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Weather Patterns Associated with Pain in Chronic-Pain Sufferers

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ABSTRACT: The belief that weather influences people's health has been prevalent for millennia. Recent studies on the relationship between weather and pain for those who suffer from chronic pain remain indeterminate, with some studies finding strong effects and others finding no effects; most studies face limitations to their study design or dataset size. To address these limitations, a U.K.-wide smartphone study Cloudy with a Chance of Pain was conducted over 15 months with 10,584 citizen scientists who suffer from chronic pain, producing the largest dataset both in duration and number of participants. Compared to other similar citizen-science studies, our retention of participants was substantially better, with 15% still entering data nearly every day after 200 days. Analysis of the dataset using synoptic climatology and compositing revealed the daily weather associated with a prevalence of high pain and low pain across the population. Specifically, our results indicate that the top 10% of days with a high percentage of participants (about 20%) experiencing a pain event (represented here by a +1 change or greater in their pain level on a 5-point scale; referred to as a high-pain day) were associated with below-normal pressure, above-normal humidity, higher precipitation rate, and stronger wind. In contrast, the bottom 10% of days with a small percentage of participants (about 10%) experiencing a pain event (a low-pain day) were associated with above-normal pressure, below-normal humidity, lower precipitation rate, and weaker wind. Thus, these synoptic weather patterns support the beliefs of many participants who said that low pressure—and its accompanying weather—was associated with a pain event.

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Hippocrates (circa 400 BCE) wrote in *On Airs, Waters, and Places* that diseases had seasonal cycles and the health of city dwellers was affected by prevailing wind directions (http://classics.mit.edu/Hippocrates/airwatpl.html). Such ideas persisted until the eighteenth century (e.g., Miller 1962; Janković 2010, chapter 1). Today, a common belief among three-quarters of patients who suffer from chronic pain is that their daily pain levels fluctuate with the weather (e.g., Hagglund et al. 1994; Timmermans et al. 2014).

Whether there is any scientific support for these beliefs remains a frustrating question to try to answer. Studies synthesizing this literature find a range of results. In a review of 43 studies examining the relationship between weather and pain in patients with chronic musculoskeletal pain, 29 (67%) found some relationship (Beukenhorst et al. 2020), although the possibility of a publication bias for positive relationships (e.g., Easterbrook et al. 1991) cannot be discounted. Even among those 29 studies, however, some of the individual studies described their own results as “not clinically important” or “not clinically significant” (e.g., Glaser et al. 2004; Dorleijn et al. 2014; Smedslund et al. 2014; Steffens et al. 2014) or “making a minimal contribution to pain” (e.g., Drane et al. 1997). Of the studies finding a relationship, some found that cold conditions were associated with pain (e.g., Aikman 1997; McGorry et al. 1998) or warm conditions were associated with pain (Telfer and Obradovich 2017); others found that high pressure was associated with pain (e.g., Gorin et al. 1999; Strusberg et al. 2002; McAlindon et al. 2007). The other 14 (33%) studies found no relationship between weather and pain.

The reasons for the inability to find consistent results were investigated by Beukenhorst et al. (2020). They found that many previous studies had either relatively small sample sizes (e.g., as few as 18–25 individuals; Koyama et al. 1996; Aikman 1997) or had surveyed patients as infrequently as once every 3 months over a 2-yr period, yielding nine total datapoints per patient (Dorleijn et al. 2014). Some studies were unable to ensure that weather observations were representative of the conditions experienced by the participants because the locations of the participants were not tracked during the study or because weather conditions were considered representative of too large an area or time. Analysis of the data also appeared to commonly lack any input from a meteorologist, leading to analysis issues such as assuming weather quantities could be treated as independent variables or poor choices in weather quantities or analysis approaches. Other studies seemed to selectively report results after multiple testing, raising the issue of *p* hacking to achieve statistically significant results for at least some quantities [e.g., Dequeker and Wuestenraed (1986) investigated 342 associations]. Finally, most studies failed to consider other variables that might explain or otherwise affect the results, such as time spent outside affecting individuals' exposure to the weather or associations with mood or physical activity ultimately influencing pain.

Finding the relationship, if any, between weather and pain is more than just an academic exercise. Were scientists to demonstrate such a relationship, it would validate the beliefs of patients suffering from chronic pain who are often dismissed by their doctors. Also, knowing the specific weather variables involved in the weather–pain relationship could lead in the future to better understanding of the physiological mechanisms for pain in the body, which could lead to better, more targeted approaches to treat or minimize the pain. Finally, if a weather–pain relationship existed, individualized pain forecasts derived from weather forecasts and a patient's condition could be produced so that patients could better manage their pain and adjust their activities accordingly (e.g., by arranging reasonable adjustments with their employer to work from home when pain is expected due to weather, by avoiding outdoor labor or vigorous exercise on days when pain is expected to be enhanced due to the weather).

