Warming Winters

U.S. Temperature Trends

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Summary

While the U.S. as a whole has seen a warming trend that has raised annual average temperatures by 1.3°F over the past 100 years, warming varies seasonally, and it's winter that has seen the fastest warming.

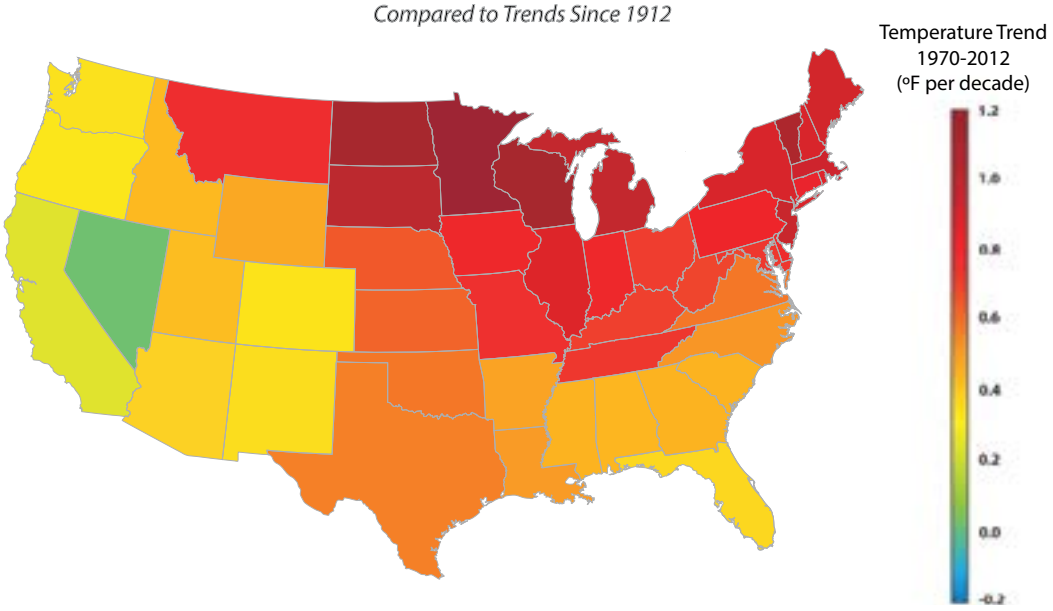
An analysis of data from the U.S. Historical Climatology Network of weather stations shows that the coldest states are warming the fastest, and across the country winter warming since 1970 has been more than four-and-a-half times faster per decade than over the past 100 years. Winter nights across the country have warmed about 30 percent faster than nights over the whole year. Some states cooled or failed to join the warming trend over the past 100 years, but since 1970, every state has shown winter-warming

To better understand winter warming patterns we analyzed average-daily temperatures and overnight-low temperatures for December through February for the continental 48 states from 1912-2012 and 1970-2012. We found:

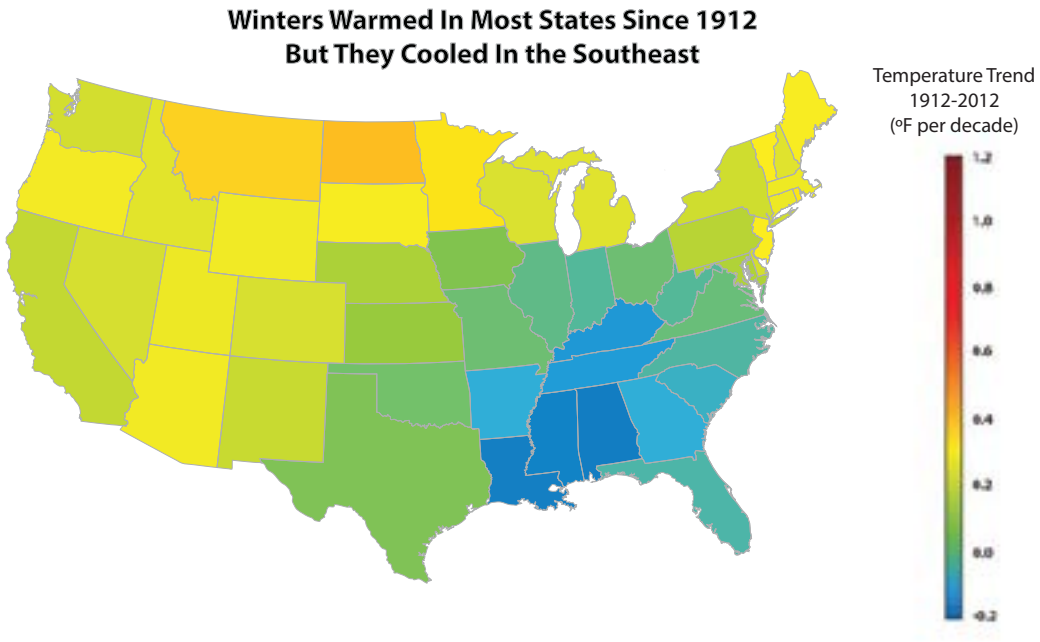
- Since 1970, winters in the top 5 fastest-warming states -- Minnesota, North Dakota, Wisconsin, Vermont and South Dakota -- heated up four-and-a-half times faster than winters in the 5 slowest-warming states: Nevada, California, Oregon, Colorado, and Washington. The five fastest-warming states have seen at least 4°F warming in winters since 1970.
- Winter warming accelerated almost everywhere since 1970, and all states have warmed since that time. Nationwide since 1970, winters warmed more than four-and-a-half times faster per decade than over the past 100 years.

Winter-Warming Accelerated In Every State But One

Compared to Trends Since 1912



- In contrast, over the past century, winters in 13 states -- 10 in the South -- bucked the warming trend and either cooled significantly or exhibited a non-significant slight cooling trend.
- