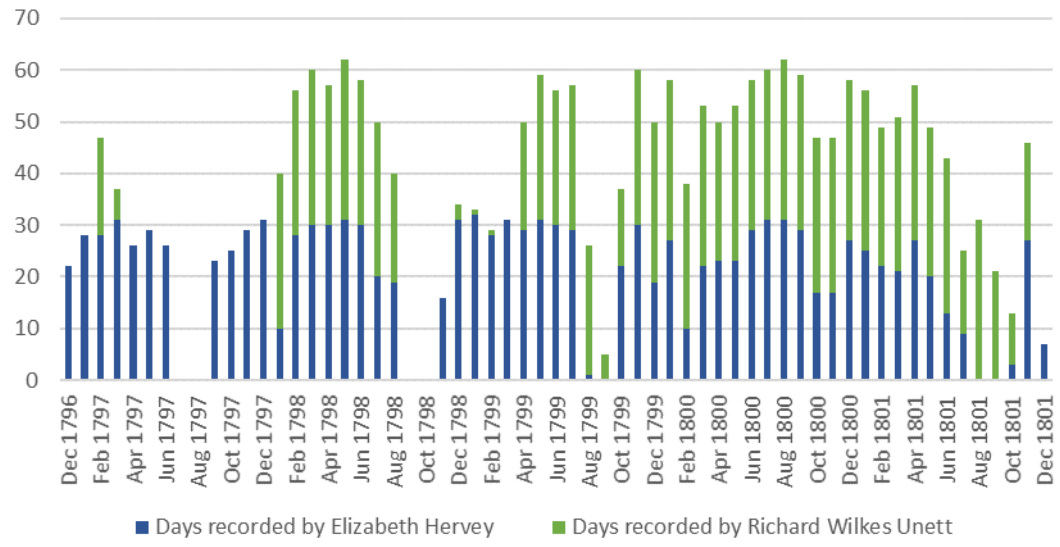
For London the nearest instrumental rainfall data covering this period comes from Kew Gardens (Todd et al., 2013). The greatest number (692) of the London records are from Elizabeth Hervey's home at Acton, (~2km (all distances from Kew)). There are also~~,~~ 540 records from an unspecified location in London (although in most cases this is likely to central London, (~15km), 533 from Woolwich (~30 km), 51 from Strawberry Hill (~5km), and a further 13 from various places around the Greater London area (Croydon, Plumstead, Shooters Hill, Turnham Green, Twickenham; Figure 1). The area is relatively ~~flat~~flat, and the weather recorded in the diaries of Elizabeth Hervey at Aston and Richard Wilkes Unett at Woolwich~~, is~~are generally very similar. For example, on the 10th March 1798 at Woolwich Richard Wilkes Unett wrote that it was 'A fine day. About 8 in the evening it began raining.' (SRO D3610/12/3), while at Acton Elizabeth Hervey wrote 'A beautiful morn[ing]… It rained violently this even[ing].' (SRO D6584/C/79). There are, however, occasions when Elizabeth Hervey compares the weather at her home in central London with the weather at Acton and identifies differences in rainfall. F~~, f~~or example, on the 31st May 1798 when she writes 'A morn[ing] that threatens rain… Tho' much rain fell here to day and yesterday, there was scarcely any at Acton, so that my Hay has not suffered at all' (SRO D6584/C/81). As most of the non-instrumental rainfall data for London comes from ~~very~~ close to Kew Gardens, it is expected that there will be a high degree of correlation between the indices and ~~the~~ recorded rainfall.

For the Trentham series, the nearest instrumental weather station is Chatsworth House in Derbyshire (Harvey-Fishenden et al., 2019) ~50km away, however Chatsworth is located i~~o~~n the ~~other side of the~~ Peak District ~~-~~(Figure 1), so the Trentham data was also compared to rainfall from Manchester (~55km) and Liverpool~~-~~ (~70km) (both Macdonald, unpublished). It is likely that the correlation between rainfall at Trentham and instrumental weather stations will not be as strong as the rainfall at Kew and London~~.~~. This ~~simply a reflection of~~mainly reflects the distance and topography between recorder and instrumental station, though there may be seasonal variations reflecting precipitation generating mechanisms. There is a good correlation between rainfall for the period 1816-1865 at Chatsworth and Manchester ($r = 0.655$, $p = <0.001$), Chatsworth and Liverpool ($r = 0.637$, $p = <0.001$) and a strong correlation between Manchester and Liverpool ($r = 0.875$, $p = <0.001$).

The role of snowfall is challenging to quantify and assess (Manley, 1958a), however long snowfall records are currently receiving renewed interest (Spencer et al., 2014), particularly within early records and long series (Murphy et al., 2020). I~~, i~~n London a long snowfall series reconstructed by (Manley, 1958b, 1969) from 1668-1960 exists for consideration, with the series currently being updated and reanalysed.

4. Testing Correlation with Instrumental Rainfall Data for London

For 36 of the 61 months of the London series both Elizabeth Hervey and Richard Wilkes Unett were~~are~~ in London and keeping their diaries. During the period 1796-1801 (Figure 2), there are four months ~~are missing all~~with no records (July and August 1797, September and October 1798), three months had less than 16 days weather recorded (September 1799, October 1801 and December 1801) and a further nine months had less than 28 days recorded (December 1796, April 1797, June 1797, September 1797, October 1797, November 1798, August 1799, July 1801 and September 1801). The period analysed has a total of 2379 daily weather descriptions, each of which was given an indexi~~ces~~ score using the three different index classification systems.



~~Figure 2. with edDays in at London from the two diarists Elizabeth Hervey and Richard Wilkes (Dec 1796-1801)~~

Initially any month with at least 16 days of weather data was included. Subsequently, t~~, however t~~he process was ~~subsequently~~ repeated with only months including at least 28 days, ~~this enabled~~enabling an analysis of the results sensitivity to record density. 16 days was initially selected as it represented >50% record for any given month and potentially accounts for the absence of records where the diarist may not have recorded the weather~~,~~ as it was considered ~~not particularly~~un-remarkable relative to the previous day(s). 28 days was selected as the maximum number of days that could be required, without systematically excluding February from the analysis.

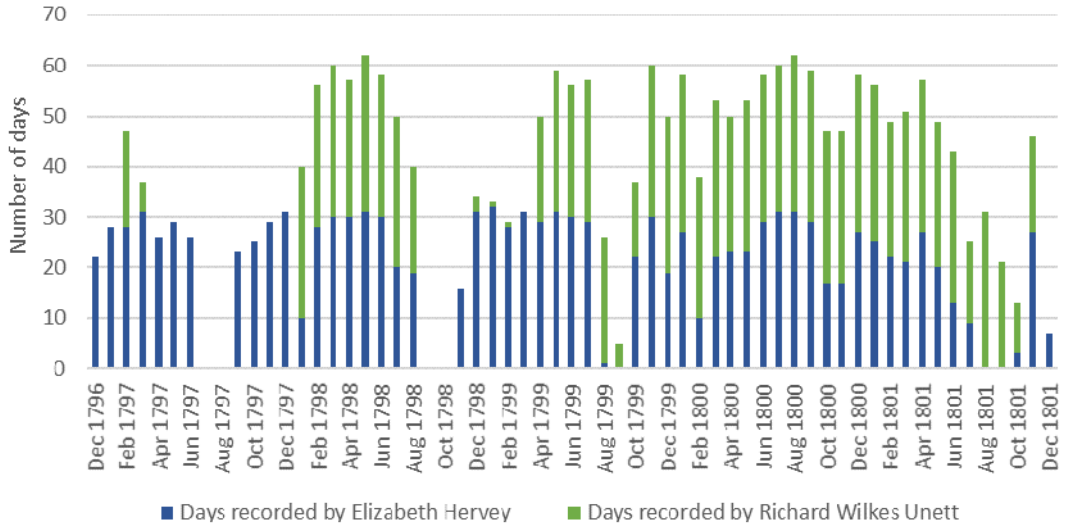


Figure 2. Number of days with weather recorded in London from the two diarists Elizabeth Hervey and Richard Wilkes Unett (Dec 1796-1801)

As different numbers of days are recorded per month within the diaries, ~~to aid comparison~~ these were standardised to aid comparison. The sum monthly~~daily~~ index value was calculated (the total of the daily index values for the month added together), ~~and then~~ ~~with~~ ~~each day~~ and then ~~was~~ divided by the number of documented days within the month. Subsequently, this was ~~and~~ multiplied by the total number days in that calendar month. For example, using ~~(e.g. using~~ index classification A for the month of December 1796, the sum 0-5 index score for each day was calculated (49), with 22 days of records that month from a possible 31~~)~~, so 49 was divided by 22, and then multiplied by 31 to get a scaled monthly value of 69~~)~~. The monthly values for each of the three ~~index~~ices ~~systems~~indices being assessed and ~~each of the~~ both of the for both data threshold levels (16 and 28 days) was plotted (Figure 3a-f). All correlations were significant ($p = <0.001$) using Pearson's product-moment correlation co-efficient (r). ~~C, with classification~~Index C with 28 days or more of data per month produced the best result (Figure 3f). Correlations between descriptive account were better than some of those between ~~neighbouring~~ instrumental weather stations (e.g. Manchester and Chatsworth). The strong relationships identified reflects the close proximity of Elizabeth Hervey's house to the Kew instrumental series, ~~but provide~~increasing confidence in the approach ~~by indicating that the methods of indexing the weather records produce a good estimate of the rainfall~~. Each of the classifications assessed produced good correlations, which were comparable or stronger than those found by similar studies, ~~e.g.~~ Linderholm and Molin (2005), for example, analysed the relationship between summer weather reconstructed from a Swedish diary and tree rings ($R = 0.59$), while Zhang et al. (2013) considered 20 years of overlapping qualitative information with instrumental data ($R = 0.67$). The strongest correlation identified (with both 16 and 28 days) was using ~~classification~~ index C, therefore this approach was selected for ~~trialling~~ assessing on the longer dataset at Trentham.