To overcome limitations in the design and execution of previous studies, our interdisciplinary research team designed a citizen-science project called Cloudy with a Chance of Pain (www.cloudywithachanceofpain.com), funded by the United Kingdom's leading arthritis charity Versus Arthritis. This study was a U.K.-based smartphone study where participants who had chronic pain used a specially designed smartphone application (i.e., app) to enter a 10-question daily report on their level of pain, other symptoms, amount of physical activity, mood, and other questions that may affect their amount of pain. For example, participants were asked "How severe was your pain today?" and reported pain on a 5-point scale: "no pain," "mild pain," "moderate pain," "severe pain," and "very severe pain." Using hourly records from the global positioning system (GPS) sensor in the phone (Beukenhorst et al. 2017), we linked the participant's location to the closest weather station in the Met Office observing network. Thus, we developed a daily profile of the average weather conditions each participant experienced, accounting for their travels within the United Kingdom during the day. Increases in pain can then be related to weather (or changes in weather). Therefore, the potential exists to engage a large population for a long time in a citizen-science project on a question of personal relevance to them and to collect data as frequently as every day and address confounding effects that have not been addressed previously.

An analysis of the Cloudy with a Chance of Pain dataset was performed by Dixon et al. (2019) using a case-crossover design, an epidemiological method that compares, within an individual, days on which a pain event happens to control days when no pain event happens. The strength of this method is that it makes only within-participant comparisons, controlling for all time-invariant participant characteristics (e.g., their subjective experience of pain, gender, medical condition). However, the downside of Dixon et al. (2019) is that it required independent sequences of days with and without a pain event within the same month to satisfy the conditions for the case-crossover design which resulted in a substantial thinning of the dataset (from 10,584 to 2,658 eligible participants; supplemental Fig. 1 in Dixon et al. 2019), but did not introduce bias. In addition, the case-crossover method quantified the effect of changes in weather conditions within a calendar month, assuming that the relationships between the weather variables and pain are linear and this relationship did not change between calendar months. The analysis demonstrated statistically significant, albeit modest, relationships between pain events and high relative humidity, low sea level pressure, and high wind speed. Temperature and precipitation did not have statistically significant relationships with pain. In addition, these results remained the same, even when accounting for mood and physical activity.

The purpose of this present study is to see if these results hold up under scrutiny from a different method, specifically one that examines the association between pain events and weather patterns. We therefore analyze the complete dataset from a meteorological perspective, using the techniques of synoptic climatology and compositing to reveal the weather patterns (if any) associated with painful days. The synoptic climatology approach has been used to examine migraine headaches (Piorecky et al. 1997; Cooke et al. 2000; Elcik et al. 2017), but has not been used more widely for chronic pain in general or musculoskeletal pain, specifically. These techniques allow us to use much more of the full dataset using a different methodology, one that is familiar to meteorologists, and allows us to visualize the synoptic-scale weather patterns associated with pain. The resulting output provides a useful visual picture of what the weather looks like on a typical day where a high fraction of participants experience a pain event. The case-crossover analysis does not provide this same visual evidence.

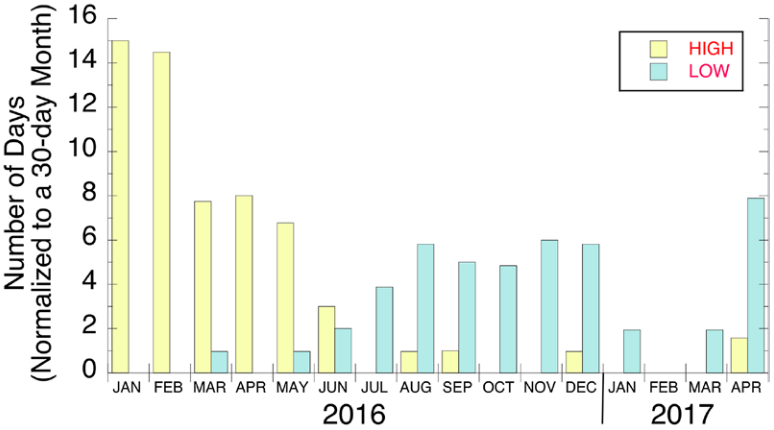

Fig. 1. Monthly distribution (normalized to a 30-day month) of HIGH days (the 45 days with the highest percentage of people experiencing a pain event) and LOW days (the 45 days with the lowest percentage of people experiencing a pain event) throughout the study (30 Jan 2016 to 19 Apr 2017).

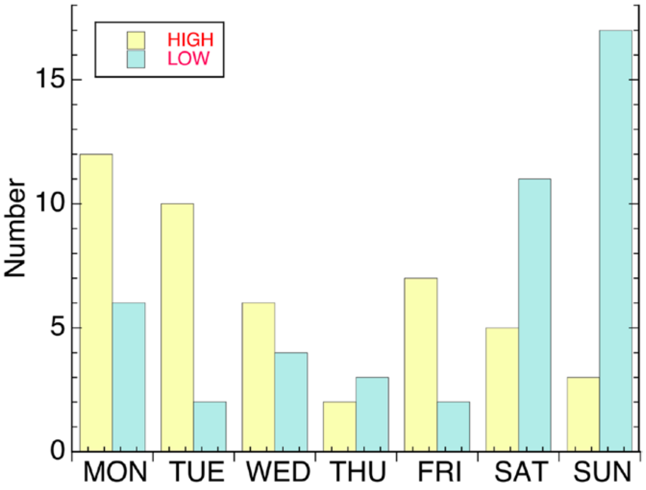

Fig. 2. Distribution by day of the week of HIGH days (the 45 days with the highest percentage of people experiencing a pain event) and LOW days (the 45 days with the lowest percentage of people experiencing a pain event).

Data and methods

The study ran for 15 months: 20 January 2016 to 19 April 2017. Before the study commenced, the app was tested and refined through interaction with a patient and public involvement group and a pilot study (Reade et al. 2017). Bolstered by two appearances on British Broadcasting Corporation (BBC) television and other national media attention (Druce et al. 2017; Fig. 2a in Dixon et al. 2019), a total of 13,207 users downloaded the study app during the 12-month recruitment period: 20 January 2016 to 20 January 2017. All 124 U.K. postcode areas were represented. Details about the demographics of the population can be found in the supplemental information in Dixon et al. (2019).

A total of 10,584 participants entered their demographic information and at least one pain report, making them eligible for the present study. A total of 6,850 (65%) participants remained in the study beyond their first week and 4,692 (44%) beyond their first month. Even after 200 days, 15% of participants were still entering data nearly every day (Druce et al. 2017; Fig. 2b in Dixon et al. 2019). This rate of engagement is exceptionally high compared to other mobile health studies where attrition often declines exponentially (e.g., Eysenbach 2005). We believe that our high retention is an indication of the easy-to-use app design, as well as the high level of interest by our participants in contributing toward an answer to this specific research question, which often has been of great personal interest to them (Druce et al. 2017, 2019).

At the start of the study, most participants believed in an association between weather and their pain. (When asked how strongly they believed in this association on a dimensionless scale from 1 to 10, the median score was 8, with an interquartile range of 6–9.) Dixon et al. (2019) split the dataset into two groups: those who believed in the association and those who did not. Results were statistically indistinguishable for each category, indicating that there was no bias from the participants knowing the research question during their data entry.

How to define a pain event is not straightforward. The self-reported nature of the pain levels in our study could lead to bias by directly comparing one participant's pain levels to another. For example, two persons reporting "very severe pain" (5 on our 5-point scale) may have completely different experiences. In addition, participants may use the pain scale differently (e.g., never report maximum or minimum values of pain). To avoid this dilemma, we refer to studies [as reviewed by Olsen et al. (2017)] that show a 20% increase in pain is clinically significant. Such a clinically significant pain event could be measured by an increase of at least 1 category on our 5-point scale. As such, we define a pain event in an individual participant when they report a 1-category or greater increase in their pain level from the previous day (e.g., moderate pain yesterday to severe pain today). We termed this a +1 or greater pain event. On any given day during the study, a minimum of 10% to a maximum of 23% of participants had a pain event from among the 193–1,777 participants on any given day who entered their pain reports on two consecutive days. [In reality, only two days in our dataset had substantially fewer than 520 entries, 30 and 31 January 2016 (193 and 409 entries, respectively), the eleventh and twelfth days of the study and the first two days in the dataset used in this present article.] By choosing "fraction of participants with a +1 increase in pain" as our outcome, our analysis is independent of how an individual interprets the pain scale and implicitly makes a within-person comparison.

We also checked our results to the sensitivity of our definition of pain. We considered two other choices. The first was a 2-category or greater increase in their pain level from the previous day, reported by a minimum of 1% to a maximum of 6% of participants on any given day. The second was when a participant reported severe pain or very severe pain on the 5-point pain scale, reported by a minimum of 12.7% to a maximum of 26.9% of participants on any given day. Both of these choices produced similar results to those herein, indicating that our results are robust to our definition of a pain event.

As many as 17% of the participants entered only the demographic information and one day's report (Druce et al. 2017; Dixon et al. 2019). With no subsequent pain report on the next day, these very low engagers could never experience a pain event in our dataset. We also noticed higher levels of pain reported on days with spikes in recruitment, which was probably an artifact reflecting time needed for participants to settle into their personal scoring system or a "regression to the mean," where participants joined the study at times of higher than average pain but then settled into a more typical pattern. As such, we excluded data from all participants' first 10 days in the study. Performing the analyses within the present study by including the first 10 days for each individual produced similar results to those herein, indicating that our results are insensitive to the inclusion or exclusion of these first 10 days.

In the dataset with the first 10 days of each patient removed, 445 days were available for study. To study the average weather conditions on days when a high percentage of participants were reporting pain, we take the top 10% (45 days) with the largest percentage of participants having a +1 or greater pain event (19.6%–23.0% of all respondents on those days), termed HIGH. For comparison, we take the bottom 10% with the lowest percentage of participants having a +1 or greater pain event (9.5%–13.9% of all respondents on those days), termed LOW. Thus, there were about twice as many participants experiencing a pain event on a HIGH day than on a LOW day.

Monthly and weekly occurrence

The number of occurrences of the 45 HIGH days and the 45 LOW days in each calendar month were counted, then normalized by the number of days in a 30-day month. The result is plotted in Fig. 1. These HIGH and LOW days appear during certain months (Fig. 1). Specifically, most HIGH days occurred in January to June 2016, whereas most LOW days occurred from June 2016 to January 2017, with a maximum in April 2017 (Fig. 1). Whether this pattern represents some sort of seasonality is uncertain, given the 15-month period of the study. Also, recruitment and attrition were not constant through calendar time, with periods of high recruitment in January 2016 and September 2016. However, there does not appear to be a pattern of pain focused around these recruitment peaks that might otherwise explain the monthly changes observed. The variations in the fraction of participants experiencing a pain event by month suggests that seasonal changes in weather might, therefore, be one component to understanding regulators on pain (e.g., Cutolo 2011; Park et al. 2017).

