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We examined the spatial distribution of monthly, seasonal, and annual changes in comfortable weather hours (CWHs) between 1950 and 2011 and explored the relationship between human wellness and the amount and timing of CWHs. Using a thermohygrometric index based on air temperature and dewpoint temperature recorded every three hours from thirty-five U.S. cities, we determined whether changes in human thermal comfort were coincident with warming and more humid atmospheric conditions. We tested for significant trends in CWHs for every season for each city for nighttime, daytime, and total (i.e., night and day) periods. Although approximately 75 percent of the cities did not experience significant changes in CWHs on an annual basis, total changes in CWHs were marked by increases during spring and decreases in summer conditions, with the largest positive changes in CWHs found during spring nights, spring days, and autumn nights and the largest negative changes during summer nights and days. Spatially, increases in CWHs were principally located west of 117°W and decreases in cities east of 81°W. Significant relationships existed between wellness metrics and seasonal and annual CWHs. Greater CWHs during the summer were positively correlated with happiness and well-being and negatively correlated with obesity. These results suggest that further declines in summer CWHs for cities might affect human wellness, as peak optimal weather conditions shift toward spring and autumn months. *Key Words: climate change, human thermal comfort, U.S. cities, wellness.*

我们检视 1950 年至 2011 年间，舒适气候时间（CWHs）的月、季和年度变迁之空间分佈，并探讨人类健康和 CWHs 总量与时间之间的关係。我们运用在美国三十五座城市中，每三小时记录的根据空气温度和露点温度的热比重指标，判定人类温暖舒适度的改变，是否与变暖和更为潮溼的大气条件相符合。我们检测每个城市在每一季的晚上、白天和总时程（例如日夜）的 CWHs 的显着趋势。儘管大约百分之七十五的城市并未经历以年度为基准的 CWHs 的显着改变，但 CWHs 的总改变量则在春天增加，在夏天的情境中则减少，而 CWHs 最大幅的正向改变，则在春天晚上、春天白天和秋天晚上发现，最大的降幅改变，则是在夏日的晚上和白天发现。在空间上，CWHs 的增加，主要落在西经 117 度以西，而在西经 81 度以东的城市中减少。健康度量和季度与年度 CWHs 之间存在着显着关係。夏季更大的 CWHs，与快乐和健康具有正相关，而与肥胖具有负相关。这些结果指出，当最高的理想气候条件转向春天和秋天的月份时，未来城市中夏季 CWHs 的减少，可能会对人类健康造成影响。*关键词：气候变迁，人类温暖舒适度，美国城市，健康。*

Examinamos la distribución espacial de cambios mensuales, estacionales y anuales de las horas de tiempo agradable (CWHs) entre 1950 y 2011 y exploramos la relación entre bienestar humano y el número y horario de ocurrencia de las CWHs. Usando un índice termohigrométrico basado en temperatura del aire y en temperatura del punto de condensación registradas cada tres horas en treinta y cinco ciudades de los EE.UU., determinamos si los cambios en la comodidad térmica humana eran coincidentes con el calentamiento y condiciones atmosféricas más húmedas. Hicimos pruebas para establecer tendencias significativas en las CWHs en cada estación para cada ciudad en los períodos nocturno, diurno y para el total (es decir, noche y día). Aunque aproximadamente el 75 por ciento de las ciudades no experimentaron cambios significativos de las CWHs en una base anual, los cambios en el total de las CWHs estuvieron marcados con incrementos durante la primavera y mermas en las condiciones veraniegas, con los cambios positivos más grandes de las CWHs registrados durante las noches de primavera, los días de la primavera y las noches de otoño, y los cambios negativos más grandes durante las noches y días del verano. Desde el

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punto de vista espacial, los incrementos de las CWHs se localizaron principalmente al occidente del meridiano 117°W, y las mermas en las ciudades situadas al oriente de 81°W. Se detectaron relaciones significativas entre las medidas de bienestar y las CWHs estacional y anual. Los mayores valores de la CWHs durante el verano estuvieron positivamente correlacionadas con los valores de felicidad y bienestar, y negativamente correlacionadas con la obesidad. Estos resultados sugieren que mayores mermas en las CWHs en las ciudades en verano podrían afectar el bienestar humano, a medida que el pico de las condiciones óptimas del tiempo se desplaza hacia los meses de primavera y otoño. *Palabras clave: cambio climático, comodidad térmica humana, ciudades de los EE.UU, bienestar.*

Air and dewpoint temperatures in the conterminous United States have trended upward since the mid-twentieth century but at different rates based on season and location (Robinson 2000; Q. Lu, Lund, and Seymour et al. 2005; E. Lu and Takle 2010; Brown and DeGaetano 2013) and time of day (Knappenberger, Michaels, and Schwartzman 1996). Although many of the consequences of warming climatic conditions are or will be problematic (Meehl and Tebaldi 2004; Emanuel 2005; Coumou and Robinson 2013), other consequences might have positive outcomes (Primack et al. 2004; Laaidi, Laaidi, and Besancenot 2005; Analitis et al. 2008). Among the potential effects of warming are changes to the duration of human thermal comfort hours, which represent periods when minor to no physiological distress is attributed to the combined effects of air and dewpoint temperatures. Here we address human thermal comfort duration in the conterminous United States since the mid-twentieth century and examine the spatiotemporal components of these changes in thirty-five selected cities and the implications for human wellness.

Several studies have quantified the broad-scale spatial aspects of climate and human comfort ranging from subcontinental to global scales (Terjung 1966, 1968; Auliciems and Kalma 1979; Mieczkowski 1985; Scott, McBoyle, and Schartzentruber 2004). All have shown that the duration of human thermal comfort varies spatially and seasonally, but insufficient information is available regarding temporal changes in the midst of a warming climate. Both Scott, McBoyle, and Schartzentruber (2004) and Matzarakis and Amelung (2008) examined the implications of climate change in the latter half of the twenty-first century, finding poleward migrations of optimal thermal regions for each season. Less is known about variations that might have already occurred since the mid-twentieth century, the relationship between comfortable weather hours (CWHs) and human wellness, and how changes in CWHs could affect well-being.

Climate, Wellness, and Health

The concept of wellness is at the center of the growing positive psychology movement (e.g., Seligman and Csikszentmihalyi 2000; Roscoe 2009). Although the concept has received significant research attention, there remains little consensus on a single definition of the term. Most theories and models of wellness describe several dimensions, including, for example, social, physical, environmental, and emotional wellness (happiness) as components of overall wellness (e.g., Ardell 1977; Jensen and Allen 1994; Roscoe 2009).

Virtually all models of wellness include a physical activity or exercise component as part of broader physical wellness, and some include outdoor activities and connectedness with nature as factors in social or environmental wellness. There is some consensus on the nature of wellness as a complex, multidimensional, synergistic construct that exists on a continuum rather than as an end state (Ardell 1977; Lafferty 1979; Hettler 1980; Teague 1987; Lorion 2000; Sarason 2000; Roscoe 2009). Not one of the various dimensions of wellness operates independently; rather, the sum of the dimensions is greater than the whole (e.g., Crose et al. 1992; Clark 1996; Roscoe 2009). Further, wellness is generally agreed to be more than the simple absence of illness but rather a state of complete physical, mental, and social well-being.

The importance of geography and the environment as influences on wellness have only recently been acknowledged, but in some cases spatial and environmental variables are highly significant and important determinants of well-being (Brereton, Clinch, and Ferreira 2008). Indeed, environmental variables such as air temperature have been so strongly linked to self-reported well-being that spatial variables, including climate, could be as important in determining happiness as the most critical socioeconomic and demographic factors, including unemployment and marital status (Brereton, Clinch, and Ferreira 2008). The existing research on climate–happiness linkages, however, is limited to national-scale analyses and suffers from the inability of nationally aggregated climate (or wellness) data to describe regional differences in the wellness-related effects of climate or climate change within a country (Rehdanz and Maddison 2005; Brereton, Clinch, and Ferreira 2008).