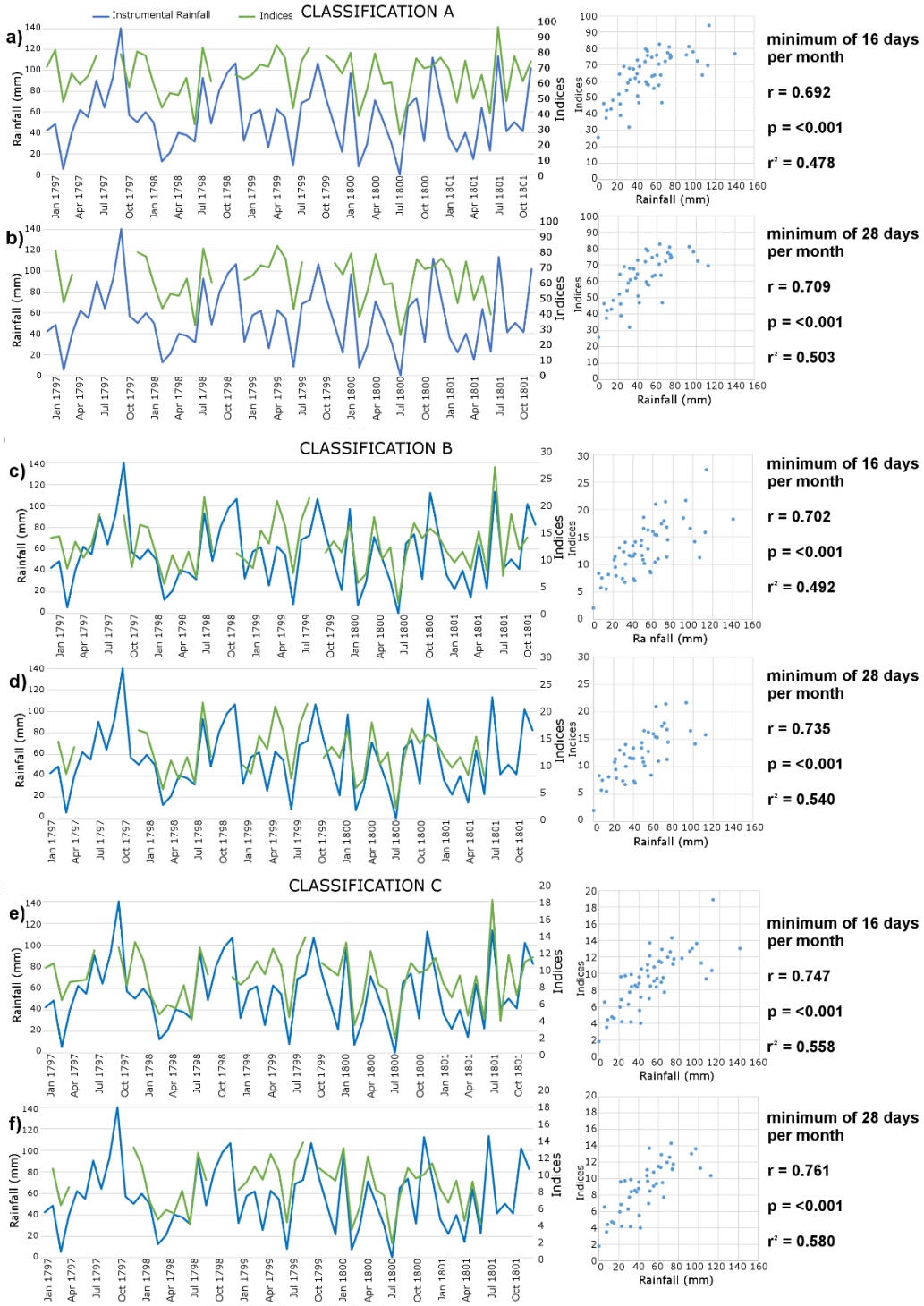
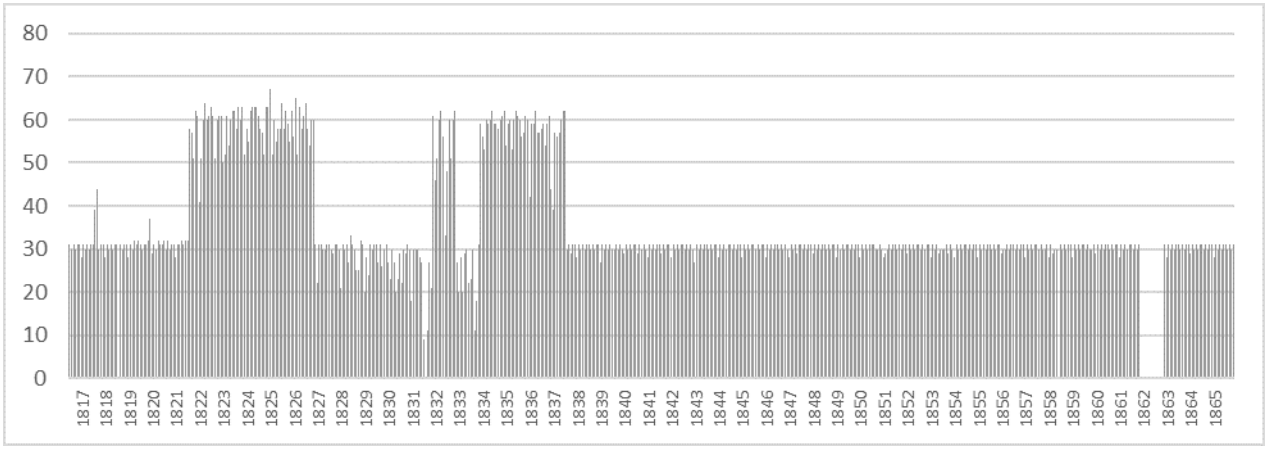

Instrumental Rainfall
Indices
CLASSIFICATION A
a)
Rainfall (mm)
Indices
Rainfall (mm)
minimum of 16 days per month
r = 0.692
p = <0.001
r² = 0.478
b)
minimum of 28 days per month
r = 0.709
p = <0.001
r² = 0.503
CLASSIFICATION B
c)
minimum of 16 days per month
r = 0.702
p = <0.001
r² = 0.492
d)
minimum of 28 days per month
r = 0.735
p = <0.001
r² = 0.540
CLASSIFICATION C
e)
minimum of 16 days per month
r = 0.747
p = <0.001
r² = 0.558
f)
minimum of 28 days per month
r = 0.761
p = <0.001
r² = 0.580

Figure 3: Statistical analysis of the three classification approaches A-C (**green**~~**blue**~~) using 16 (a,c,e) and 28 (b,d,f) day records respectively compared to instrumental rainfall at Kew (**blue**~~**green**~~) ~~London Rainfall using 3 different indicesexes (A-C), a,b,c,d,e and f a) 16 days index A; b) 28 days index A; c) 16 days index B, d) 28 days index B, e) 16 days index C, f) 28 days index C.~~

54. Analysis of the Trentham Records for North Staffordshire

~~Compared to the London weather information analysed (Figure 3), there~~ There is considerably more data covering a longer timeframe for Trentham in North Staffordshire (nearly fifty years from August 1816 to December 1865), compared to the London weather information analysed (Figure 3). ~~The Trentham series spans nearly fifty years, from August 1816 to December 1865.~~ Overall, there were 20,657 weather records for Trentham for this period. Each of these records was~~, with each account~~ assigned a value from 0-1, following ~~classification~~ index C ~~as tested with the London data~~.

The threshold for inclusion in the analysis at Trentham was set at 20 days per month. W~~, w~~hilst two levels were assessed in London, with more days (28) presenting a stronger correlation with the instrumental precipitation series, selection of the higher threshold at Trentham would leave several gaps and 45 months missing. ~~, including 1827-1833 (apart from 1832, William Lewis's memoranda book and letters are the only available source material), September 1818, September 1831, July 1858 and the whole year for 1862.~~ Therefore, the threshold was lowered to 20 days. T~~, t~~his pragmatic reduction in threshold resulted in greater temporal coverage, with the results from London suggesting the impact on correlation would be relatively limited (Figure 3e compared to 3f). O~~, with o~~nly 20~~five~~ months contain~~ed~~ing insufficient records to meet the revised lower threshold. All records for 1862 are missing, as are September 1818, September 1832 and July 1858. ~~,~~February 1831 (which only had 18 days), August 1831 (9 days), October 1831 (11 days), October 1833 (11 days) and November 1833 (18 days) were also excluded from the analysis (Figure 4).