When the 45 HIGH and 45 LOW days are plotted as a function of day of the week, there is a dramatic distinction (Fig. 2). HIGH days tend to occur throughout the week, with a slight preference for Monday and Tuesday, whereas LOW days have a much larger weekly cycle with a midweek minimum and sharp maxima on Saturday and Sunday. The analysis presented later in this article was carried out by separating LOW days into weekdays and weekend days; the results were similar for each set of days (not shown). Another clue to understanding this weekly cycle is that Christmas (Sunday 25 December 2016) and three Monday bank/government holidays (Easter Monday on 28 March 2016 and 17 April 2017, Boxing Day on 26 December 2016) all are LOW days. Similarly, if holidays were eliminated from LOW days (9% of the days), then the results did not change.

Surface weather observations

Because of the GPS in participants' smartphones, we were able to identify the closest weather station to their location. The median number of weather stations associated with each participant during the course of their active data collection period was 9 (interquartile range of 4–14), with a maximum of 82 stations. These values indicate how mobile the participants were during the course of the study and the importance of accounting for the weather at different locations over the course of the study. These hourly weather observations were averaged together to construct average daily weather conditions for each participant who provided a daily report on their pain. For all those who provided a pain report on any given day, their daily averaged weather was averaged together to produce a U.K.-average weather for the day (midnight to midnight). This U.K.-average weather served as an indication of the type of weather that was experienced by the participants reporting on that day.

To compare this averaged weather during HIGH versus LOW days, box-and-whisker plots were created, illustrating the distributions of the weather variables between the two groups (Fig. 3). These box-and-whisker plots show significant (defined as the median of one being outside the interquartile range of the other) or near-significant differences between HIGH and LOW days for 2-m temperature, 2-m dewpoint, sea level pressure, and 10-m wind speed, with HIGH days being associated with lower temperature, lower dewpoint, lower sea level pressure, and higher wind speed (Figs. 3a–c). In contrast, 2-m relative humidity for HIGH and LOW days showed no significant difference (Fig. 3d), perhaps because the typical large diurnal cycle in relative humidity is averaged over the course of the day. Such analysis is consistent with Dixon et al. (2019), who found significant relationships between high pain with low pressure and high wind speed, although they found that the relationship with relative humidity was significant (despite being averaged over the day) and the relationship with temperature was not significant. The different sizes of the datasets (10,584 vs 2,658) and different analysis approaches are likely to be the reason for these small differences. The present results are also consistent with what participants believed before the study started with 6,941 (66%) saying their pain was associated with cold and with 3,687 (35%) saying their pain was associated with changes in barometric pressure (Table S1 in Dixon et al. 2019). In a free-text box, 83 participants said their pain was associated with "wind" and 49 participants said their pain was associated with "storm" (i.e., low pressure), again supportive of these results. We also examined boxplots for one and two days before the pain event, and one and two days after the pain event. Although there were small changes in these mean quantities from day to day, none were statistically significant.

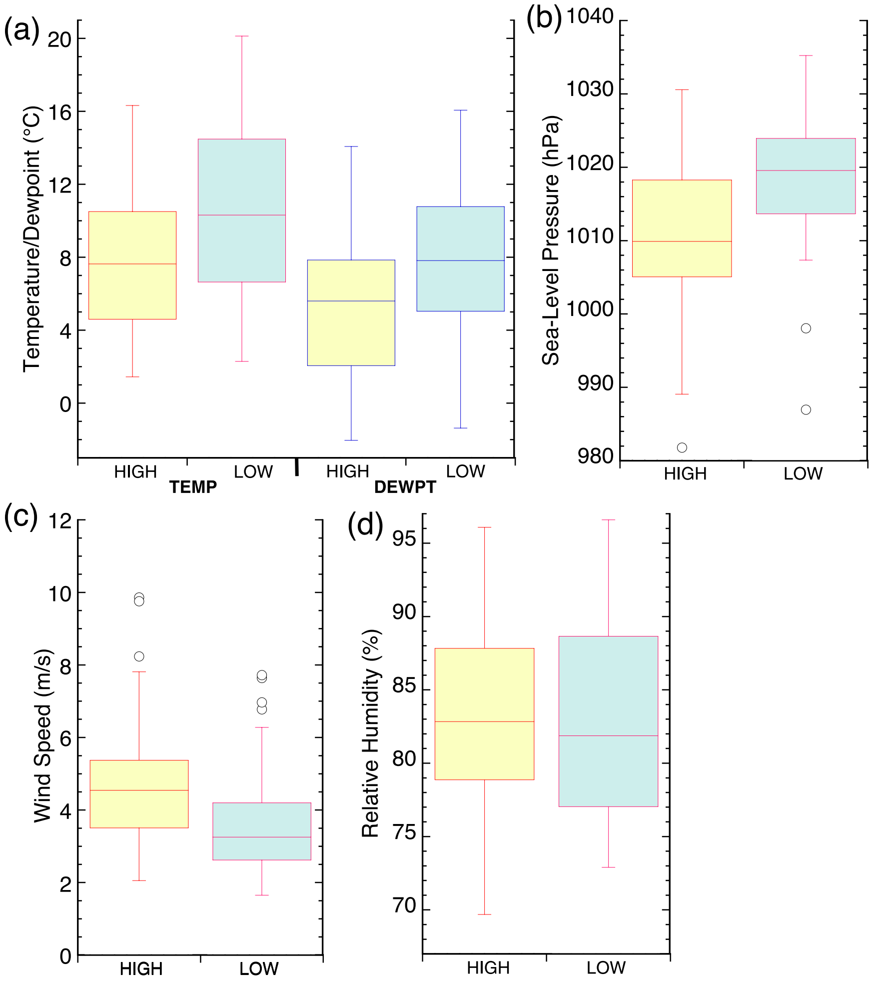

Fig. 3. Box-and-whisker plots of various quantities averaged over the United Kingdom for HIGH days (yellow boxes) and LOW days (blue boxes): (a) 2-m temperature and dewpoint, (b) sea level pressure, (c) 10-m wind speed, and (d) 2-m relative humidity. Quantities represented are median (bar in the middle of the box), the interquartile range (box), range (length of whiskers), and any outliers (circles whose value is greater than 1.5 times the interquartile range from the interquartile range).

Synoptic composites

Synoptic compositing is a common technique in synoptic meteorology. It consists of taking the mean of a number of weather maps that have some event in common. Composite analyses are constructed from the NOAA/ESRL website (www.esrl.noaa.gov/psd/data/composites/hour/) using the NCEP–NCAR reanalysis (Kalnay et al. 1996). The 1200 UTC weather maps for each day we averaged together to produce the composites. To examine fields in the lower troposphere, we selected 925 hPa (about 750–800 m above sea level). Other levels in the lower troposphere were also investigated (i.e., surface, 850 hPa) for the quantities described below and yielded similar results.

Composite analysis of 500-hPa geopotential height, sea level pressure, precipitation, 925-hPa moisture, wind, and temperature reveal the weather patterns present during HIGH versus LOW days (Figs. 4–7). Anomalies are computed from averages of the daily-mean fields. During HIGH days, a trough lay over the United Kingdom, North Sea, and Norway, indicated by a –40-m 500-hPa height anomaly and a –5-hPa sea level pressure anomaly (Figs. 4a,b). This surface pressure anomaly associated with a 500-hPa height anomaly indicates the tropospheric-deep structure of the flow on HIGH days. Also, a ridge lay to the southwest over the North Atlantic Ocean (Figs. 4a,b). During LOW days, on the other hand, a ridge lay over the United Kingdom, indicated by a +60-m 500-hPa height anomaly and a +5-hPa sea level pressure anomaly, with anomalously low heights southeast of Greenland (Figs. 4c,d). The difference between the patterns on HIGH and LOW days indicates remarkably different weather patterns for the United Kingdom. The patterns are consistent with the box-and-whisker plot in

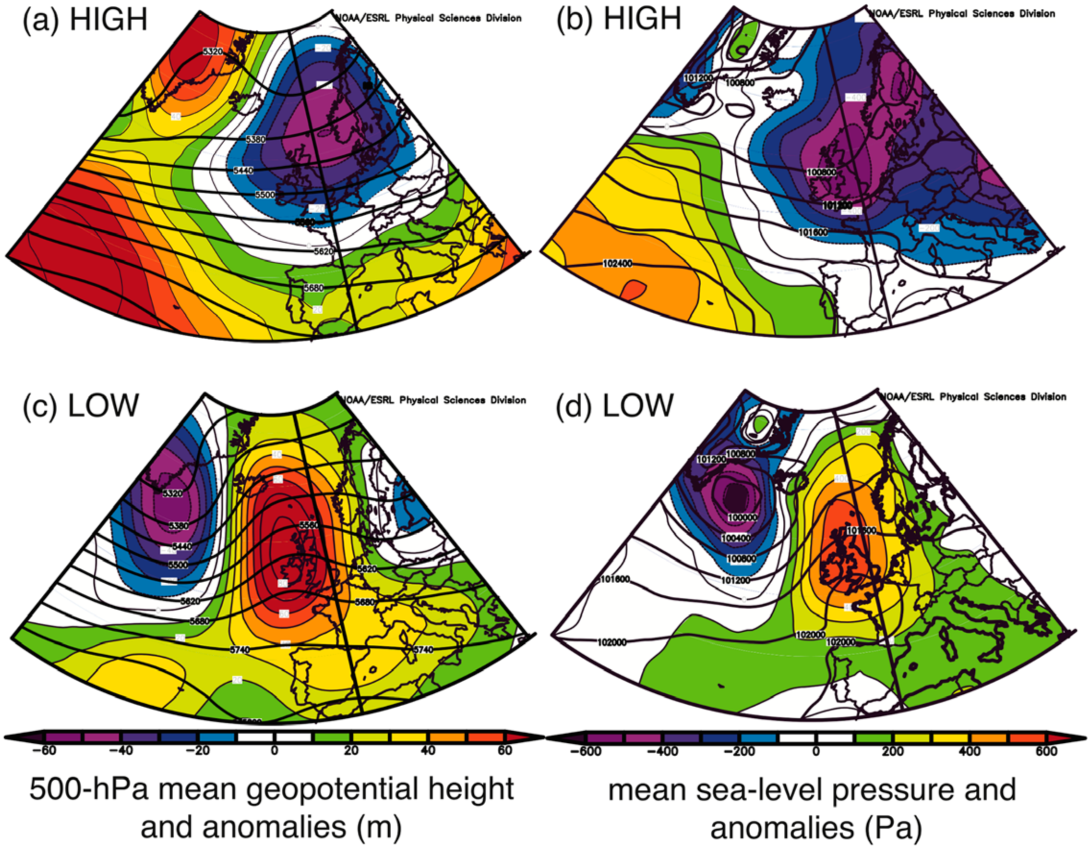

Fig. 4. Synoptic composites of (a),(b) HIGH and (c),(d) LOW days. (a),(c) 500-hPa mean geopotential height (thick solid lines every 60 m) and anomalies [colored according to the scale in (c)]. (b),(d) Mean sea level pressure (thick solid lines every 4 hPa) and anomalies [colored according to the scale in (d)]. Anomalies computed relative to the weighted average of the daily 1981–2010 means. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website (www.esrl.noaa.gov/psd/).

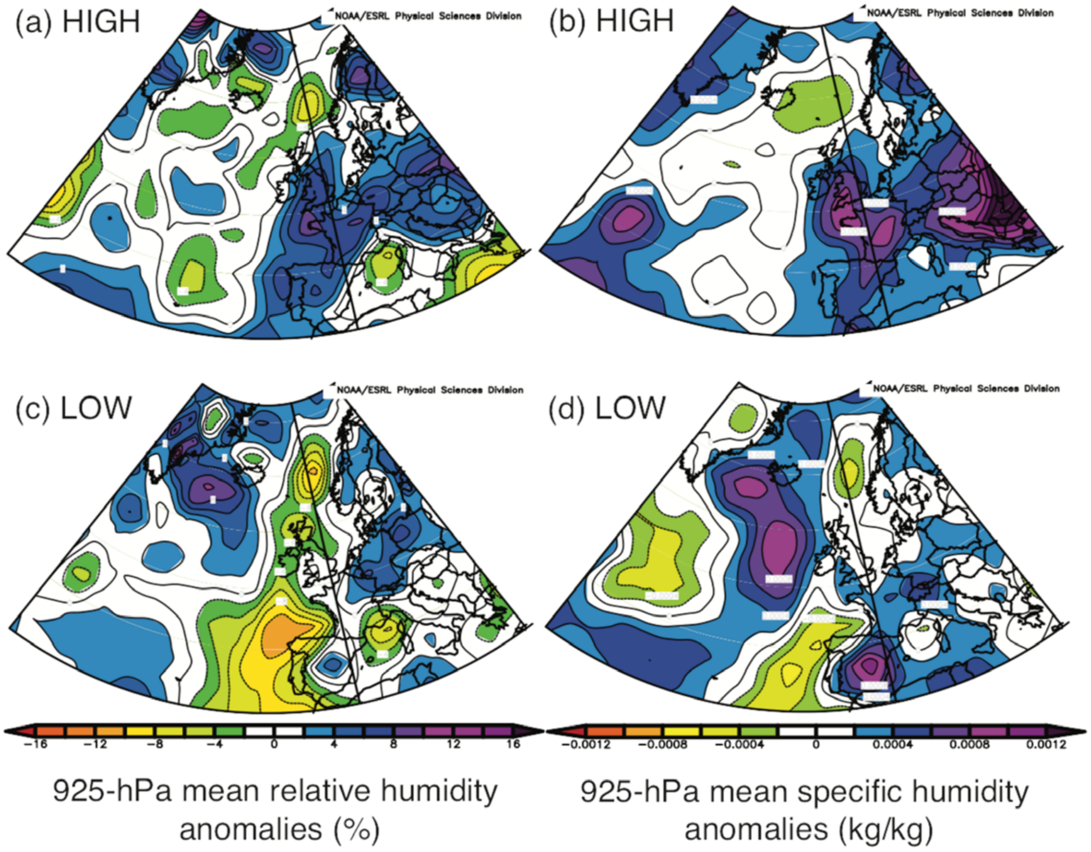

Fig. 5. Synoptic composites of (a),(b) HIGH and (c),(d) LOW days. (a),(c) 925-hPa mean relative-humidity anomalies [colored according to the scale in (c)]. (b),(d) 925-hPa mean specific-humidity anomalies [colored according to the scale in (d)]. Anomalies computed relative to the weighted average of the daily 1981–2010 means. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website (www.esrl.noaa.gov/psd/).

Fig. 3b and with patient beliefs in other studies (e.g., Dixon et al. 2019; Croitoru et al. 2019).

The 925-hPa relative humidity and specific humidity on HIGH days shows a band of more humid air extending from Spain to the United Kingdom (Figs. 5a,b) and a local maximum in daily average precipitation rate over the United Kingdom (Fig. 6a). In contrast, the same fields on LOW days show a dry anomaly over the same band and a similarly shaped region of minimum precipitation rate (Figs. 5c,d, 6b). Specific-humidity fields show similar patterns to the relative-humidity fields (Fig. 5), which are consistent with the box-and-whisker plots of the dewpoint, but not the relative humidity (Figs. 3a,d). The discrepancy between the results from the box-and-whisker plots (Fig. 3d) and the composites (Figs. 5a,c) is because very different measurements go into each plot. The surface relative-humidity values that go into the box-and-whisker plot are averaged each hour and for all surface reporting station locations across the United Kingdom closest to where participants are reporting. In contrast, the 925-hPa relative-humidity anomaly fields in the synoptic composites are the average of 45 days from reanalyses, all taken at 1200 UTC. Given the different origin and calculation of these averages (i.e., hourly vs 1200 UTC, surface vs 925 hPa, single averaged relative humidity value for the United Kingdom on each day vs a field of relative humidity anomalies from climatological values, observations vs model reanalyses), it is perhaps not surprising that small discrepancies occur.

