Temperature Change in the Contiguous 48 States Between 1901 and 2020

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ABSTRACT

Climate change has become a global emergency. Many people have studied the rise in temperatures over the last few decades. But few have studied how monthly average temperatures at the state level in the United States have changed for more than a century. The authors divide the 120-year period January 1901 to December 2020 into two 60-year periods and then compare the monthly average temperature in each period for each of the 48 contiguous U.S. states. When these data are divided into seasons, the largest changes are observed for winter (December, January, ad February) and summer (June, July, and August) months, especially among states that have coastal access to the Pacific Ocean or the Atlantic Ocean in the northeast. Apart from presenting a series of two-sample *t*-tests for each of the 48 states for all seasons combined and one for each of the four seasons, the authors also present color-coded maps summarizing the statistical results for the winter and summer seasons. The maps use the *p*-value of each two-sample *t*-test to show which states in each season between the two 60-year periods are getting cooler (green, light blue, dark blue) and which states are getting warmer (yellow, orange, red).

Introduction

Few climate-related studies have analyzed monthly temperature averages for each year and each U.S. state for more than a few decades.

In a 2017 report, the U.S. Global Change Research Program found that annual average temperature over the contiguous United States increased by 1.2° Fahrenheit for the period
1986 – 2016 relative to 1901 – 1960 and by 1.8° Fahrenheit based on a linear regression for the period 1895 – 2016 [1].

Wang *et al.* [2] analyzed Northern Hemisphere temperature data from 1952 to 2011 and found that the four seasons are no longer of roughly equal length – summers are longer at the expense of the three other seasons.

In 2021, Patel [3] wrote that "[o]ver the past seven decades, researchers found high summertime temperatures are arriving earlier and lasting longer in the year because of global warming."

In this paper, we compare the monthly temperature average in the 48 contiguous states between January 1901 and December 2020. For each of the four seasons, we can tell which states and regions of the continental U.S. are getting significantly warmer and which, if any states, contrary to popular belief, are getting cooler.

The Data

The National Oceanic and Atmospheric Administration (NOAA) has compiled data on monthly state temperature averages (degrees Fahrenheit, hereafter abbreviated F, to tenths of a degree) from January 1895 to the present. These data can be found at https://www.ncei.noaa.gov/pub/data/cirs/climdiv/ and then by selecting the file named climdiv-tmpcst-v1.0.0-20220505 (accessed in June 2022). The last eight digits in the filename change each month as the file is updated. All states are included except for Hawaii. The twelve monthly values for Alaska begin in the year 1925.

And, the temperature values for the District of Columbia are incorporated into the values for Maryland. A detailed description of how the statewide averages are derived can be found in a documentation file at https://ncei.noaa.gov/pub/data/cirs/climdiv/state-readme.txt.

We use monthly state temperature averages for the 48 contiguous U.S. states from January 1901 through December 2020, for a total of 69,120 (= 12 months × 120 years × 48 states) observations. The winter months are December, January, and February; the spring months are March, April, and May; the summer months are June, July, and August; and the fall months are September, October, and November.

When these data are divided into two 60-year periods (January 1901 – December 1960 and January 1961 – December 2020), we find that the five warmest states (all seasons combined) in the first 60-year period are: Florida (69.99° F), Louisiana (66.58° F), Texas (64.68° F), Mississippi (63.93° F), and Georgia (63.51° F); the five coldest states are North Dakota
(39.33° F), Minnesota (39.77° F), Maine (39.78° F), Wyoming (40.49° F), and Montana
(40.83° F). The five warmest states in the second 60-year period are the *same* five states in the *same* order as in the first period; the five coldest states in the second period are also the *same* five states in the *same* order as in the first period.

The five states that experienced the largest increase in temperature from one 60-year period to the next (as a percentage of their first 60-year period average monthly temperature) were: Rhode Island (3.32 percent), Maine (3.24 percent), North Dakota (3.10 percent), Minnesota (3.07 percent), and New Jersey (2.93 percent). Most of the five states that experienced the largest *decrease* in temperature are located in the Deep South: Alabama (-0.65 percent), Mississippi (-0.55 percent), Tennessee (-0.21 percent), Kentucky (-0.20 percent), and Arkansas (-0.18 percent).