Physiologically, the rates of ischemic stroke (Feigin et al. 2000; Hong et al. 2003), coronary-related issues (Kloner, Poole, and Perritt 1999; Cagle and Hubbard 2005; Wanitschek et al. 2013), influenza and pneumonia mortality (Davis, Rossier, and Enfield 2012), and respiratory illness (Ge et al. 2013; Xu et al. 2013) have been directly associated with temperature variations, particularly periods of either colder conditions or larger diurnal ranges. Heat-related mortality events are well documented (Luber and McGeehin 2008; Sheridan, Kalkstein, and Kalkstein 2009; Grundstein and Dowd 2011), especially events such as the 2003 heat wave in Europe (Bouchama 2004; Fouillet et al. 2008). Although some literature suggests that the human health effects of heat events are less severe and have shorter term impacts than cold events (e.g., Deschenes and Moretti 2009), it remains unclear whether mortality is more directly associated with heat- or cold-related events because of data set limitations (Dixon et al. 2005).

Seasonal weather conditions can affect self-reported well-being. For example, Russian households strongly dislike cold winters and hot summers (Frijters and Van Praag 1998), and a positive association between happiness and both mild winters and hot summers was found in Ireland (Brereton, Clinch, and Ferreira 2008). Seasonal weather is linked with the extent of physical activity and has been associated with obesity prevalence (Dietz and Gortmaker 1984; Merrill et al. 2005; Tucker and Gilliland 2007). In the United States, the highest amounts of physical activity typically occur during April through August and peak during July and August (Tucker and Gilliland 2007). Moderate, dry conditions during summer have been significantly linked to increased physical activity (Merrill et al. 2005), suggesting that seasonal climate conditions can directly affect wellness.

A growing body of evidence indicates that happiness, not income, is the ultimate goal of most individuals (Rehdanz and Maddison 2005). Happiness might be relatively unrelated to income, and the factors that make people happy seem to correspond across populations, both nationally and internationally (Rehdanz and Maddison 2005). Happiness might be directly associated with climatic conditions (Parker 1995; Keller et al. 2005; Tsutsui 2013). Conversely, both the perception of climate change (Doherty and Clayton 2011) and suboptimal temperature conditions such as hot spells have been linked to a suite of mental health issues, including aggression (Boyanowsky 1999; Bushman, Wang, and Anderson 2005) and violent behavior (Anderson 2001; Anderson and DeLisi 2011). On a larger scale, Zhang et al. (2011) showed a direct linkage between societal crisis—including the golden and dark ages in Europe—and climate change. Although there are many ways in which either weather events or seasonal weather conditions (climate) affect wellness, the spatiotemporal changes in CWHs and the potential effects of these changes on human wellness have not been examined. In this study we address three objectives related to changes in comfortable weather duration between 1950 and 2011 and the potential influences on human wellness. Specifically, we identify (1) cities that have experienced the most positive and negative changes in CWHs during the sixty-two-year study period; (2) how these changes have varied by time of day, season, and geographic location; and (3) how the spatiotemporal patterns of comfortable weather are significantly related to measures of wellness including happiness, obesity, and well-being.

Data and Methods

Determining Comfortable Weather Duration

We used air temperature and dewpoint temperature data recorded manually every three hours from thirty-five selected first-order weather stations from 1950 through the early 1990s and later replaced in the 1990s by selected Automated Surface Observing System (ASOS) weather stations (National Oceanic and Atmospheric Administration 1998) distributed throughout the conterminous United States (Figure 1) to examine spatiotemporal patterns between 1950 and 2011 (National Climatic Data Center 2011). We selected stations principally on data completeness exceeding 98 percent and representing broad geographical coverage. We defined seasons as boreal winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). Due to a lack of high-quality neighboring sites, we did not fill in missing data, so the final tallies of CWHs might be slightly underreported. We examined possible data inhomogeneities related to either station moves or changes from manual to ASOS recording techniques that occurred in the 1990s.

Figure 1. Location of thirty-five cities with Automated Surface Observing System stations selected for study. Station specifics are listed in Table S1.

These stations have the best high-quality data available and we found no evidence that data errors produced systematic bias but acknowledge possible data shortcomings. Guttman and Baker (1996) suggested that the change to ASOS recording techniques typically resulted in lower temperature readings, which would underestimate the trends in CWHs in this study. Thus, use of this data set might have caused a conservative bias of CWHs trends.

We determined comfortable weather using the thermohygrometric index (THI; Thom 1959), which combines the effects of air and dewpoint temperatures (i.e., the sensation caused by still, saturated air) to determine optimal human comfort conditions. The THI is expressed as

$$\text{THI}\,(^\circ\text{C}) = t - (0.55 - 0.0055f)(t - 14.5)$$

where air temperature (t) is measured in degrees Celsius and (f) is relative humidity derived from dewpoint and air temperatures. THI values are categorized (Kyle 1994, cited in Unger 1999) into ten groups ranging from hyperglacial (<–40°C) to torrid (>30°C) and with comfortable—the criterion used in this study—ranging from 15°C to 19.9°C.

Caveats of Using the THI

The THI is one of many available indexes that attempt to represent the human health effects of exposure to different combinations of temperature, humidity, and other factors. Different indexes are chosen based on specific research needs, and Barnett, Tong, and Clements (2010) determined that no single temperature measure or combined temperature and humidity measure was superior for predicting heat- and cold-related mortality. We considered using several human thermal comfort indexes, such as the universal thermal climate index (Jendritzky, DeDear, and Havenith 2012) and physiological equivalent temperature (Matzarakis, Mayer, and Iziomon 1999), but chose the THI largely because the raw data requirements allowed for the greatest spatial density of stations between 1950 and 2011. Although THI excludes variables such as wind speed that can affect human comfort, it remains a widely used metric (Unger 1999; Emmanuel 2005; Toy, Yilmaz, and Yilmaz 2007; Irmak et al. 2013). Davis et al. (2006) showed that the effectiveness of different thermal comfort indexes during heat waves produced similar results despite use of different variables and weightings. Although many human thermal comfort indexes are strongly dependent on climatic mean air temperature (Tseliou et al. 2010), attempts to correct the indexes using seasonal climatic mean temperature produce only minor improvements.

Our selection of the comfortable range of THI values (15°C–19.9°C) does not imply that people are uncomfortable, for example, at 14.9°C or 20°C but that the likelihood of comfort is greater between 15°C and 19.9°C. Further, the THI comfort range does not imply that all people experience comfort equally, regardless of age, gender, or other factors. Although there is evidence that both age and gender might modulate the health effects of high temperatures (e.g., Yu et al. 2010) in the context of regional health effects across the conterminous United States, this level of specificity about individuals is unmanageable. Finally, the use of a fixed index does not account for regional or seasonal acclimatization, as individuals might adapt to heat stress both within seasons and interannually (e.g., Cheung, McLellan, and Tenaglia 2000; Taylor and Cotter 2006; Barnett, Tong, and Clements 2010).