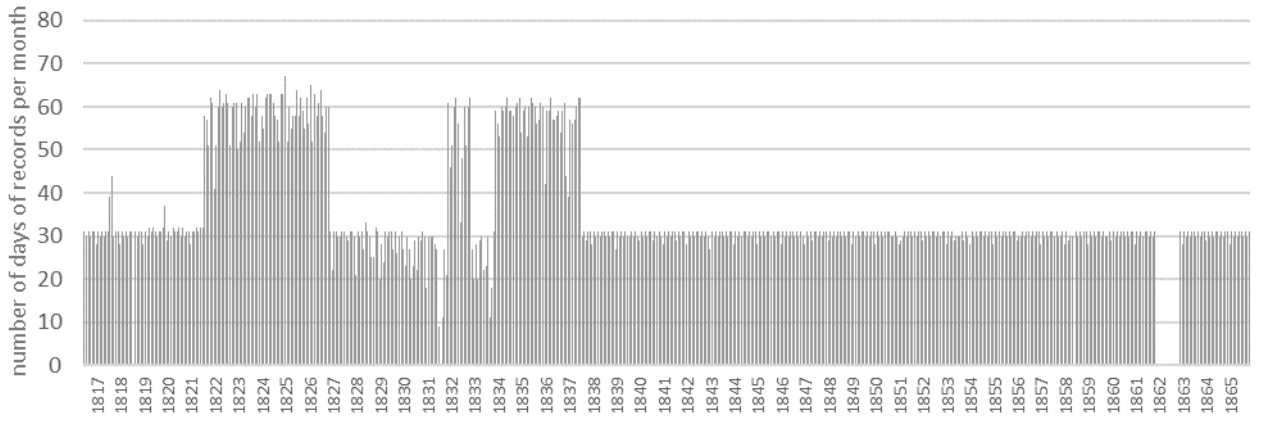


Figure 4. Number of r~~R~~ecord~~sed number of diary entries s~~ of daily weather per month at Trentham (August 1816-1865)

The resulting ind~~ic~~exs were compared to the instrumental precipitation series from Chatsworth, Manchester and Liverpool (CML). All three showed significant correlation (p = <0.001), with Chatsworth the weakest (r = 0.579), Manchester (r = 0.664) and Liverpool (r = 0.667) stronger (Figure 5: 1a, 2a and 3a respectively). There is an even stronger correlation between the average of all three instrumental stations and the ind~~ices~~ex generated at Trentham (r = 0.706, p = <0.001~~; Figure 5: 1b, 2b and 3b respectively~~); a potential explanation may be that averaging has a smoothing effect on the data, reducing/removing localised extremes. While notable wet and dry periods in the instrumental precipitation series ~~(Figure 6)~~ correspond well with the Trentham ind~~ices~~ (as demonstrated in Figure 6), there are discrepancies in the distribution of data. There are much greater extremes of heavy rainfall seen in the instrumental precipitation from Chatsworth, Manchester and Liverpool (Figure 5: 1b, 2b and 3b respectively). E~~, as e~~xtremes are hard to capture from descriptions in archive documents, because of different people's perceptions of heavy or light rain, and the potential for observers to mi~~s~~s~~-~~describe the weather if they have spent key periods of the day inside, or if the heaviest rainfall happened over night.

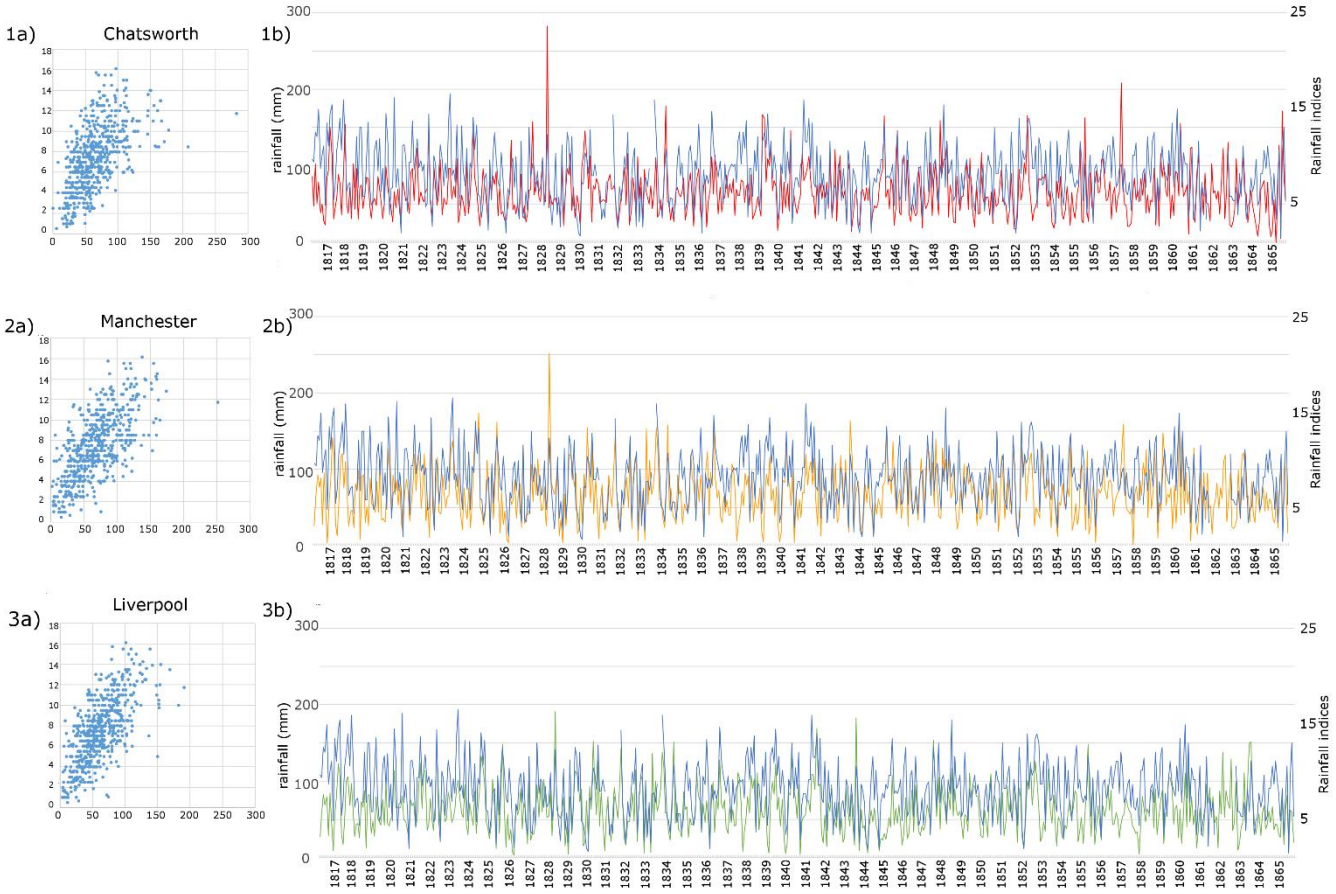
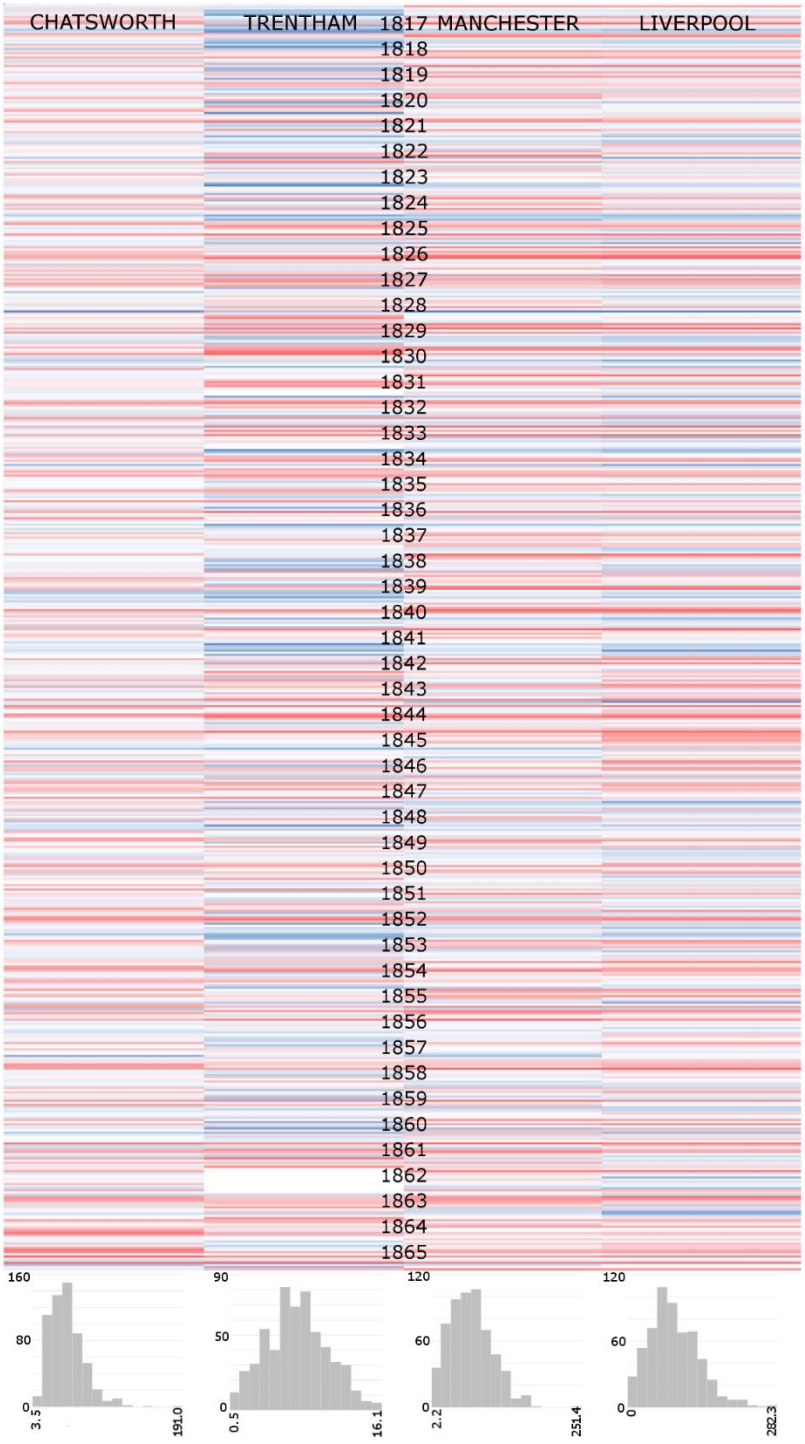