Methodology

The 120-year period between January 1901 and December 2020 is divided into two 60-year periods. For each state, the average monthly temperature between January 1901 and December 1960 is compared to the corresponding average over the following 60-year period between January 1961 and December 2020. The comparisons (five for each state: all seasons combined, winter, spring, summer, and fall) use a two-sample *t*-test on the difference between two means. Under the null hypothesis, the two 60-year averages are equal; under the one-tailed alternative hypothesis, the 60-year average in the earlier period is *less than* the 60-year average in the latter period. For each two-sample *t*-test, we report the *p*-value of the one-tailed test. If the *p*-value is less (greater) than .05, a customary level of significance, then one can conclude that the average monthly temperature has (not) increased from one 60-year period to the next. If, however, the *p*-value of the test is greater than .95, one could argue that the one-tailed test could have been flipped from "less than" to "greater than." That is, if the *p*-value is greater than .95, there is evidence that average monthly temperatures from one 60-year period to the next have become cooler.

Because the results of five two-sample *t*-tests for each of the 48 contiguous states may be difficult to assimilate, we produce maps of the continental U.S. which show the temperature changes from one 60-year period to the next. In lieu of using the difference between the two 60-year means, we use the *p*-value of the test. The difference between two means could be "large" (a few degrees Fahrenheit), but the dispersion (noise) around these two monthly averages might be large enough to result in a *p*-value that exceeds .05. Recall that the *p*-value measures the probability of obtaining the observed results, assuming that the null hypothesis is true. The lower the *p*-value, the *greater* the statistical significance of the observed difference between the two 60-year monthly mean temperatures. We present for the two seasons, winter and summer, a color-coded map of the continental U.S. Blue ($p \geq .95$), light blue ($.50 \leq p < .95$), and light green ($.05 < p < .50$) denote cooler temperatures; yellow ($.01 < p \leq .05$), orange ($.001 \leq p \leq .01$), and red ($p < .001$) denote warmer temperatures. At a glance, one can look at the maps and see (for each of the two seasons) which states (and regions of the U.S.) are getting cooler or warmer.

The Results

The results of the two-sample *t*-tests that compare the average monthly temperature for each of the 48 contiguous states between January 1901 and December 1960 to the corresponding average between January 1961 and December 2020 are reported in Table 1. There are five *t*-tests for each state, one for all seasons combined and one for each of the four seasons.

For all four seasons combined, only four states experienced a significant increase in their average monthly temperature (California, New Jersey, Oregon, and Rhode Island) and *no* states experienced a significant decrease (using an alpha-level of 0.05). For the winter season alone (that includes the months of December, January, and February), twenty-seven states experienced a significant increase and only one state (Mississippi) experienced a significant decrease. For the spring season (March, April, and May), *no* states experienced a significant increase or decrease in mean monthly temperature (again, at the 0.05 level of significance). For the summer season (June, July, and August), twenty-four states experienced a significant increase and three states (Alabama, Kentucky, and Mississippi) experienced a significant decrease. Finally, for the fall season (September, October, and November), *no* states experienced either a significant increase or decrease in average monthly temperature.

The statistically discernible change (92.7 percent of them increases) took place during either the winter or summer seasons. Moreover, the most dramatic changes in average monthly temperature in the two aforementioned seasons were recorded in states which have access to either the Pacific Ocean or the Atlantic Ocean in the northeast.

Figure 1 shows a map of the continental U.S. The *p*-values for the two-sample *t*-tests involving winter months are color coded, where cooler average monthly temperatures are represented in light green, light blue, and (coolest) dark blue, while warmer monthly mean temperatures are represented in yellow, orange, and (warmest) red. Figure 2 shows the color-coded *p*-values for the two-sample *t*-tests involving summer months.