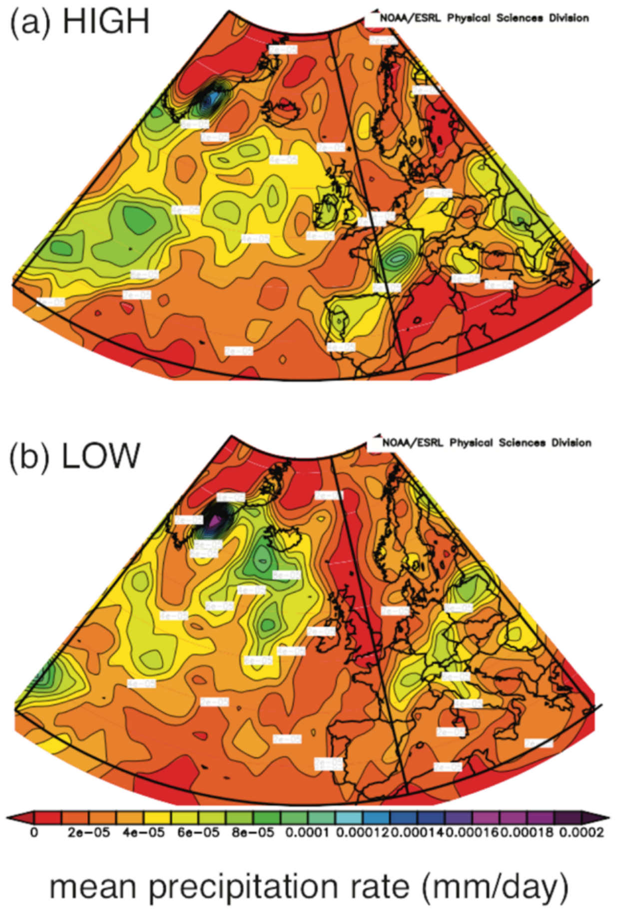

Fig. 6. Synoptic composites of mean precipitation rate on (a) HIGH and (b) LOW days [colored according to the scale in (b)]. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website (www.esrl.noaa.gov/psd/).

In line with the height field in HIGH (Fig. 4a), the 925-hPa mean wind field shows the United Kingdom in the left-exit region of westerly flow (Fig. 7a). In contrast, the wind field in LOW shows the jet moving north of the United Kingdom (Fig. 7c), consistent with the ridge (Figs. 4c,d). The values of mean winds from the reanalyses over the United Kingdom are roughly the same on HIGH and LOW days, in contrast to the box-and-whisker plot of the surface wind observations on HIGH and LOW days (Fig. 3c).

The 925-hPa temperature anomalies on HIGH days show warmer air over and east of the United Kingdom, with cooler air to the west (Fig. 7b). In contrast, the temperature on LOW days is also anomalously high over the United Kingdom and to the west, but the anomaly is less than for HIGH (Fig. 7d). This result appears to be substantially less distinctive than the results from the box-and-whisker plot of temperature on HIGH and LOW days (Fig. 3a).

Together, these results suggest that HIGH days (when a high percentage of participants experience a pain event) occur with lower pressure over the United Kingdom, which is also associated with more wind, moisture, and precipitation. In contrast, on LOW days (when a low percentage of participants experience a pain event) higher pressure over the United Kingdom brings weaker winds and drier air.

Caveats

Although the results are intriguing, these findings from the United Kingdom should not necessarily be extrapolated to different climates where the weather is different. Such a study as Cloudy