Figure 5. ~~Trentham Rainfall Indices alongside instrumental rainfall from Chatsworth, Manchester and Liverpool.~~ **1a**) ~~shows the~~ **correlation between** ~~the~~ **Chatsworth rainfall** ~~and~~ **the Trentham indi**~~ce~~**exs** **series** ~~(blue line, secondary axis),~~ **(r= 0.579**~~:~~ ~~(~~**p= <0.001); 2a**) ~~between~~ **Manchester** ~~orange~~ **rainfall and Trentham ind**~~exices~~ **series** ~~(blue),~~ **(r= 0.664**~~;~~ ~~(~~**p= <0.001); 3a**) ~~between~~ **Liverpool rainfall and Trentham** ~~indices~~**index** **series** ~~(blue):~~ **(r= 0.667**~~;~~ ~~(~~**p= <0.001)**~~,~~ 1-3b). ~~1b, 2b and 3b plot the Trentham indices against the recorded rainfall at Chatsworth, Manchester and Liverpool respectively.~~ Comparison of the Trentham rainfall index (blue) alongside instrumental rainfall from Chatsworth (red), Manchester (orange) and Liverpool (green) respectively.


CHATSWORTH
TRENTHAM
1817
MANCHESTER
LIVERPOOL
1818
1819
1820
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1860
1861
1862
1863
1864
1865
160
80
0
3.5
191.0
90
50
0
0.5
16.1
120
60
0
2.2
251.4
120
60
0
0
282.3

275 9

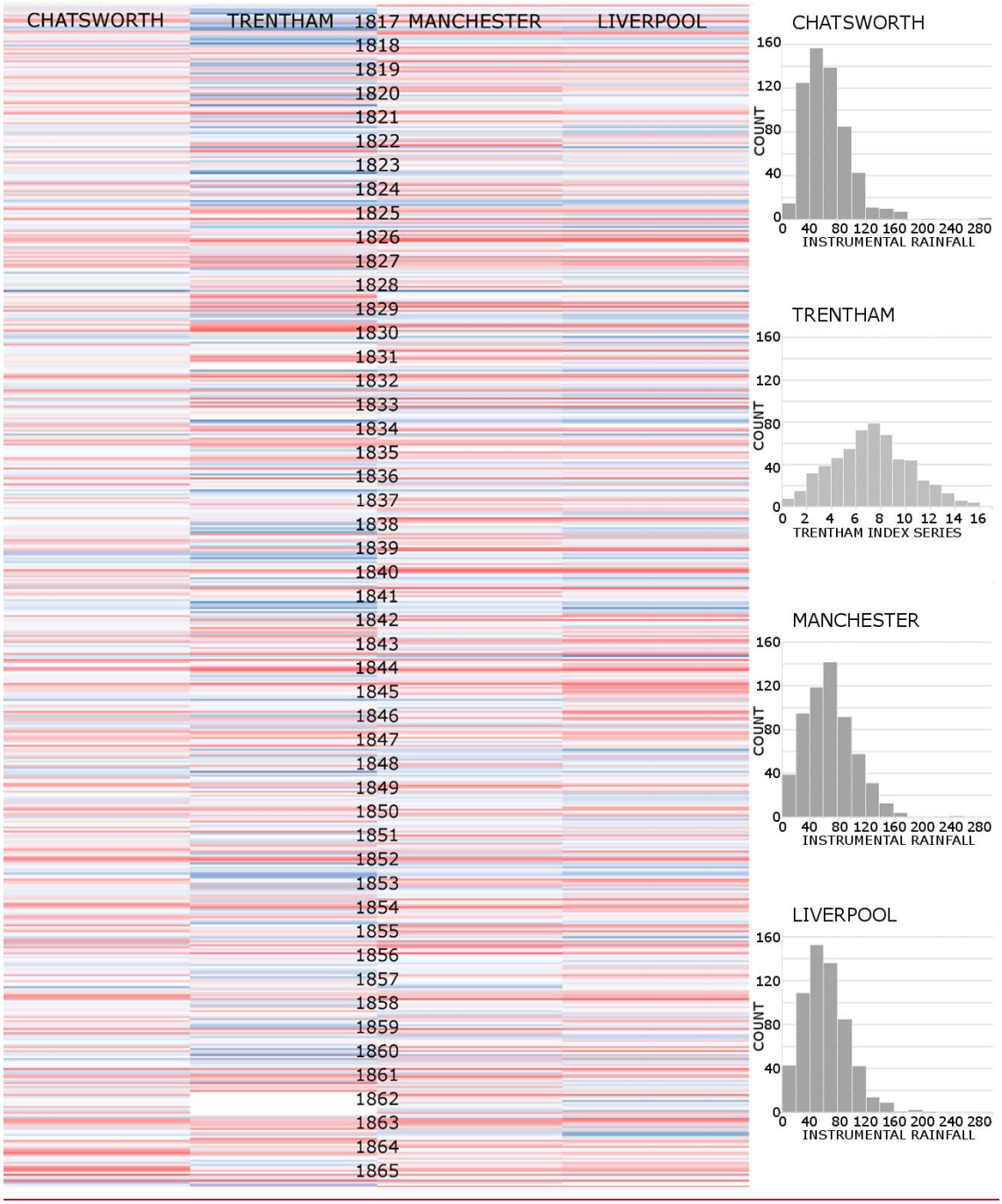


Figure 6. Wet (blue) and dry (red) months August 1816-December 1865, with distribution (note data for 1862 at Trentham is missing)

An assessment of the methodology applied by ~~Brazdil~~Brázdil et al. (2019b) ~~(~~using the ranking of the months by days of rainfall, and giving them ~~indices from~~ values from -3 to 3 was undertaken, with 8.3% of the months receiving the most extreme index values~~ices~~ (-3 and 3), and all other indices (-2 to 2) being applied 16.6% of the months~~)~~. However, t~~T~~his was determined to be

undersirable as it resulted in a loss of detail and slight reduction in the correlation with the instrumental series from Manchester (r=0.65, p= <0.001).

65. Extreme Weather: Indices as Recorders of Snow, Rain and Droughts

Extremes present challenges even within instrumental series, whether it is defining the absence, excess or form of precipitation, with considerable efforts still being made to improve and reliably identify extremes in instrumental rainfall (Archer and Fowler, 2018; Miller et al., 2013) and snow measurement (Kay, 2016). These same challenges exist within descriptive accounts of the weather, whilst general wet and dry phases are reliably captured, extremes, or at least the extremeness of rainfall can be difficult to capture.

65.1 The problem with snow

There has long been an awareness of the challenge of under-catch in the early instrumental records. In 1891, George James Symonds (founder or the British Rainfall Organisation) spoke about the history of rain gauges in an address to the Royal Meteorological Society (Symons, 1891). He noted that prior to introducing the introduction of Snowdon pattern rain gauges in 1864, there was a large under-catch of snow due to absence of a protective rim on the rain gauge. The instrumental data examined here extends to 1865, so (Kew Gardens 1796-1801 and CML 1816-1865) was collected prior to the introduction of these gauges. Recently, work has challenged widely reported long term trends in precipitation for England in Wales, by showing that much of the trend towards wetter winters and drier summer can be explained by under--catch in the early record (Murphy et al., 2020). It is important, therefore, to consider the contribution of snow to this datahistoric data. To this end, aAn assessment of snow days and months with snowfall at Trentham was undertaken, as evidenced (Figure 7a). References to snow can be found in these records in the diaries in the months, between October and May. Most years had at least some snow, with the greatest snowfall in January, with an average of 1.9 days, closely followed by March with 1.8 days, and then February with 1.6 days. A, all other months have less than a day of snowfall on average; December (0.9), April (0.8), November (0.5), May (0.2) and October (0.1). Most snow in the records is in winter (December-February), with an average of 4.43 days per winter, followed by the Spring (March-May; 2.76 days) and autumn (September-November 0.66 days). Visual examination of the Trentham indicexs against recorded rainfall at Chatsworth, Liverpool and Manchester showed that months with snowfall tended to have less rainfall in the instrumental record than was suggested by the indicexs.