Data Analyses

For each climate station, we compiled the number of observations (documented every three hours) recording comfortable weather conditions for each calendar day for the sixty-two-year period. Thus, for a given day (e.g., 1 January) the sum of the three-hourly observations (range = 0–8) of comfortable weather (i.e., CWHs) was recorded annually for each of the sixty-two years, with the daily data then summed by season and the seasons combined for the annual data. CWHs were documented from the conditions only at the time of recording and thus what we call one CWH could in reality represent one to three actual hours of comfortable weather. We further parsed the data into twelve-hour nighttime and twelve-hour daytime categories, also by season and all four seasons combined (i.e., annual conditions). Due to different local time zones in the United States, we gathered slightly different coordinated universal time (UTC) three-hourly observations to ensure the recordings corresponded to local nighttime and daytime conditions. For Eastern and Central Standard Time zones, nighttime was based on 03, 06, 09, and 12 UTC three-hourly observations, whereas the three-hourly daytime observations were based on 15, 18, 21, and 24 UTC. For Mountain and Pacific Standard Time zones, we based three-hourly observations on 06, 09, 12, and 15 (night) and 18, 21, 0, and 03 (day) observations. Using this method, nighttime observations occurred at 10 p.m., 1 a.m., 4 a.m., and 7 a.m. and daytime observations at 10 a.m., 1 p.m., 4 p.m., and 7 p.m. for stations in the Eastern or Pacific Time zones. For stations in the Central or Mountain Time zones, 11 p.m., 2 a.m., 5 a.m., and 8 a.m. represented night, and 11 a.m., 1 p.m., 4 p.m., and 7 p.m. day. Our division of night and day into twelve-hour periods does not account for the seasonal relationship between daylight and latitude, but the limitations of using three-hourly observations under a wide range of day-length periods existing between cities rendered a more precise approach unviable.

We used linear regression to determine whether significant ($p < 0.05$) trends occurred in the seasonal and annual data for nighttime, daytime, and combined (i.e., night and day) conditions for each of the thirty-five cities. For each significant trend, we calculated the difference in unstandardized predicted values of CWHs from 1950 to 2011 to determine the amount of change that occurred during the sixty-two-year period. When no significant trend in CWHs occurred, we entered a value of zero. We tested our data for normality and found that the majority of the data series were normally distributed. Winter conditions in high latitudes or at high elevation and summer daytime conditions in some southern states, however, had nonnormal data and the use of linear regression was invalid. In each of these cases, nearly all of the CWH values were zero and thus no trend was possible. For these stations we did not perform a trend analysis and changes in CWHs also were entered as zero. No regression analysis was performed for 29 February.

For spatial representation, we mapped seasonal and annual number of CWHs totals using graduated circles (ArcMap, version 10.1; Esri 2012) for each city for nighttime, daytime, and total (i.e., nighttime and daytime values combined). Dewpoint temperatures are highest during the summer and thus should have their greatest influence on CWHs during this period. To determine the relative contributions of air temperature and dewpoint temperature on summer CWHs across the United States, we derived Wald chi-square values from two separate Poisson regression analyses using daily CWHs as the dependent variable and air temperature and dewpoint temperature as the independent variables. All Poisson regression models met assumptions for model fit based on a goodness-of-fit test. Significance at $p < 0.05$ indicated the presence of a dominant variable, with larger chi-square values representing a greater contribution of that variable for a given city.

Ranking Cities by CWHs

We ranked cities based on CWHs for each month to illustrate the relative national shifts in comfortable weather throughout the year. We additionally compiled the mean annual number of CWHs (night and day combined) and used these data to determine average annual rank. Finally, we compared mean annual CWHs rank during two periods (1950–1980 and 1981–2011) to determine potential geographic shifts in relative rank. We selected this time frame because it evenly split our study period. The early period closely matches Hansen, Sato, and Ruedy's (2012) 1951 to 1980 reference period of global-scale temperature stability, and the latter period represents a time of broad-scale pronounced warming.

Relationship Between CWHs Measures and Human Wellness

In the economics literature, subjective well-being data meet a high scientific standard for internal consistency, reliability, and validity (e.g., Veenhoven 2000; Rehdanz and Maddison 2005; Brereton, Clinch, and Ferreira 2008). We employed three different measures of wellness: (1) a happiness index derived from word choice used in tweets in 2011 (Mitchell et al. 2013); (2) an overall well-being index for 2012 (Gallup-Healthways 2013) and composed of the following interrelated dimensions: social, purpose, financial, community, and physical; and (3) percentage obesity also determined by the 2012 Gallup-Healthways survey. We used Spearman rank-order correlation to examine the relationship between CWHs based on total three-hourly observations of comfortable weather between 1950 and 2011 and three wellness measures for each city. Gallup-Healthways data were unavailable for Bismarck, North Dakota, and Cheyenne, Wyoming, and happiness index data were unavailable for Las Vegas.

These human wellness indexes provide a broad-scale representation of mental, physical, and overall wellness. The Gallup-Healthways Well-Being Index samples are weighted to correct for unequal selection probability, nonresponse, and double coverage of landline and cell phone users and weighted to match the U.S. population for gender, age, race, Hispanic ethnicity, education, region, population density, and phone status (Gallup-Healthways 2014). Thus, the three indicators reliably reflect subjective well-being, including one multidimensional construct (overall well-being), one targeted only on happiness or psychological wellness, and one focused only on obesity, which is related to physical wellness and health. Some shortcomings of this three-indicator approach include the potential overlap between the obesity index and

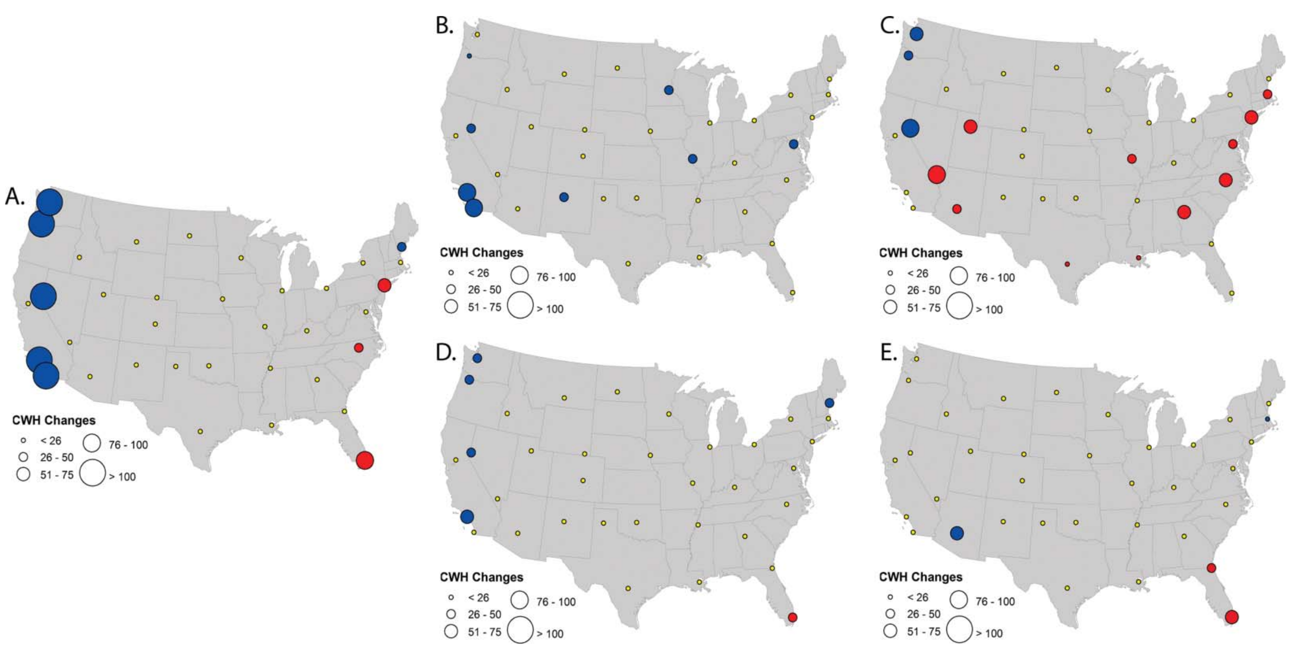

Figure 2. Annual (A) and seasonal (spring, summer, autumn, and winter identified as B–E, respectively) patterns representing the changes in comfortable weather hours between 1950 and 2011 during daytime and nighttime conditions combined. Blue (red) circles indicate significant increases (decreases) in comfortable weather hours and yellow circles indicate no significant changes. Values are shown in Table S1. CWH = comfortable weather hours. (Color figure available online.)

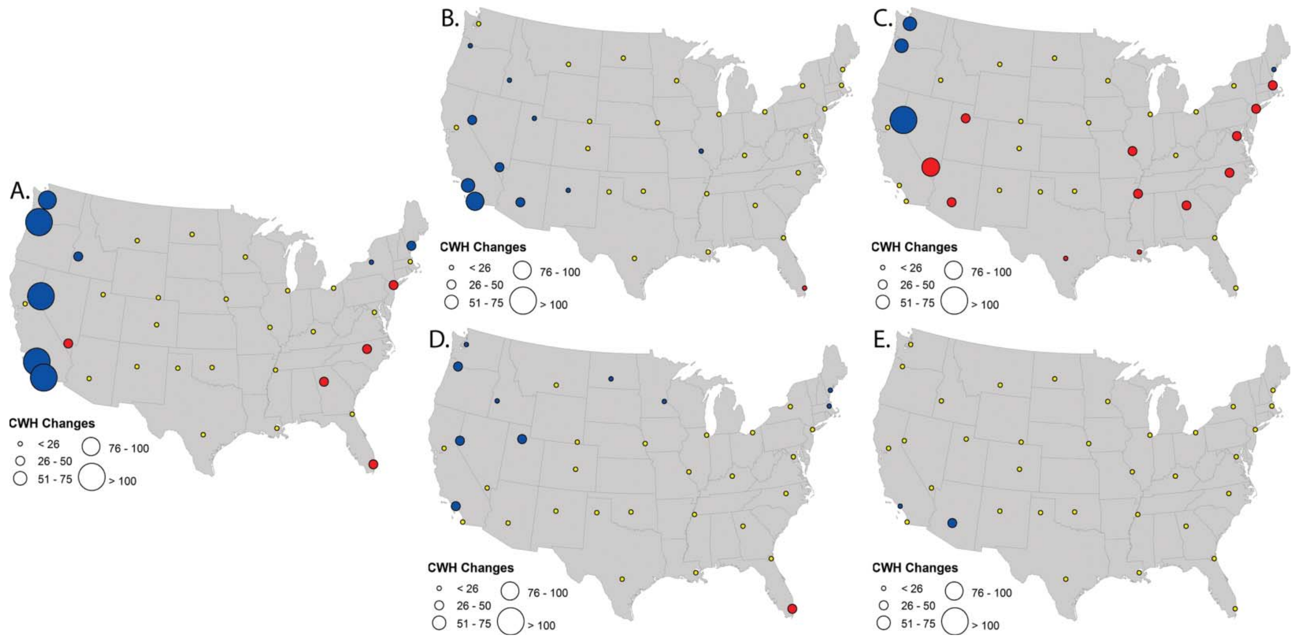

Figure 3. Annual (A) and seasonal (spring, summer, autumn, and winter identified as B – E, respectively) patterns representing the changes in comfortable weather hours between 1950 and 2011 during nighttime conditions. Blue (red) circles indicate significant increases (decreases) in comfortable weather hours and yellow circles indicate no significant changes. Values are shown in Table S1. CWH = comfortable weather hours. (Color figure available online.)

the overall well-being index (which includes a physical dimension), as well as the lack of analysis of other (e.g., socioeconomic) data that might further explain regional variation and temporal changes in subjective wellness. In spite of these limitations, the regional effects of climate change on wellness and health deserve attention and our three-indicator approach provides reliable information about differences in

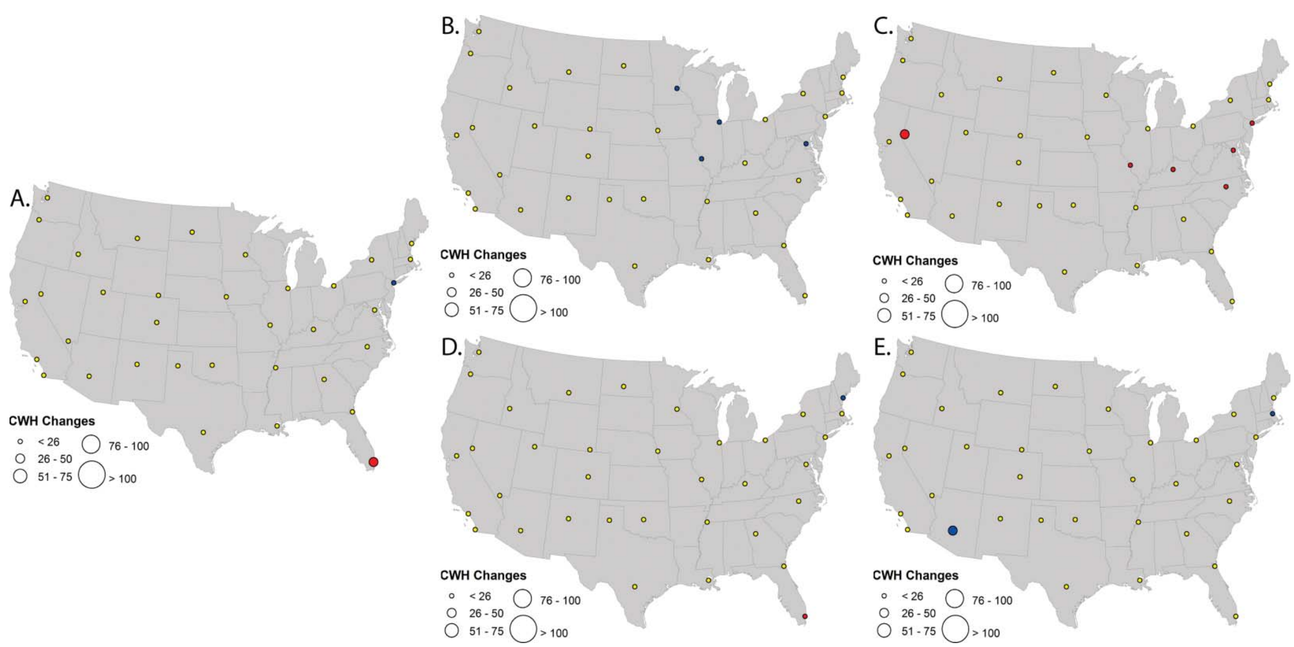

Figure 4. Annual (A) and seasonal (spring, summer, autumn, and winter identified as B – E, respectively) patterns representing the changes in comfortable weather hours between 1950 and 2011 during daytime conditions. Blue (red) circles indicate significant increases (decreases) in comfortable weather hours and yellow circles indicate no significant changes. Values are shown in Table S1. CWH = comfortable weather hours. (Color figure available online.)

Table 1. Mean monthly and mean annual comfortable weather hours for each city based on the number of three-hourly observation periods from 1950 to 2011

City	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Portland, OR	609	0	2	12	30	61	98	118	127	105	50	5	0
Seattle	500	0	2	5	18	49	83	110	117	88	26	2	0
Sacramento	706	6	24	51	67	81	81	86	89	88	87	44	8
Reno	554	1	6	21	46	79	89	80	80	77	58	16	2
Los Angeles	1,379	60	60	75	99	153	184	152	137	150	177	122	70
San Diego	1,443	74	76	101	133	189	198	135	97	123	174	135	81
Boise	548	0	1	11	37	78	95	82	94	93	51	5	0
Las Vegas	691	19	42	89	120	105	45	7	11	62	124	69	17
Phoenix	684	56	67	93	105	92	39	3	4	36	103	86	57
Salt Lake City	547	0	1	14	43	84	93	68	82	95	58	9	0
Billings	527	0	1	9	29	63	93	99	104	79	43	6	1
Albuquerque	744	2	11	40	85	118	98	70	90	119	88	22	2
Cheyenne	499	0	1	7	26	57	84	100	101	74	42	7	1
Colorado Springs	606	3	4	16	40	74	94	108	109	86	56	14	3
Amarillo	635	12	21	43	69	90	77	54	68	95	75	32	12
Bismarck	449	0	0	3	24	66	88	84	87	66	28	2	0
San Antonio	520	53	64	94	80	43	9	1	2	23	70	75	59
Oklahoma City	532	11	21	49	82	92	45	13	21	66	87	43	13
Omaha	482	0	2	15	48	91	74	43	58	81	57	13	1
Minneapolis	503	0	0	3	31	84	98	73	90	83	37	4	0
St. Louis	503	5	8	28	66	95	52	24	36	78	77	32	7
New Orleans	516	57	60	92	83	39	6	1	1	17	77	79	61
Memphis	518	21	27	59	90	80	23	6	13	54	88	54	24
Chicago	503	0	1	10	35	72	81	68	74	93	54	13	1
Lexington	568	5	8	28	69	100	70	43	54	83	74	30	7
Atlanta	609	20	29	62	98	99	41	12	16	67	101	59	25
Jacksonville	545	60	63	93	89	54	11	1	1	15	69	84	65
Cleveland	545	1	1	12	37	78	87	73	84	98	55	17	3
Miami	303	79	74	64	34	8	0	0	0	0	11	43	69
Raleigh	580	17	21	47	82	96	53	23	32	72	85	48	21
District of Columbia	501	5	6	24	62	100	58	20	29	80	83	32	7
Syracuse	511	1	1	5	28	72	91	83	90	86	41	12	2
New York City	549	1	1	8	37	97	98	39	46	107	89	24	3
Boston	566	1	1	4	21	68	105	84	98	115	55	14	2
Portland, ME	505	0	0	1	10	47	94	112	115	94	28	3	0

subjective well-being that might be linked to changes in CWHs.

Results

Annual and Seasonal Changes in CWH: 1950–2011

CWH Changes in Total Values. There were distinct geographic patterns in the occurrence of CWHs, with five of the six stations west of 117°W experiencing significant increases in the amount of comfortable weather (Figure 2A). Increases during the shoulder seasons of spring and autumn were most common, whereas no changes occurred during winter. Los Angeles and Reno experienced the greatest annual increases, with Reno increasing CWHs during all seasons except winter. Only Miami, Raleigh, and New York experienced decreases in CWHs, but there was no consistency in the seasonality of the changes. For Miami, CWHs during autumn and winter seasons significantly decreased, whereas for Raleigh and New York the annual decrease was driven by a significant reduction in CWHs during summer. With the exception of Portland, Maine, which had an overall increase in CWHs, all of the other stations (n = 26) experienced no annual changes in CWHs, although a third of these stations recorded significant decreases in hours of comfortable weather during summer (Figure 2A).

CWH Changes in Nighttime Values. Annual increases in CWHs during nighttime occurred at all stations west of 116°W (Figure 3A). These changes were principally driven by increases in spring and autumn conditions and at some stations, changes during summer (Figures 3A–3E). Conversely, three of the five cities with negative changes in annual CWHs are located in the Southeast. Seasonally, the greatest increase in CWHs typically occurred during spring and autumn in the western cities (Figures 3B and 3D), particularly Los Angeles (+73.7 CWHs in spring and +43.8 CWHs in autumn), Reno (+28.2 and + 44.3), and San Diego (+88.6 spring). Nine cities experienced an increase in CWHs during spring, whereas Miami had a decrease in CWHs. Similar conditions occurred during autumn, with ten cities experiencing increases in CWHs and only Miami experiencing a decrease (Figure 3D).

Twelve of the thirty-five cities had decreases in CWHs during summer nights (Figure 3C). Las Vegas (–75.4 CWHs) experienced the greatest decrease, followed by Atlanta (–49.9), Salt Lake City (–48.7), and New York (–48.5). Four cities experienced large increases (Reno; Portland, Oregon; Seattle; and Portland, Maine), but the increase in Reno was the most extreme (+132.9 CWHs) and more than twice the increase of the other cities. Changes in CWHs in winter were less remarkable than the other seasons, with only two cities, Phoenix and Los Angeles, recording increases and no cities experiencing decreases (Figure 3E).

CWH Changes in Daytime Values. Annually, changes in daytime CWHs were minimal (Figure 4A) with no geographic pattern. Seasonally, changes principally occurred during spring, with increases at four stations, and summer, with decreases at six stations (Figures 4B and 4C). Minimal changes also occurred during autumn and winter periods (Figures 4D and 4E).

CWH Patterns, Monthly Ranks, and Relationships with Wellness

Cities in the Pacific Southwest, with the exception of Reno, had the greatest amount of annual comfortable weather. Five of the ten highest ranked cities based on CWHs (Table 1, Figure 5) are located in this

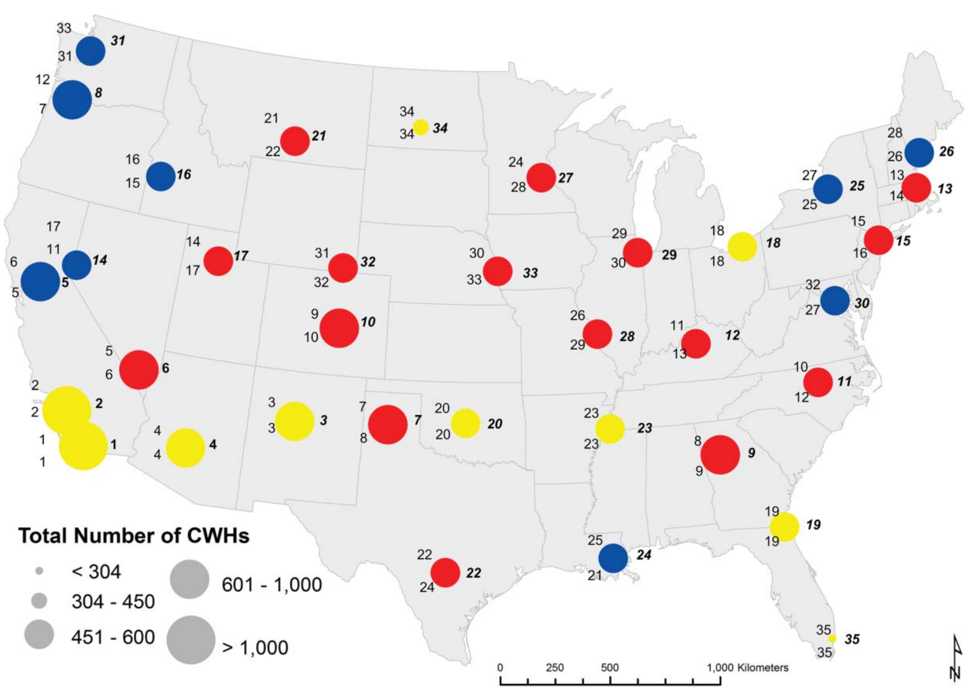

Figure 5. Annual mean number of comfortable weather hours based on three-hourly observations with annual relative rank (number on right), relative rank between 1950 and 1980 (top left) and relative rank between 1981 and 2011 (bottom left). Blue circles indicate stations with increased relative rank from the early-to-late period, red circles indicate decreases, and yellow circles indicate no change. Values are shown in Table S2. CWH = comfortable weather hours. (Color figure available online.)

region and each city recorded an annual average of at least 650 CWHs. The southwestern coast had the most comfortable weather, particularly San Diego and Los Angeles (Figure 5). Although considerably inland, Albuquerque ranked third. Other southwestern U.S. cities ranked in the top ten, including Sacramento, Las Vegas, and Phoenix. These cities ranked highly during the nonsummer months but generally fell to the bottom quartile during June through September (Figures 6 and 7).

The second highest amount of comfortable weather occurred in the southeastern Atlantic region, as Atlanta, Raleigh, and Lexington ranked ninth, eleventh, and twelfth annually. Other southern U.S. cities did not rank as highly but rather had a split of low- and high-ranking months, indicating that the annual rank does not illustrate the comfort level for this region (Figures 6 and 7). Instead, these locations (e.g., Jacksonville, Miami, New Orleans) were represented by a period of above-average rankings of CWHs in the cool-season months but low rankings from late spring through late autumn (Figures 6 and 7).

The lowest ranked cities also exhibited a pronounced geographic pattern. With the exception of Portland, Oregon, no city north of 40°N had an overall CWH rank within the top ten (Table 1, Figure 5). In particular, Bismarck (rank = 34), Omaha (33), Cheyenne (32), and Seattle (31) all had comparatively low CWHs totals (Figure 5) because of unfavorable cool-season conditions. Conversely, several southeastern cities had low annual CWH ranks because of the unfavorable warm-season conditions. Miami, for example, ranked thirty-fifth despite optimal conditions during winter (Figures 5–7) and experienced 21 percent of the CWHs of San Diego and 67 percent of Bismarck's CWHs total (Table 1).

The monthly differences in CWHs illustrate the spatiotemporal patterns of the shift in comfortable weather from the south in the winter to the north in the summer (Figures 6 and 7) as would be expected in the Northern Hemisphere midlatitudes. The seasonal shift from north to south, however, is more pronounced in the eastern United States (Figures 6 and 7) and less defined in the western United States (particularly San Diego and Los Angeles). The monthly rankings demonstrate that most cities experience a high level of variability in comfortable weather that is difficult to discern from annual rankings.

CWHs during the individual summer months and summer season combined were significantly related with each of the three wellness metrics of happiness, obesity, and well-being for total-day conditions and for happiness and obesity for nighttime and daytime conditions (Table 2). CWHs during spring and winter

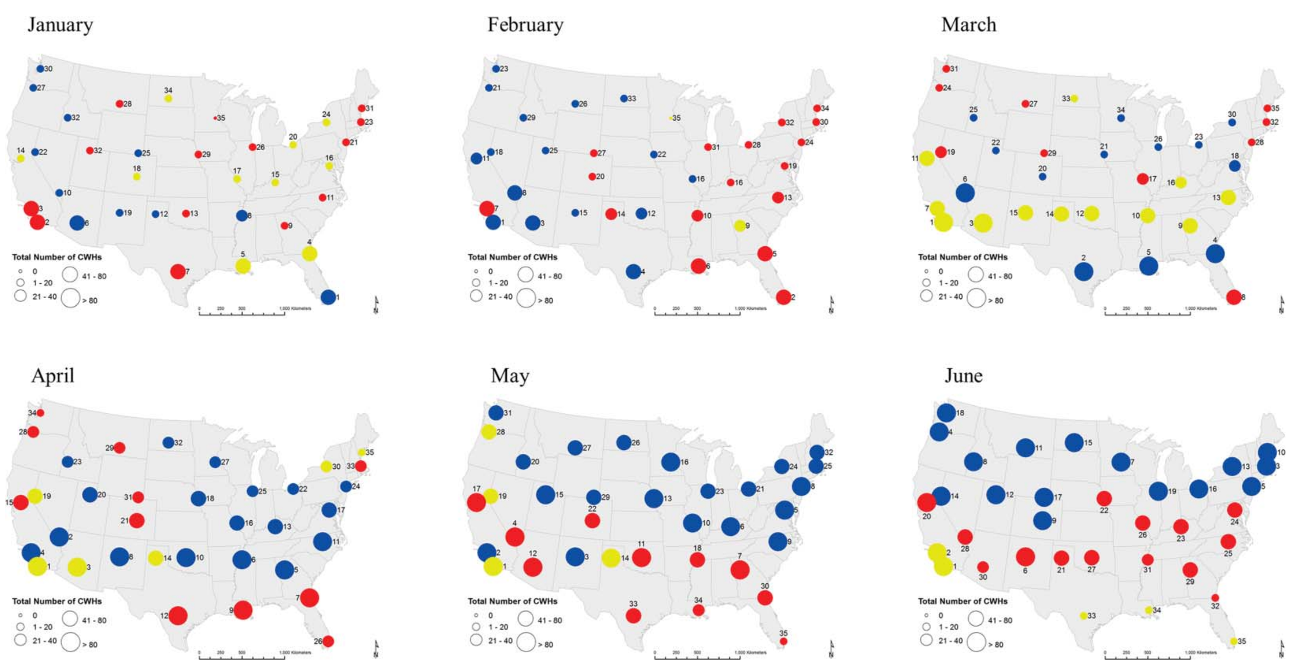

Figure 6. Mean monthly number of comfortable weather hours for each city with rank. Color represents increasing (blue), no change (yellow), and decreasing (red) change in rank from previous month for January through June. Values are shown in Table 1. CWH = comfortable weather hours. (Color figure available online.)

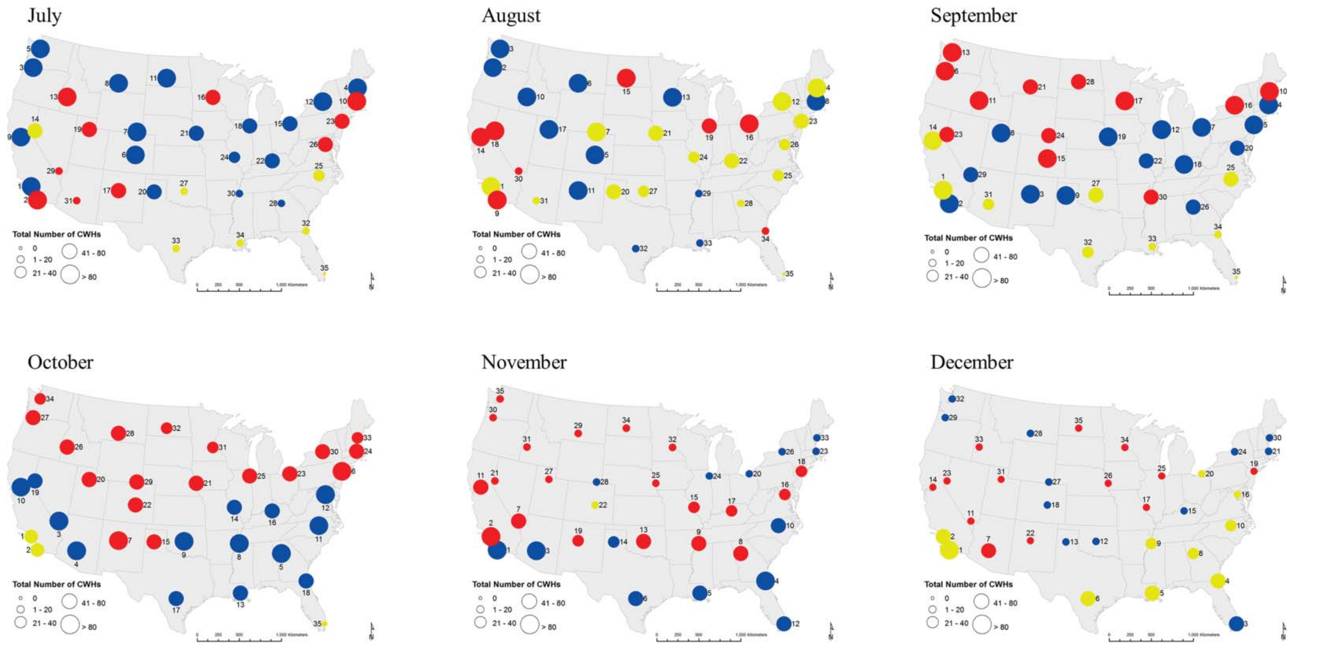

Figure 7. Mean monthly number of comfortable weather hours for each city with rank. Color represents increasing (blue), no change (yellow), and decreasing (red) change in rank from previous month for July through December. Values are shown in Table 1. CWH = comfortable weather hours. (Color figure available online.)

were not significantly related to the wellness metrics, whereas obesity was significantly negatively related to autumn CWHs during daytime in September (Table 2). These results indicate that the relationship between CWHs and wellness has a distinct seasonal component that might reflect the influence of CWHs on the reported summertime peak in physical activity in the United States (e.g., Tucker and Gilliland

Table 2. Correlation results showing Spearman's rank, r and p values between comfortable weather hours and well-being and happiness indexes (n =33) and obesity (n =34) for monthly and seasonal conditions

	Wellness measures		
	Well-being index	Happiness index	% Obesity
Total CWHs	−0.017 (0.924)	0.096 (0.588)	−0.291 (0.100)
CWHs rank	0.065 (0.720)	0.193 (0.273)	0.133 (0.460)
Jan. CWHs	−0.257 (0.149)	−0.287 (0.100)	0.072 (0.689)
Feb. CWHs	−0.177 (0.323)	−0.168 (0.342)	0.112 (0.535)
Mar. CWHs	−0.231 (0.196)	−0.225 (0.200)	0.168 (0.351)
Apr. CWHs	−0.166 (0.355)	−0.260 (0.137)	0.133 (0.460)
May CWHs	0.151 (0.403)	−0.063 (0.724)	−0.171 (0.343)
Jun. CWHs	**0.353 (0.044)**	**0.447 (0.008)**	**−0.571 (0.001)**
Jul. CWHs	**0.350 (0.046)**	**0.418 (0.014)**	**−0.396 (0.023)**
Aug. CWHs	**0.396 (0.022)**	**0.404 (0.018)**	**−0.390 (0.025)**
Sep. CWHs	0.302 (0.088)	0.301 (0.084)	**−0.554 (0.001)**
Oct. CWHs	−0.049 (0.785)	−0.268 (0.125)	−0.042 (0.817)
Nov. CWHs	−0.212 (0.236)	−0.317 (0.067)	0.075 (0.678)
Dec. CWHs	−0.222 (0.215)	−0.291 (0.095)	0.055 (0.762)
JJA CWHs (Total)	**0.386 (0.027)**	**0.462 (0.006)**	**−0.440 (0.010)**
JJA CWHs (Night)	0.296 (0.095)	**0.409 (0.016)**	**−0.489 (0.004)**
JJA CWHs (Day)	0.335 (0.057)	**0.382 (0.026)**	**−0.387 (0.026)**
SON CWHs (Day)	0.079 (0.663)	−0.057 (0.747)	**−0.390 (0.025)**

Note: Significance values are shown parenthetically with $p < 0.05$ shown in bold. Nonsignificant correlations between seasonal comfortable weather hours, and wellness are not shown. CWH = comfortable weather hours; JJA = June, July, and August; SON = September, October, November.

2007). Additionally, total CWHs and CWHs rank by city did not have a significant relationship with any of the well-being metrics (Table 2).

Changes in annual relative rank by city from the early (1950–1980) to the late (1981–2011) periods also exhibited spatial patterns (Figure 5). Nine cities experienced enough annual CWH increases in the latter period to move closer to the top of the relative rankings, whereas sixteen cities experienced a decrease in rank, and seven cities experienced no change in relative CWHs ranking between early and late periods. The decreases in CWHs rank occurred principally in noncoastal cities with the exception of New York and Boston, each of which dropped one spot in the rankings. The most substantial decreases were concentrated in the Midwest, Great Plains, and Intermountain West. The largest increases in relative CWH rank were in the Pacific Northwest (including Northern California) and parts of the Northeast, with the exception of New Orleans, which was the only city south of 35°N to experience an increase in relative rank over the period of study. With the exception of Bismarck and Cleveland, cities with no change were largely concentrated in a relatively narrow east-to-west band covering much of the southern tier of the United States and included cities at the top of the relative rankings (San Diego and Los Angeles) as well as lower ranked cities in the Mid-South and Florida. The western cities with no change in annual relative rank are areas in which modest spring and autumn CWHs gains and no losses in summer produced annual CWHs gains, keeping these cities near the top of the overall CWHs rankings. The central and eastern cities with no change reflect either no change in any season (i.e., Oklahoma City, Memphis, Bismarck, and Cleveland) or modest CWHs decreases in autumn and winter with no spring or summer increases (i.e., Jacksonville and Miami).

Discussion

Changes in CWHs

Increasing temperatures and rising dewpoint temperatures in the conterminous United States since the mid-twentieth century produced changes in CWHs. The distinct seasonal and geographical patterns reduce the possibility that changes in CWHs were related to relocation of stations or changes in observation techniques. The combined increases in CWHs during spring and, to a lesser degree, autumn were greater than the net losses in CWHs during summer and winter. Combining the seasons, three cities experienced net decreases in CWHs (i.e., less comfortable weather), six experienced net increases, and no changes occurred for twenty-six cities. These results indicate a minor overall increase in CWHs in the continental United States between 1950 and 2011 but with two distinctive features. For all cities combined, total increases in CWHs during spring (+375) were matched by losses in CWHs in summer (–325), with moderate gains in autumn (+170) thus accounting for the overall net increase. The largest positive changes in the amount of comfortable weather, however, principally occurred in a few cities west of 117° W (Figure 2). Thus, on a geographical scale, one region experienced large net increases in CWHs, whereas for the majority of the remaining cities minor changes occurred, with increases in spring and autumn CWHs matched by losses in summer CWHs.

Significant changes in CWHs also occurred more frequently during the nighttime as opposed to daytime hours—a finding that might indicate the influence of an urban heat island effect that is most pronounced at night (Oke 1973; Klysik and Fortuniak 1999). The majority of changes during daytime occurred in more humid locations, consistent with the recent finding that in wetter climates urbanization leads to a 58 percent reduction in convection efficiency, whereas in dry-climate cities urbanization increases convection efficiency and promotes a cooling effect (Zhao et al. 2014).

In the eastern and southern United States, the additional influence of increasing summertime dewpoint temperatures (Brown and DeGaetano 2013) decreases nighttime cooling and thus the proportion of the annual seasonal cycle when comfortable weather conditions would most likely occur. For example, Raleigh's summer minimum dewpoint temperatures have significantly increased approximately 2°C since 1950, resulting in reduced CWHs during summer nights and days. Temperature, however, remains the principal ($p < 0.05$) influence on summertime CWHs at thirty-one of the thirty-five cities, with all exceptions occurring in the humid Southeast. Only Jacksonville, Memphis, Miami, and New Orleans had higher Wald chi-square values for dewpoint temperature—indicating its primacy on CWHs—than for air temperature.