Concluding Remarks

Average monthly temperatures for each of the 48 contiguous states are compared between two 60-year periods, January 1901 to December 1960 and January 1961 to December 2020. While there were no discernable differences between the two periods of time in either the spring (March through May) or fall (September through November), about half of all states recorded much warmer or, in a few cases, cooler temperatures in winter (December through February) and summer (June through August).

The implications of global warming across the U.S. are already evident in many states:
increased wildfires, declining water supplies, flooding and erosion in coastal states, shorter ski seasons in the northeast, and a changing growing season that will impact crop and livestock production.

Future research at the state level could compare over the two aforementioned 60-year periods differences in monthly heating and cooling degree values, average precipitation, and various drought indices.

Acknowledgment

The authors wish to thank Howard J. Diamond, Climate Science Program Manager at NOAA's Air Resources Laboratory, who helped the authors find the monthly values on state temperature averages between January 1901 and December 2020.

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Alabama			
All seasons	63.41	63.00	.7231
Winter	47.02	46.34	.9278
Spring	63.04	62.96	.5456
Summer	79.29	78.73	.9976
Fall	64.29	64.00	.6196
Arizona			
All seasons	59.16	60.24	.0724
Winter	41.93	43.17	.0003
Spring	56.94	58.02	.0693
Summer	77.15	78.21	.0002
Fall	60.61	61.54	.1797
Arkansas			
All seasons	60.60	60.49	.5585
Winter	41.62	41.29	.7617
Spring	60.09	60.48	.3182
Summer	78.96	78.64	.8771
Fall	61.72	61.53	.5934
California			
All seasons	57.09	58.30	.0244
Winter	43.15	44.57	<.0001
Spring	54.33	55.30	.0527
Summer	71.99	73.23	.0003
Fall	58.89	60.11	.0774

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Colorado			
All seasons	44.38	45.43	.0991
Winter	25.10	26.34	.0016
Spring	42.37	43.66	.0583
Summer	64.33	65.34	.0011
Fall	45.74	46.39	.2692
Connecticut			
All seasons	47.74	49.07	.0605
Winter	26.57	28.34	.0002
Spring	45.74	46.95	.1065
Summer	67.94	69.20	<.0001
Fall	50.71	51.79	.1309
Delaware			
All seasons	53.99	55.18	.0700
Winter	34.46	35.72	.0047
Spring	52.09	53.22	.1043
Summer	73.08	74.33	<.0001
Fall	56.32	57.45	.1237
Florida			
All seasons	69.99	70.75	.0557
Winter	58.70	59.12	.1472
Spring	69.28	70.12	.0574
Summer	80.35	81.15	<.0001
Fall	71.65	72.61	.0773

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Georgia			
All seasons	63.51	63.57	.4611
Winter	47.49	47.56	.4322
Spring	63.18	63.38	.3931
Summer	78.95	78.74	.8704
Fall	64.41	64.61	.4129
Idaho			
All seasons	42.40	43.27	.1387
Winter	23.62	25.18	.0007
Spring	40.84	41.51	.1921
Summer	61.66	62.50	.0369
Fall	43.50	43.88	.3581
Illinois			
All seasons	51.63	52.02	.3387
Winter	28.15	28.37	.3584
Spring	50.87	51.95	.1491
Summer	73.60	73.48	.6521
Fall	53.88	54.28	.3627
Indiana			
All seasons	51.35	51.69	.3578
Winter	28.95	29.12	.3845
Spring	50.28	51.28	.1633
Summer	72.63	72.40	.7789
Fall	53.56	53.95	.3631

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Iowa			
All seasons	47.53	47.83	.3859
Winter	21.08	21.59	.2126
Spring	47.26	48.10	.2345
Summer	71.60	71.41	.7078
Fall	50.19	50.23	.4846
Kansas			
All seasons	54.11	54.56	.3133
Winter	31.12	31.94	.0616
Spring	52.78	53.91	.1244
Summer	76.62	76.61	.5193
Fall	55.89	55.80	.5328
Kentucky			
All seasons	55.72	55.61	.5542
Winter	35.82	35.54	.7025
Spring	55.03	55.43	.3286
Summer	74.88	74.37	.9707
Fall	57.17	57.11	.5192
Louisiana			
All seasons	66.58	66.51	.5464
Winter	51.37	50.68	.9405
Spring	66.30	66.56	.3483
Summer	81.19	81.18	.5177
Fall	67.47	67.60	.4419

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Maine			
All seasons	39.78	41.07	.0931
Winter	15.14	17.16	.0001
Spring	37.94	38.90	.1937
Summer	62.40	63.52	.0003
Fall	43.66	44.69	.1563
Maryland			
All seasons	53.63	54.54	.1326
Winter	33.77	34.69	.0279
Spring	52.15	53.05	.1609
Summer	72.86	73.80	.0004
Fall	55.75	56.63	.1870
Massachusetts			
All seasons	46.66	47.91	.0740
Winter	25.43	27.05	.0005
Spring	44.60	45.64	.1433
Summer	66.89	68.20	<.0001
Fall	49.73	50.73	.1476
Michigan			
All seasons	43.30	44.46	.1112
Winter	19.87	21.39	.0028
Spring	40.95	42.54	.0790
Summer	65.66	66.32	.0221
Fall	46.72	47.58	.2126

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Minnesota			
All seasons	39.77	40.99	.1454
Winter	10.04	12.02	.0030
Spring	39.74	41.25	.1262
Summer	66.12	66.75	.0342
Fall	43.18	43.95	.2793
Mississippi			
All seasons	63.93	63.58	.6900
Winter	47.29	46.51	.9512
Spring	63.61	63.67	.4668
Summer	80.07	79.64	.9827
Fall	64.74	64.50	.5985
Missouri			
All seasons	54.59	54.73	.4357
Winter	32.20	32.41	.3540
Spring	53.93	54.75	.1996
Summer	75.77	75.43	.8359
Fall	56.45	56.35	.5378
Montana			
All seasons	40.83	41.96	.1071
Winter	18.89	21.10	.0007
Spring	39.71	40.88	.1141
Summer	62.50	63.29	.0382
Fall	42.22	42.56	.3780

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Nebraska			
All seasons	48.29	48.93	.2562
Winter	24.37	25.68	.0130
Spring	46.95	48.09	.1355
Summer	71.80	71.87	.4250
Fall	50.03	50.05	.4908
Nevada			
All seasons	49.25	50.33	.0842
Winter	31.19	32.82	.0002
Spring	46.96	47.70	.1593
Summer	68.55	69.67	.0057
Fall	50.29	51.11	.2140
New Hampshire			
All seasons	42.07	43.27	.0980
Winter	18.74	20.51	.0004
Spring	40.40	41.46	.1633
Summer	63.76	64.84	.0003
Fall	45.39	46.28	.1874
New Jersey			
All seasons	51.11	52.61	.0360
Winter	30.68	32.49	.0001
Spring	49.15	50.52	.0717
Summer	70.85	72.34	<.0001
Fall	53.76	55.11	.0842

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
New Mexico			
All seasons	52.75	53.59	.1308
Winter	35.05	36.00	.0054
Spring	51.53	52.58	.0842
Summer	70.91	71.59	.0018
Fall	53.52	54.19	.2484
New York			
All seasons	44.38	45.23	.1778
Winter	21.52	22.84	.0084
Spring	42.39	43.30	.2012
Summer	65.86	66.36	.0465
Fall	47.74	48.41	.2574
North Carolina			
All seasons	58.65	58.84	.3922
Winter	41.33	41.53	.3207
Spring	57.95	58.19	.3788
Summer	75.52	75.59	.3813
Fall	59.79	60.06	.3893
North Dakota			
All seasons	39.33	40.55	.1474
Winter	9.59	12.15	.0008
Spring	39.43	40.57	.1937
Summer	66.09	66.76	.0458
Fall	42.21	42.71	.3573

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Ohio			
All seasons	50.42	50.91	.2904
Winter	28.90	29.24	.2753
Spring	49.05	50.04	.1617
Summer	71.04	71.13	.3877
Fall	52.69	53.23	.3069
Oklahoma			
All seasons	59.83	59.80	.5133
Winter	39.04	39.14	.4200
Spring	58.85	59.41	.2609
Summer	80.11	79.74	.8585
Fall	61.33	60.93	.6412
Oregon			
All seasons	46.14	47.35	.0295
Winter	31.35	33.32	<.0001
Spring	44.11	44.80	.1229
Summer	61.66	62.94	.0017
Fall	47.42	48.33	.1553
Pennsylvania			
All seasons	48.09	48.69	.2440
Winter	26.87	27.68	.0577
Spring	46.68	47.33	.2581
Summer	68.29	68.63	.1142
Fall	50.53	51.12	.2792

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Rhode Island			
All seasons	48.17	49.77	.0254
Winter	28.22	30.06	.0001
Spring	45.54	47.02	.0516
Summer	67.36	69.22	<.0001
Fall	51.55	52.78	.0913
South Carolina			
All seasons	62.52	62.69	.4011
Winter	45.91	46.01	.4041
Spring	62.05	62.36	.3432
Summer	78.69	78.73	.4177
Fall	63.42	63.65	.4013
South Dakota			
All seasons	44.34	45.22	.2048
Winter	17.68	19.54	.0045
Spring	43.46	44.49	.1887
Summer	69.52	69.98	.1460
Fall	46.68	46.87	.4438
Tennessee			
All seasons	57.90	57.78	.5588
Winter	39.25	38.91	.7488
Spring	57.47	57.69	.3948
Summer	75.92	75.57	.9160
Fall	58.95	58.95	.5009

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Texas			
All seasons	64.68	65.06	.2977
Winter	47.30	47.72	.1518
Spring	64.35	65.29	.1027
Summer	81.49	81.36	.7211
Fall	65.58	65.86	.3813
Utah			
All seasons	47.30	48.41	.0958
Winter	27.14	28.52	.0025
Spring	45.66	46.61	.1197
Summer	68.05	69.36	.0006
Fall	48.36	49.18	.2273
Vermont			
All seasons	41.11	42.25	.1159
Winter	16.97	18.81	.0007
Spring	39.43	40.54	.1658
Summer	63.30	64.10	.0044
Fall	44.73	45.57	.2093
Virginia			
All seasons	54.86	55.24	.3129
Winter	36.21	36.55	.2329
Spring	53.97	54.45	.2899
Summer	72.95	73.25	.1172
Fall	56.30	56.69	.3441

Table 1. Average Temperatures Between Two 60-Year Periods, January 1901 – December 1960 and January 1961 – December 2020, by State and by Season
(Continued)

State	January 1901 to December 1960	January 1961 to December 2020	*p*-value on difference*
Washington			
All seasons	45.88	46.79	.0825
Winter	30.06	31.93	<.0001
Spring	45.09	45.48	.2695
Summer	61.55	62.49	.0077
Fall	46.80	47.28	.3029
West Virginia			
All seasons	51.71	51.87	.4243
Winter	32.37	32.34	.5211
Spring	50.85	51.30	.3117
Summer	70.29	70.20	.6323
Fall	53.35	53.63	.3906
Wisconsin			
All seasons	42.20	43.10	.1949
Winter	15.38	16.91	.0081
Spring	41.43	42.68	.1498
Summer	66.49	66.80	.1796
Fall	45.48	46.02	.3270
Wyoming			
All seasons	40.49	41.57	.1073
Winter	19.93	21.50	.0008
Spring	38.43	39.74	.0691
Summer	61.93	62.81	.0201
Fall	41.68	42.24	.3071

*All *p*-values are for a one-tailed less than alternative, that is, that the average temperature in the period January 1901 – December 1960 is less than the corresponding average in the period January 1961 – December

Figure 1. Color-Coded Change in Average Temperatures Between Two 60-Year Periods, By State in Winter Months

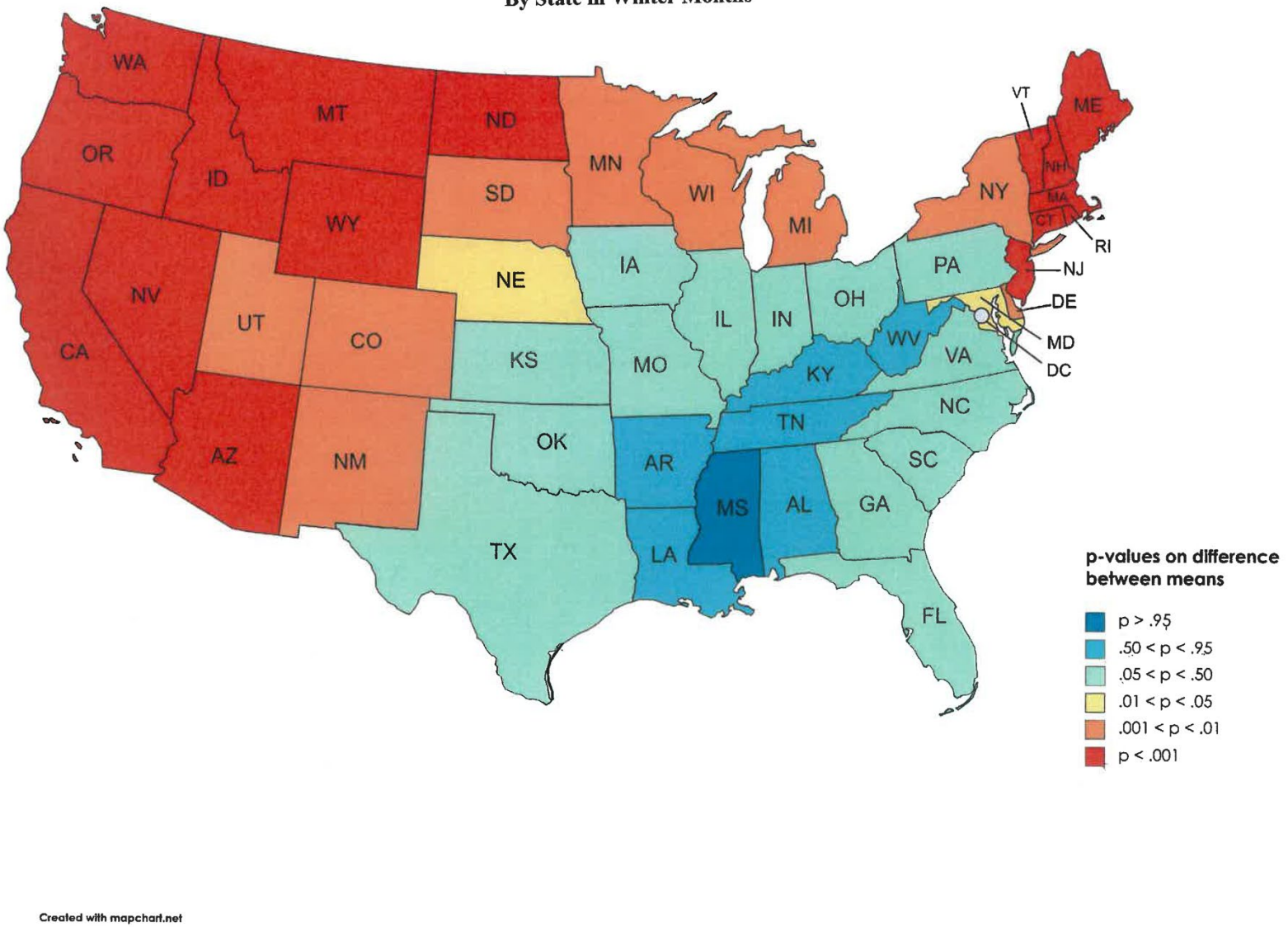
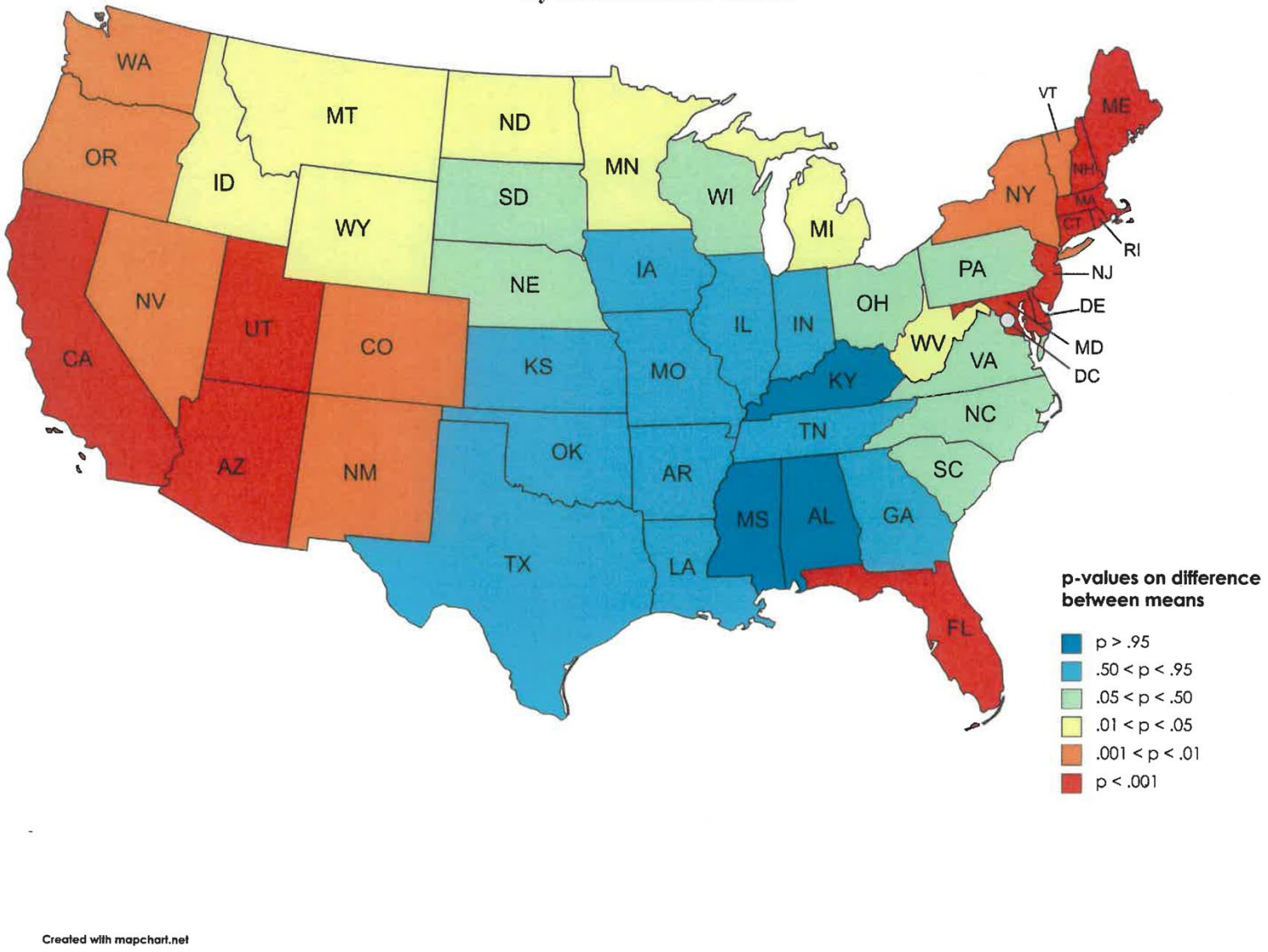


Figure 2. Color-Coded Change in Average Temperatures Between Two 60-Year Periods, By State in Summer Months



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