Separating out the months with and without snow gives a stronger correlation to the Manchester precipitation series for the months without snow (r= 0.71), and a similar correlation for months with snow (r=0.63) (Figure 7b and 7c respectively). The indices are systematically indicating slightly more precipitation than is recorded by the rain gauges. There are four possible reasons for this systematic difference between the records:

i. The potential of under-catch in the instrumental record (e.g. (Murphy et al., 2020).

ii. It might reflect over estimation of precipitation in the Trentham series due to overreporting of snow. Snow is a highly visible weather phenomenon, and therefore might be over reported (Spencer et al., 2014). There is also the complication of whether, when a record says 'snow', ~~whether~~ it is referring to new snowfall, or snow lying on the ground.

iii. It may reflect over estimation of precipitation resulting from the way snow has been translated into any particular ~~indice~~index~~s~~. Snow has been treated in the same way as rain in the ind~~ex~~ex~~ices~~ classification system, but it is possible that it should have been treated more like showers than substantial rainfall.

iv. The potential for greater variability in snowfall between ~~the~~ two sites compared to rainfall, reflecting local topographic and climatic conditions, with a ~~slightly greater capacity for snowfall at Trentham~~higher propensity for snowfall at Trentham (Barrow and Hulme, 2014; Mayes, 2000).

It is likely that a combination of these factors may account for the differences in the two series. The ind~~ex~~ex~~ices~~ for the 138 months with two or less days of snow had a better correlation with the rainfall at Manchester (r= 0.70) compared to the 58 months with more than two days of snow (r= 0.51). When plotted (Figure 7a), many of the outliers come from months with ~~the medium~~ moderate amounts of snowfall (i.e. 2.5-4 days of snow). This~~,~~ suggest~~sing~~ that over reporting of snow (perhaps the reporting of snow remaining on the ground, rather than fresh snow) may be the cause of the lower correlations for the months with more snow.

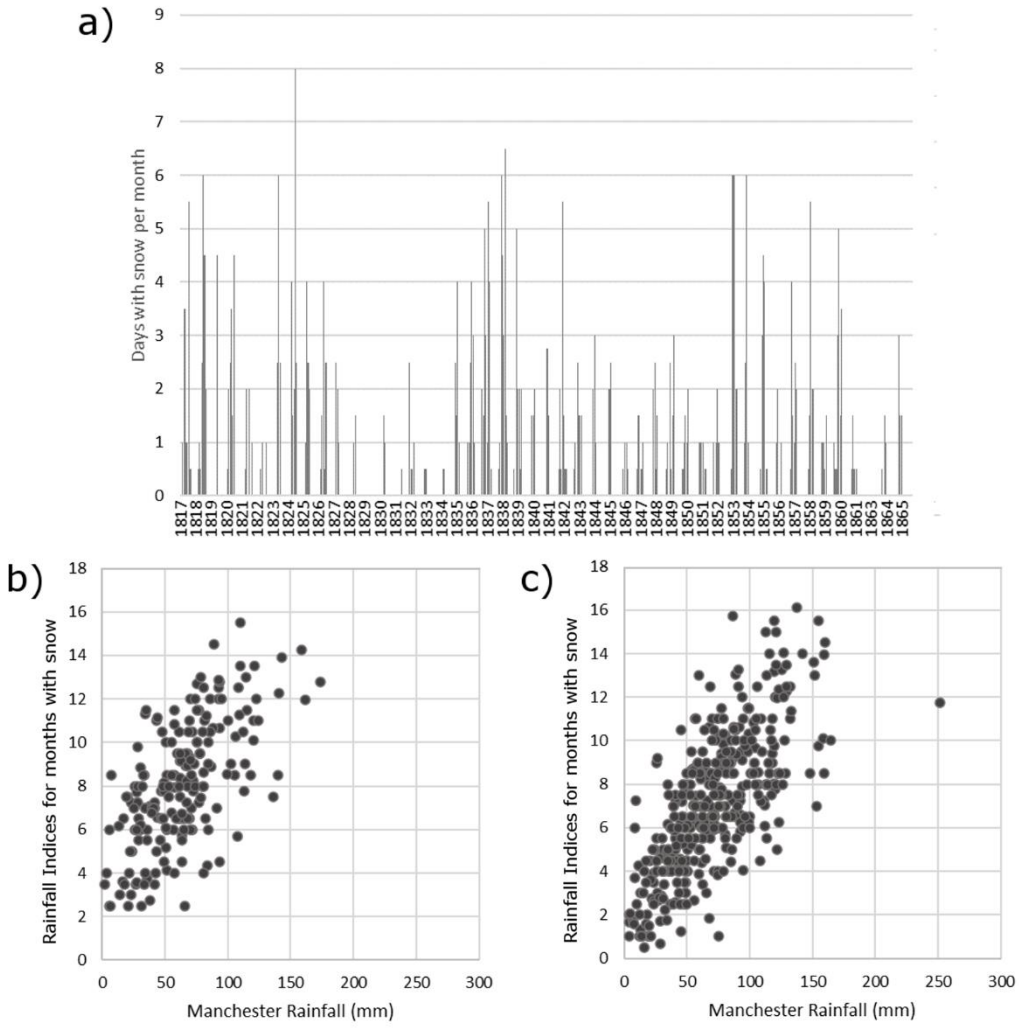
Snow can have severe impacts on farming in the UK (Jones et al., 2012). An example of this can be found in this material from Trentham in the winter of 1819-20; with snow lying on the ground between the 30 December 1819 and the 29th January 1820, with a thaw beginning on the 22nd January causing flooding (SRO D593/K/3/2/2, SRO D593/L/6/2/2 and SRO D593/K/3/2/1). On the 3rd January 1820, William Lewis recorded that the average depth of the snow was 22 inches (0.56m) (D593/L/6/2/2). Lewis's letters highlight some of the impacts of this extended period of cold weather. On the 17th January he wrote:

"The Storm continues and no appearance of any alteration. The Snow has been ever on the ground which causes both Sheep and Cattle to be fed out of doors with every morsel they consume" (letter sent by William Lewis to James Loch (SRO D593/K/3/2/2).

While towards the end of the episode he records that:

"[T]he severe weather has completely put all out door work at a stand for some weeks which is the cause of the present distress [amongst the parishioners] a moderate thaw has now taken place which I trust will continue" (letter from William Lewis to James Loch, 23rd Jan 1820 SRO D593/K/3/2/2).

The long-~~-~~lying snow led to underemployment (Lewis notes that he will take on more labourers for ditching and draining when the weather allows), and higher costs in cattle farming. While creating an ind~~ex~~ex~~ies~~ allows weather to be contextualised and compared with instrumental records, the original qualitative weather records tell of impacts and add details ~~that are~~ absent from the ~~indices~~ index alone (e.g. impacts of an event).


a)
Days with snow per month
b)
Rainfall Indices for months with snow
Manchester Rainfall (mm)
c)
Rainfall Indices for months with snow
Manchester Rainfall (mm)

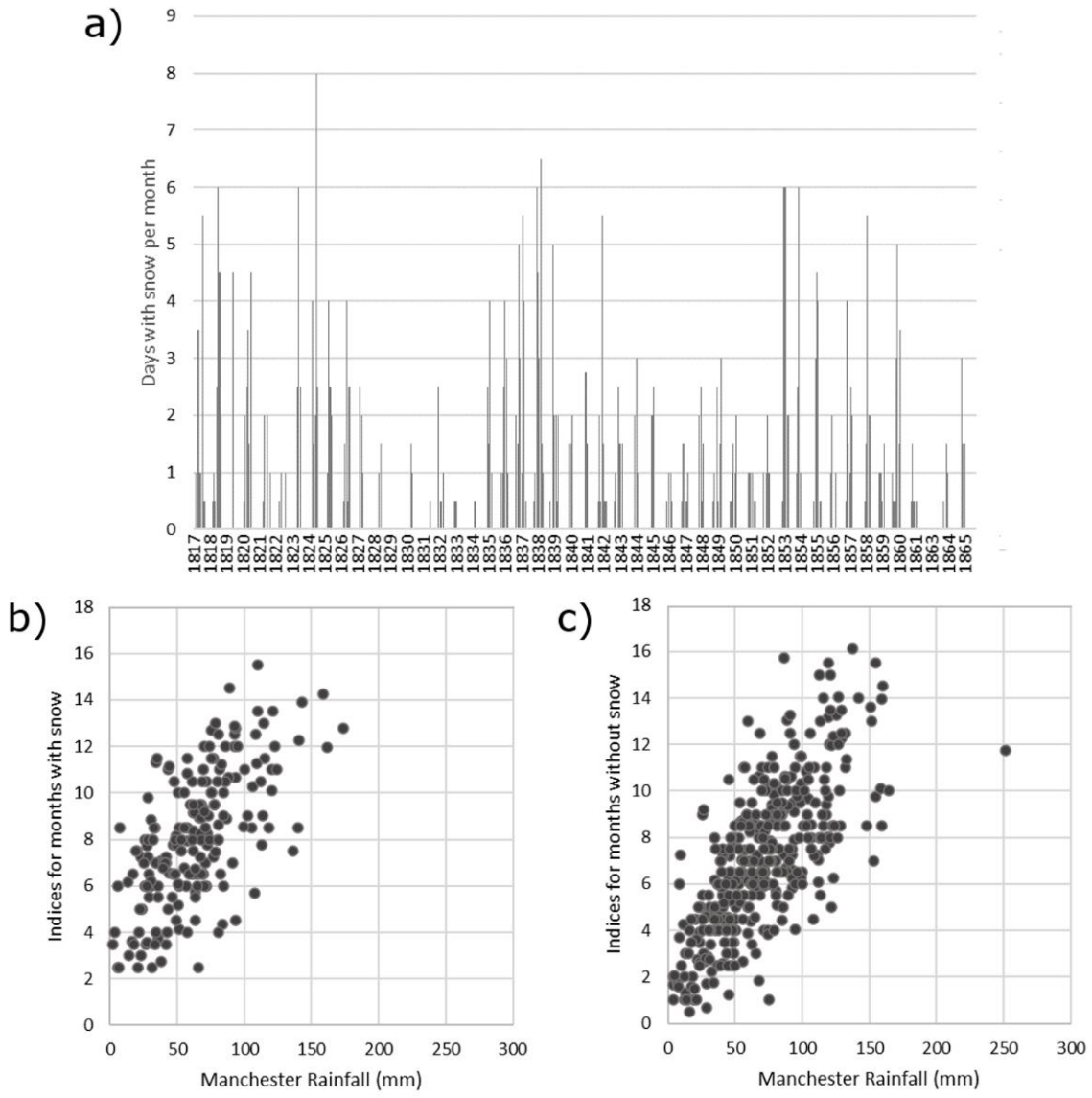


Figure 7. a) Days of snow per month at Trentham (note data for 1862 is missing) and precipitation indexices for months with (b), and months without (c) snow, plotted against Manchester rainfall. For the months with snow r=0.63, for months without snow r=0.71 (for all correlations p=<0.001). ~~Data for 1862 is missing.~~

~~5~~6.2 Heavy rainfall

While an indi~~c~~e~~s~~x may be ~~are~~ good at ~~capturing~~ representing dry weather and moderate rainfall events, ~~they~~ it appears to be weaker at~~for~~ capturing heavy and extreme rainfall. This is an inherent problem of descriptive records, which often lack clear distinctions between moderate to heavy and then extreme rainfall. When a writer describes 'rain' or a 'shower', there is no

way of knowing how much rain fell, or where the threshold between 'shower', 'rain' and 'heavy rain' is. ~~There is a large range in amounts of rainfall which could fall during 'rain' or during a 'shower'.~~ When a lot of rain falls in a short period of time, these ~~ic~~indices will generally underestimate precipitation, since ~~the maximum value that can be given for a day is 1.~~there is a maximum value which can be given for a day (in this case 1). For this reason, studies ~~that have collected~~with similar data have thought it inadvisable to attempt conversion into quantitative values (for example Lee and MacKenzie, 2010). The difficulties in accurately estimating extremes and the problems with trying to convert qualitative information into quantitative values is demonstrated by ~~f~~Figure 8, where ~~; comparison~~ comparison of the ~~of the~~ average of the three stations (Chatsworth, Liverpool and Manchester) and the Trentham indices (Figure 8), to produces a very rough conversion from indexices to rainfall (millimetres) has been attempted~~, and presented alongside the precipitation recorded at the CML stations~~. There are various ways to do this; for example, Zhang et al (2012) used monthly precipitation~~s~~ days to reconstructed the seasonal precipitation for Beijing (1860-1897), by using regression models relating the precipitation and precipitation days based on modern data. In this case, however, since there is nearby contemporary instrumental rainfall data available~~To convert the index, to rainfall (mm)~~ a linear regression is applied, derived from the average of the CML stations rainfall and the ~~index at~~ Trentham index series. Compared to the instrumental data from CML stations the minimum monthly value of the ~~converted indicexs~~rainfall series created from the Trentham ind~~icesex~~ is higher (14.48mm, compared to between 0mm and 3.54mm) and the maximum value much lower (123.78mm, compared to between 190.95-282.35mm) ~~and~~with the standard deviation also lower (21.26mm, compared to between 31.43-35.05mm).

~~-~~Unlike the issues around snow where there are possibly multiple contributing factors resulting in differences between the index series~~ices~~ and recorded instrumental rainfall, it is apparent here that the main issue with extremes of rainfall is around the lack of range in the ind~~icesex~~ series, particularly when it comes to heavy and extreme rainfall. It might, however, be possible to address these deficiencies ~~of the indicexs~~ at representing extreme rainfall by adjusting ~~the indices~~the monthly index values. For example, they might be improved by increasing the values for months with recorded floods, or other severe impacts. This would be similar to approaches undertaken by Brázdil et al. (2019b) ~~in the application of an indicesx,~~ where after applying an ind~~ic~~exs based on ranking of days of rain per month, the values~~y~~ were adjusted to account for months with particularly heavy or light rainfall.

However, taking for example July 1828, this method might not always improve results. In July 1828, 282.35mm rainfall fell at Chatsworth, 251.42mm at Manchester and 190.95mm at Liverpool, whereas Trentham only experience 11.75 days of rainfall (which ~~using a simple regression to convert to rainfall equates to~~ using this method of conversion gives 94.07mm). It seems likely, therefore, that this is a substantial underestimation of the rainfall caused by above average rainfall on multiple days. There are six 'very wet' days mentioned in the diary descriptions, but no severe impacts of wet weather that might ~~that, which might flag~~ indicate a need for this month to be adjusted. The only impact mentioned is a delay in 'getting in the hay' (SRO D593/L/2/2b), which could be caused by even mild wet weather. For the current data, it is hard to see how any methodology based on impacts would flag this month as one meriting adjustment.

Figure 8. Rainfall (in mm) at Chatsworth (red), Manchester (yellow) and Liverpool (green), and an estimate of the rainfall (in mm) at Trentham (blue) based on the index conversion.

From the perspective of quantifying and comparing rainfall, therefore, conversion to millimetres ~~does~~ using this approach may create a ~~not create a useful~~ dataset or limited utility and ~~is~~may also be unnecessary. F~~; however, f~~urther analysis, however, may explore a more probabilistic fitting approach based on a predefined distribution, possibly from local contemporary instrumental records, to better define upper and lower bounds, although this is beyond the scope of this paper. To better quantify and compare rainfall across instrumental and non-instrumental records, it would be interesting to compare the number of days of rain per month within the instrumental record with the days in these diaries, and to investigate the amounts of rain per day in the instrumental record. Unfortunately, most of the surviving instrumental records for this period only contain monthly totals, and do not include~~not~~ daily totals nor records of the number of days of precipitation.

~~5~~6.3 Droughts

There are several droughts ~~which have been~~ identified elsewhere in the literature ~~which~~ that occurred during the period covered by the records from London and Trentham. In London~~First~~, there is a drought period identified by Todd et al. (2013) between 1801 and 1808. T~~8; t~~he most severe drought episode begins in September 1802 at Kew~~,~~ however it is preceded by conditions fluctuating between normal and rainfall deficit. This period of dry weather preceding drought onset is evident in the qualitative records from London. On the 20th July 1800 Elizabeth Hervey reports that 'ground is sadly parched' (SRO D6584/C/93) and on the 25th July 1800, she writes that there is 'Still burning weather the leaves fall as in winter' (SRO D6584/C/93). The leaves falling from the trees is corroborated by Richard Wilkes Unett, who on the 24th September 1800 wrote 'Owing to the very dry weather in July, most kind of trees lost their leaves the same as in October' (D3610/12/3 p139). Notably low rainfall in the Kew series of 7.9mm in February 1800 and 0mm in July 1800 is reflected in the indices for London, although the low value in February 1797 of 5.6mm is not captured ~~as well~~particularly ~~-~~well within the indices.

In terms of the Trentham record, droughts are recorded at Chatsworth in 1821, 1826-8, 1835-6, 1844-5 and 1847-8, all of which are relatively minor droughts, within the context of the long drought series available (1760-2015; Harvey-Fishenden et al., 2019). The farm and wood-ranger reports accompanying~~, which accompany~~ the weather information recorded at Trentham ~~,~~ mention drought in Spring 1817, writing that the 'trees planted this spring are suffering much from the extreme drought, except the Mountain Ash planted in Trentham coppice which having a cool soil, and being shaded by the larger oaks are looking very well' (D593/L/6/2/2). The CML series all show low rainfall in January 1817, March 1817 and April 1817, while the Trentham ind~~eiexes~~ show dry weather in January and April 1817 and a wet March. This reflects the challenge of truly capturing a 'drought' accurately following precipitation, particularly using historical descriptive accounts~~ truly capturing a 'drought' accurately following precipitation.~~, ~~as~~ A~~a~~ short phase of rainfall may offer some respite, but may not formally terminate a drought event as defined and classified using drought indices. The dry weather may no longer have an agricultural or water resource impact but may still technically be a meteorological drought.