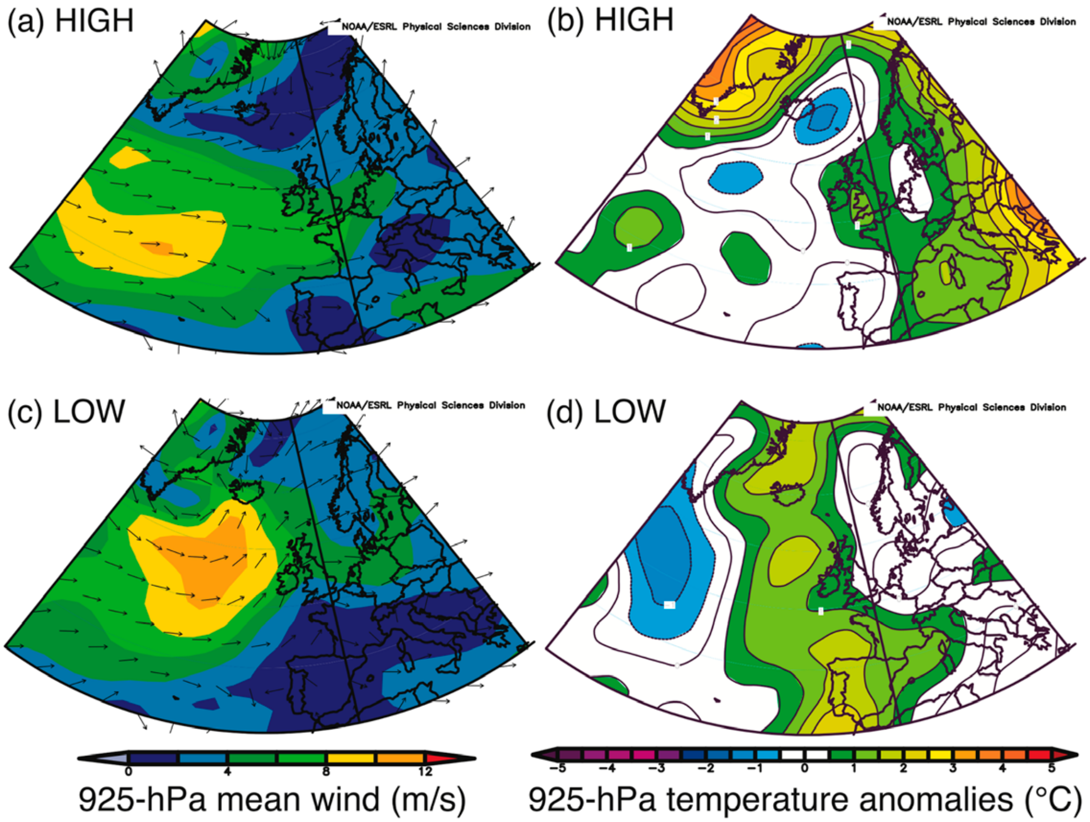

Fig. 7. Synoptic composites of (a),(b) HIGH and (c),(d) LOW days. (a),(c) 925-hPa mean wind speed [colored according to the scale in (c)] and direction (arrows). (b),(d) 925-hPa temperature anomalies relative to the weighted average of the daily 1981–2010 means [colored according to the scale in (d)]. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website (www.esrl.noaa.gov/psd/).

with a Chance of Pain should be replicated elsewhere to determine if the weather patterns associated with painful days presented here generalize to other locations in other climates.

Another caveat with this study is that the analysis involved all 10,584 who participated and suffered from chronic pain (i.e., a population-wide analysis). Participants were living with one or more of a number of different diseases such as unspecified arthritis (34.6%), fibromyalgia or other widespread pain (26.4%), osteoarthritis (24.1%), rheumatoid arthritis (18.5%), neuropathic pain (15.1%), chronic headache and migraine (10.3%), and gout (3.5%) (Table S1 in Dixon et al. 2019). The present analysis assumes that all participants would have the same weather–pain relationship. Different diseases may have different sensitivities to pain (as has been shown by other studies; e.g., Guedj and Weinberger 1990; Strusberg et al. 2002; Vergés et al. 2004), and—even within and across diseases—participants may be affected differently due to pathology, genetics, or other factors. For example, someone with constant severe pain may not be affected by, or may not notice, fluctuations caused by the weather. Using the whole population means that our results may underestimate the most important associations for subsets of our population. Initial analyses revealed no notable differences when stratifying the results by pain condition (supplemental Fig. 4 in Dixon et al. 2019), although the smaller sample sizes limited statistical power. Work on identifying subsets of our population continues.

A third caveat is that the amount of time spent inside by participants will affect their exposure to the weather. Because the air pressure inside a building is generally in equilibrium with the air pressure outside, that should not be a factor. However, the temperature and humidity of air inside the building often differs from that outside, and being inside is protection from wind and precipitation. So, if the weather affects people's pain, we might expect to see some influence from the amount of time spent outside. However, the relationship between weather, pain, and time spent outside is complex; time spent outside is often influenced by an individual's pain, meaning we might expect different levels of pain in participants who are indoors versus outdoors, irrespective of the weather. Untangling the effect of those who stayed inside because their pain was severe and those who were inside for other reasons is difficult and requires further analysis.

Conclusions

The box-and-whisker plots of mean surface observations and synoptic composites reveal that small inconsistencies exist, but the results are consistent with lower pressure over the United Kingdom associated with more wind, moisture, and precipitation on HIGH days when a high percentage of participants experience a pain event. In contrast, on LOW days when a low percentage of participants experience a pain event, higher pressure over the United Kingdom brings weaker winds and drier air. Furthermore, the synoptic composites help to explain the results from the case-crossover method in Dixon et al. (2019) through a means more familiar to meteorologists. Although the results of this present article paint a generally consistent picture with those from Dixon et al. (2019), the details of which meteorological quantities differ between the two studies because of the different dataset sizes and analysis approaches employed.

On any given day, about 16% of people suffering with chronic pain experienced a +1 or greater pain event in the United Kingdom, a number that increased to a maximum of 23% on a high-pain day and decreased to a minimum of 10% on a low-pain day. Weather patterns can explain a portion of that variability. Although the weather may not be the primary cause of people's pain, our results through multiple independent methodologies demonstrate that weather does modulate pain in at least some individuals. Who is the most susceptible remains to be determined with our dataset in the future.

People have been talking about the effect of weather on their pain for millennia, so why is this particular research project important? First, our study is the largest in terms of both duration and number of participants (e.g., Fig. 2 in Beukenhorst et al. 2020), allowing greater confidence in the fidelity of our results. Second, not everyone believes in the link between weather and pain. The results of this project should give comfort and support to those who have claimed that the weather affects their pain, but have been dismissed by their friends, their coworkers, and even their doctors. Finally, our research also begins to shed light on the environmental conditions that modulate pain, insight that might be explored further for improving the treatment, management, and forecasting of pain.

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