Continued warming and rising dewpoint temperatures in the next decade (Intergovernmental Panel on Climate Change 2013) will likely cause further changes in the spatiotemporal patterns of CWHs. Despite the overall annual increase in CWHs, these results show that summer CWHs decreased at eleven of the thirty-five stations and most locations are likely to incur further losses if air and dewpoint temperatures continue to rise. Thus, we anticipate the trend toward fewer CWHs during summer to continue with additional cities incurring negative trends, particularly the southeastern U.S. locations characterized by persistently warm and humid conditions with minimal nighttime cooling. Our results are consistent with findings and projections for other midlatitude locations (e.g., Fujibe 2009; Fischer and Schär 2010; Ding and Qian 2011; Willett and Sherwood 2012), suggesting that humid locations will have the largest increases in heat stress.

The overall pattern of summertime decreases in CWHs is in concert with trends toward higher minimum temperatures prevalent throughout much of the world (e.g., Alexander and Arblaster 2009; Fujibe 2009; Fischer and Schär 2010; Lauritsen and Rogers 2012; Willett and Sherwood 2012) and particularly in urban areas (McCarthy, Betts, and Best 2010; Fischer, Oleson, and Lawrence 2012; He et al. 2013). For example, urban heat island effects could account for some of the decreases in summer CWHs in rapidly growing cities outside the humid southeastern United States, such as Las Vegas, Salt Lake City, and Phoenix. Conversely, the duration of comfortable weather might increase (decrease) during spring (autumn) with an earlier (later) onset occurring (Cayan et al. 2001) depending on location. Perhaps more intriguing is whether positive trends in CWHs will emerge during winter, particularly in the southern cities. Our analysis showed few changes during winter, yet several cities including San Antonio, New Orleans, and Phoenix have the potential for significant increases, as all have experienced warming trends since the late 1970s (E. Lu and Takle 2010).

The overall spatial pattern of changes in rank between early and late periods (Figure 5) implies that, on an annual basis, cities nearer the center of the United States generally experienced relative reductions in CWHs in recent decades. With a few exceptions, coastal cities, especially in the west, experienced relative CWH increases in the same time period. The annual total (day and night combined) CWH increases in these western cities reflect seasonal increases in one or more of spring, summer, and autumn seasons, whereas each of these cities experienced no change in winter. This is an important finding, given the relative importance of the warm season in terms of peak physical activity and the implications for wellness. A potential caveat to our findings is that climatically regulated human comfort is subject to change with acclimatization and adaptation (de Dear and Brager 1998; Humphreys and Nicol 1998; Stathopoulos, Wu, and Zacharias 2004). Thus, under conditions of regional-scale climate change, conditions currently viewed as comfortable might change.

CWHs and Wellness

Although an association between happiness and health has been identified, only recently has theoretical and empirical work in positive psychology suggested several mechanisms of the effect(s) of happiness on health. These include evidence that happiness enhances individual cognition, attention span, and repertoires of thoughts and actions. These enhancements in turn promote improved physical health and ability to cope with adversity, undo or correct the detrimental effects of negative emotions, and produce resilience, which contributes to psychological well-being and physiological recovery (Siahpush, Spittal, and Singh 2008). Thus, the effects of climate or climate change on happiness might be particularly relevant in the context of their impacts on overall wellness and health. The climate impacts on health are direct, insofar as research suggests linkages between climate variables and physical activity and exercise, which have physical and psychological benefits (e.g., Roscoe 2009). The indirect health impacts of changes in comfortable weather might result from the positive or negative influence on individual subjective well-being, which is an important component of wellness and therefore of health (Siahpush, Spittal, and Singh 2008; Roscoe 2009). In this context, climate alone does not determine wellness or health but could be an important input to several different dimensions of overall wellness, which itself is linked to health (e.g., Siahpush, Spittal, and Singh 2008; Roscoe 2009).

To our knowledge, no study has identified that it might not be the total amount or persistence of comfortable weather but rather its timing in the annual seasonal cycle that provides a link between wellness and climate. Our results suggest that it is predominantly the amount of CWHs during summer (Table 2) that is significantly related to the wellness metrics of happiness, well-being, and obesity. These results concur with studies that have found either climate or changing climate to be one of the significant predictors of wellness (Shapiro and Smith

1981; Cragg and Kahn 1997, 1999; Frijters and Van Praag 1998; Maddison 2003; Maddison and Bigano 2003; Rehdanz and Maddison 2005; Berry, Bowen, and Kjellstrom 2009; Maddison and Rehdanz 2011; Weissbecker 2011) and are noteworthy in their consistency of response to the summer months. More people engage in non-work-related activities during the summer, and summer is the primary season for vacations. Hence, the coincidence of optimal (or better) weather and increased outdoor time might explain this relationship.

Greater day lengths during summer offer more daylight hours to enjoy the benefits of comfortable weather, but we found no significant relationship between day length and wellness metrics (data not shown). Many other characteristics inherent to each city (e.g., demographics, cost of living, crime, school quality, transportation ease, culture) affect physical and psychological wellness, but our results show that the effects of climate on happiness, obesity, and well-being can be temporally independent of other local variables and that these wellness metrics had remarkably similar correlations to summertime CWHs. Conversely, the absence of significant correlations between CWHs and wellness during the nonsummer months suggests that the importance of some other factor(s) become more operative. As such, additional changes in summertime CWHs might have larger impacts on wellness than during any other season.

Conclusions

Are people experiencing more or less weather-related discomfort over time and place, and are people living in certain places happier because of the climate they live in? Our results suggest the answer is yes to both questions. We know that the duration of comfortable weather can be viewed as a measurable commodity to attract people to specific areas based on tourism (Gómez Martín 2005; Becken and Wilson 2013), walkability, outdoor dining, and an overall sense of wellness (Keller et al. 2005; Tsutsui 2013), so our findings have substantial implications. Spatiotemporal patterns identified in this study suggest that the amount of comfortable weather is a dynamic feature subject to significant change at many locations and has been influenced by warmer and more humid conditions during the latter half of the twentieth and early twenty-first century. Our results suggest that in the continental United States, the majority of changes have occurred during the nighttime hours with noteworthy increases in comfortable weather principally during spring and autumn and decreases during summer (Figures 3B, 3C, and 3D). Conversely, fewer changes have occurred during daytime hours. Total day conditions also show few changes, with increases concentrated along the West Coast and decreases principally in the South (Figures 2A–2E).

Calendar year 2014 was the warmest year dating to 1880 (National Oceanic and Atmospheric Administration National Centers for Environmental Information 2015) and was preceded by a series of above-average temperature years during the prior decade, including the hottest year on record in the United States in 2012 (National Oceanic and Atmospheric Administration National Centers for Environmental Information 2014). Thus, the likelihood of declines in summertime CWHs and increases in spring and autumn CWHs should continue if warming trends in the continental United States persist into the next decade and beyond. Less certain is the potential effect of continued changes in summertime CWHs on the spatial pattern of wellness in the United States. Our findings showed that approximately a third of the selected cities exhibited decreases in summertime CWHs. This trend is likely to continue and might affect the current spatial pattern of wellness in the United States, suggesting another potential consequence of warming atmospheric conditions during the twenty-first century.

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Supplemental Material

Supplemental data for this article can be accessed on the publisher's website at: http://dx.doi.org/10.1080/00045608.2015.1095058

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