Neither the 1821 drought nor the 1826-8 drought are reported as severe weather events in the archival records, with no adverse drought impacts ~~are~~ reported at Trentham. The dry weather in 1821 seems to have led to abundant crops and fine weather, whereas in 1826-8, diary entries are focused on the day to day running of the farm and fail to identify any negative impacts ~~there is no entry assessing the wider impact~~ of the weather. There are two other droughts ~~which occur during~~within this record; 1835-1836 at Chatsworth, lasting 16 months, with a peak severity of -1.0 (using the Standardised Precipitation Index) in August 1835, and 1844-1845 at Chatsworth, lasting 15 months with a peak severity of -1.5 in March 1845. Once again, although dry, there is no comment on the weather or its impact in these records from Trentham.

~~5~~6.4 Other extreme weather

One of the strengths of multi-source qualitative recording is that sometimes the overlap between different archival sources can tell you more about the impacts of extreme weather than any one document alone. For example, a letter sent 26th June 1824, from William Lewis to James Loch about the impacts of a storm, ~~which~~ reads:

"In my last I forgot to name to you that we had a severe Thunder storm on Monday last and the lightening (sic) killed six Deer under a Tree close by the reservoirs & the Day following a cow at Corn Croft be-longing to one of Mr Lord's labourers" (D593K/3/2/6).

Accordingly, in the monthly report for June 1824 at the Trentham estate, we see an entry for the previous Monday, the 21st June reads 'Thunder and Rain'. In the accompanying Park Keepers report for the same month, it notes that 1 buck and 5 does were killed by lightning (although does not give a date) (SRO D593/L/6/2/2). ~~Examination of~~ William Lewis's own memoranda book for the same date, however, ~~details that he~~ merely notes 'a very dull morning' (SRO D593/L/2/2b). The different sources tell complementary stories; the letter identifies ~~which~~ the event that killed the deer, but not the date, the monthly report gives the date for the storms, but does not state which storm killed the deer. William Lewis's memoranda book does not even mention the event at all. The notes on the weather kept by William Lewis appear to have generally been made quite early in the morning, and he appears to sometimes revisit the previous day to update it with later changes in the weather, but sometimes, as in this case, fails to do so.

Descriptive accounts can also provide valuable insights relating ~~in~~ to weather events that are poorly recorded in early-instrumental records, such as tornado~~'~~s, mists, fog, haars and lightning storms, with documentary sources offering a valuable tool in creating long reconstructions (e.g. Camuffo et al., 2000).

~~7~~6. 'The Year without a Summer' (1816) in Staffordshire

In April 1815, Mount Tambora in Indonesia erupted, with impacts around the world (Pfister and White, 2018a)~~.~~, 1816 has been described as the 'year without a summer' by several authors (Stothers, 1984; Veale and Endfield, 2016; White et al., 2018), with the impacts of the Tambora eruption on weather extensively recorded across Europe. The diaries of Elizabeth Hervey offer considerable potential for examining its impact from a different perspective, that of a female traveller, as she travels around Europe during the summer 1816.

It is unfortunate that the Trentham record misses much of this 'summer', beginning~~s~~ in August 1816, as it fails to capture the potential impacts of the Tambora eruption on the day-to-day running of~~for~~ the farm~~, as the daily reports since it misses much of this 'summer'~~. ~~However~~ ~~It is possible, h~~However, the fact that the farm reports and memoranda book start part-way through 1816 may ~~may reflect on~~ reflect~~s~~ a desire to record farm experiences based on an unusual year at that point. June saw some of the worst impacts across Europe, with anomalously cold and wet weather (Luterbacher and Pfister, 2015). There have been

several attempts to use diaries from this period to examine the effects of the Tambora eruption in the UK., such as Lee and MacKenzie (2010), for example, who used a farmer's diary from near Manchester (~5km away), which is (about 50km north of Trentham),, which recordedith –wind direction, barometric pressure and observations of weather and other phenomena recorded (including red skies), to examine the impact of the Tambora eruption. The Trentham records primarily record rainfall, and there are no descriptions of non-weather phenomena, such as red skies. Veale and Endfield (2016) also used diary sources to situate the year 1816 within a UK context. They describe the general pattern of the weather nationally (UK) around this time; Iin August much hay was spoilt by rain, September was cold and frosty, there were floods in October, while November was wet and very cold (Veale and Endfield, 2016). These conditions led to food shortagesshortages and following on from this ; with 1817 is described as having the fourth successive cold and sunless spring, and also being dry (Veale and Endfield, 2016). There was a heatwave in June, with July, August and September wet. The Trentham records , primarily document rainfall, and there are no descriptions of non-weather phenomena, such as red skies identified in other sources. The records from Trentham, however, do support some of the overall narrative put forward by Veale and Endfieldthis; with August to December 1816 are all relatively wet months at Trentham. This, hThis is at odds, however, differs fromwith the instrumental records from Manchester and Liverpool, with August quite dry (although it is wet at Chatsworth), and September and November are either dry or average at instrumental stations. In October (1816) the Trentham farm reports state that 'grain of all descriptions much injured by the inclemency of the weather', however other crops such as beans and turnips seem to have given normal yields (D593/L/6/2/2). There is, therefore some variance in these records from the gerenal picture presented by Veale and Endfield.

The weather patterns accounts identified by Veale and Endfield (2016) for 1817 are replicated in the Trentham records. March at Trentham has five full days of snow, or 'snow, hail and rain', and a further evening of rain and snow, although it appears to have only been a few inches deep. There were also fine days, some 'gentle showers' and one day which is described as 'fair very mild'. April has ten days which aredescribed as 'Fair cold', three which are 'fair very cold' and one which was 'very cold with a little snow'. There also fair days and drizzly days. In May there are three references to it being cold and four occurrences of hail (SRO D593/L/6/2/2). The spring months are therefore generally, although not universally consistent with the overall pattern described by Veale and Endfield (2016). The heatwave as reported lasted from the 19th 25th June; at Trentham the 19th to the 26th June are described as 'very hot', with several thunderstorms. Nationally, July, August and September were generally wet (Veale and Endfield, 2016), however, Trentham, Chatsworth, Manchester and Liverpool follow the same pattern, with July and August wet, but September dry. Generally, the weather records from Trentham seem to fit well with the patterns described by Veale and Endfield for the years following the Tambora eruption, although these years are not statistically different from preceding years.

~~7~~8. Confidence in Documentary Source Reconstructions

The quantity and quality of ~~data~~ information contained within the sources impact the confidence in ~~on~~ any derived index classification~~ices~~. A particular issue with diaries is that, when incomplete (not-daily), they tend to only report more notable~~extreme~~ events and, in the UK and northern Europe, are biased towards snow and rainfall ~~in the UK and northern Europe~~. Globally,~~However, a~~ biases towards recording extremes are~~is~~ not ~~unknown or~~ uncommon, but vary regionally. ~~as~~ Nash (1996) noted a preference to documenting droughts in the Kalahari, whilst Endfield and O'Hara (1997) note a similar pattern towards droughts and water scarcity in Central Mexico.~~.~~ ~~For example,~~ Table 1 shows the entries for the first half of December 1807 from the diary of Thomas Birds (in Eyam in Derbyshire, SRO D1229/4/6/7) and James Caldwell (~45 km away at Talke, in North Staffordshire). These demonstrate that James Caldwell is only recording particularly extreme days, and does not report on 'fine' days, and if we were to ~~produce an indices~~ use~~based on both~~ these sources together to produce an index score for ~~the month~~December 1807, this month might look rather colder and snowier than it was. While the London data demonstrates the benefits of having diarists recording simultaneously when producing indices, the source material must record both extreme and normal days.

Much of the collected data from Trentham, from William Lewis's memoranda and the farm reports, does not include impacts, which limits its utility when considering extreme weather, however they do record day-to-day activities such as harvest or ploughing, which may be delayed due to inclement or inappropriate weather.

While there is insufficient information in the documentary records to produce a temperature ind~~ice~~x~~s~~, the Trentham farm reports include temperature measurements, taken at 8am and 8pm from 1821 onwards, while both Elizabeth Hervey and Richard Wilkes Unett had access to a thermometer and occasionally reported temperatures, particularly extremes. There is one day (14th July 1800) in the London series where they both report the temperature. Richard Wilkes Unett writes 'Very close & warm. The glass today in a room where there are three doors was at 75º most of the day' from Woolwich (D3610/12/3 p127), while from Acton Lodge, Elizabeth Hervey writes 'Hottest day we have yet had thermometer 75 in the shade.' (D6584/C/93). Unfortunately, neither of these diarists consistently record the temperature, and because they both lived relatively transient lifestyles, the readings they give are not always from the same thermometer.

Table 1. Diary entries for Thomas Birds and James Caldwell December 1807

Date	Thomas Birds (Eyam)	James Caldwell (Talke)
1 Dec 1807	A fine winters day	
2 Dec 1807	A plashy day & some rain	
3 Dec 1807	A very fine frosty morn	
4 Dec 1807	A most tempestuous wet day	

5 Dec 1807	Showry day	
6 Dec 1807	Snowy day	Snow.
7 Dec 1807	A severe frost	Severe frost.
8 Dec 1807	A most tempestuous snowy day	
9 Dec 1807	A fine day	
10 Dec 1807	A fine day	
11 Dec 1807	A partial thaw at home	At night great fog & Snow.
12 Dec 1807	A fine day continued thawing a little	
13 Dec 1807	A fine day	
14 Dec 1807	A very fine day	

~~While there is insufficient information in the documentary records to produce temperature indices, the Trentham farm reports include temperature measurements, taken at 8am and 8pm from 1821 onwards, while both Elizabeth Hervey and Richard Wilkes Unett had access to a thermometer and occasionally reported temperatures, particularly extremes. There is one day (14th July 1800) in the London series where they both report the temperature. Richard Wilkes Unett writes 'Very close & warm. The glass today in a room where there are three doors was at 75º most of the day' from Woolwich (D3610/12/3 p127), while from Acton Lodge, Elizabeth Hervey writes 'Hottest day we have yet had thermometer 75 in the shade.' (D6584/C/93). Unfortunately, neither of these diarists consistently record the temperature, and because they both lived relatively transient lifestyles, the readings they give are not always from the same thermometer.~~

~~In undertaking the classification, the indices were applied by one person, with 27,794 records (20,657 for Trentham, and 2,379 using three different methods for London). Previous studies have had indices applied by two or more researchers and then been compared (Nash et al., 2016). It would be impractical to have two researchers look at this volume of material reviewed in this study. It is highly likely therefore that there are occasional errors in this; between transcription errors from volunteers who collected and transcribed some of the data, possible inconsistencies in the application of the indices (since they were not all done in one sitting) and typographical errors, there are multiple opportunities for errors to arise. However, the methods used limit the impact of such errors occurring. This kind of reconstruction of precipitation series using indices is most valuable when no nearby instrumental records are available. This work has shown that if carefully applied these indices reconstruction approaches can have good correlation with instrumental records of rainfall and could therefore be used where no instrumental records exist, to help understand and contextualise reported impacts of extreme weather.~~

Different types of sources record weather differently, influencing how the resulting data can be used. Diaries often use weather as a starting point for an account of the day, as do some letters. M~~: m~~undane weather acts as a space filler, a neutral topic. If a diary records the weather every day, or a letter is not primarily about the weather, a full range of different types of weather are likely to be recorded. If, however, it is a diary that only records the weather occasionally it is likely to record more unusual weather, for example heavy rain, snow or frost (Table 1). Likewise, letters where the weather is one of the main topics, are

likely to record extreme weather events. The other type of weather that appears in letters, is weather used to explain actions, or inaction, in estate correspondence. For example, William Lewis wrote to his superior, James Loch in 1824; 'I followed up the old proverb "make hay while the sun shines" the weather still remains favourable and dry and all have been busy with the Turnips which are in a very forward state and very promising.'

A further consideration is the purpose of the original diaries; most of the records are not intended to record the weather accurately for ~~posterity but~~posterity, but are instead a record of someone's life and thoughts. A possible criticism of weather reconstructions from diaries is that they only record the weather during the daytime (Adamson, 2015). Whilst true, all the diaries used in this project tend to comment on heavy rain or snow if it occurs overnight, so if the object is to record rainfall, this may not always ~~a~~ be problematic.

Careful analysis of the Elizabeth Hervey diaries presents a contrasting perspective to comments by Adamson (2015) that diaries as a source of information in climate research provide 'highly personal documents…representing an unbiased account'. There is evidence in the diaries of Elizabeth Hervey of her reading aloud from her diaries for her friends and acquaintances, and of the diaries being edited after her death by her son (with sections he considered uninteresting, or unsuitable being redacted or removed). Although sometimes described as 'private' diaries, these sources are not necessarily private, but rather personal accounts which were regularly shared and performed.

~~The records described here could be complemented by use alongside other weather records, for example the thrice daily weather observations made by staff at Boulton and Watt Soho Manufactory in Birmingham between 1793 and 1830 identified by Veale and Endfield (2016), or as noted previously in Scotland in comparison to Margaret Mackenzie's temperature series.~~

~~8~~9. Conclusion~~s~~

Work on diaries to date has often focussed on specific weather diaries continuously recorded for long periods (Pfister and White, 2018b). T~~, t~~his paper demonstrates the value and utility of personal diaries reflecting shorter periods, particularly when used alongside other nearby ~~contemporary~~ coeval diaries. In analysing over 27,500 records, providing a rich depiction of the weather in two regions of England during the periods 1797-1801 and 1816~~-1770~~-1865, we ~~It also d~~demonstrate~~s~~ the ~~great~~ considerable potential ~~in for the use~~ of personal diaries that ~~which record~~recorded~~ing~~ weather incidentally rather than as the primary purpose for reconstructing long weather series. The results demonstrate the potential of indices in weather reconstruction~~ing weather~~ from qualitative sources. Having~~, with an opportunity to~~ evaluated ~~the~~ current approaches employed in such studies, and b~~. B~~ased on our~~the~~ dataset of over 27,5~~0~~00 records, we advocate that future studies consider an approach that deploys a nuanced classification depicting heaviness of the rainfall (i.e. assigning a value of 0 to no precipitation, 0.25 to very light rain or heavy fog, 0.5 to showers or light rain and 1 to heavy rain - our index C), as this provided the strongest correlations with existing nearby instrumental series. A~~However, a~~ pragmatic approach should be deployed to ensure that

threshold selection (preferably between 16-28 days a month) results in the inclusion of an optimal number of months. I ~~inclusion, i~~f threshold selection is set to low or high then sub-optimum results may be achieved. ~~This type of reconstruction could be a valuable tool globally for addressing gaps in instrumental records.~~

~~Such diaries could provide greater spatial and temporal coverage than instrumental records currently offer, presenting opportunities for extension of existing knowledge to areas where no, or limited, instrumental information exists. Even where instrumental records do exist, these records can provide greater resolution where only monthly or yearly totals are available and help to describe extreme events in detail.~~

~~The records described here could be complemented by use alongside other weather records, for example the thrice-daily weather observations made by staff at Boulton and Watt Soho Manufactory in Birmingham between 1793 and 1830 identified by Veale and Endfield (2016), or as noted previously in Scotland in comparison to Margaret Mackenzie's temperature series.~~

~~The indices approaches described are valuable in considering the influence of different weather systems and in identifying wetter and drier periods, qualitative data can provide additional information beyond instrumental records (e.g. nature of precipitation) and the subsequent responses undertaken by individuals and communities to events.~~ This paper demonstrates that for periods with overlap between documentary sources, indices can create valuable and reliable records of precipitation. We demonstrate that while indices can statistically represent the nature of the rainfall ~~better than other~~comparably to available precipitation series in this period (1770-1865)~~,~~ they failed to represent extremes well. F~~; with f~~urther work is required that considers how descriptive records may be represented in indices and the potential for statistical fitting approaches in defining the bounds of potential indices applied. In addition, alternative high-resolution indices could be created

~~There is value in qualitative daily data used in the creation of the indices, since it would also allow creation of targeted indices~~, such as consecutive dry days, which may be more useful than monthly data for investigating specific impacts such as drought (Pfister et al., 2020).

Personal diaries can provide greater spatial and temporal coverage than instrumental records currently offer, permitting the extension of existing weather and climate knowledge to areas where no, or limited, instrumental information exists. It is likely that diaries with the potential to be used in a similar way can be found in almost all regions of the world, with the potential to extend back much further than is often possible with instrumental series, as demonstrated by Chen et al. (2020) in considering the weather from fourteenth century China. Even where instrumental records do exist, diaries can provide greater temporal resolution, overcoming challenges where only monthly or annual instrumental totals are available, as such it may enable the scaling of monthly or annual instrumental totals to the (sub-)daily. ~~A further strength of this type of data over contemporaneous instrumental data is that it reflects a finer scale, as such it might be possible to use such information to scale monthly or annual rainfall totals from instrumental records to the (sub-)daily scale.~~

Descriptive accounts such as diaries can provide significant extra detail, enabling us to understand and contextualise the impacts of past extreme weather events, enabling us to contest and contextualise claims of uniqueness, unparalleled magnitude

or severity, within recent instrumental records. The qualitative nature of diaries means we can also consider the adaptive responses undertaken by individuals and communities to events, and the nature of actions undertaken during periods between extremes that may exacerbate risk.

Data Availability

The original archival materials used in this study, as detailed in the list of archive material, are available at the Staffordshire Record Office. The data used to create graphs is available from the corresponding author.

Author Contributions

AHF prepared the manuscript, extracted data from the archives and ran a volunteer project extracting data from the archives, ~~and~~ produced the indices, ~~carried out~~undertook the analysis and made the figures. NM secured the funding, provided instrumental precipitation data and contributed to the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

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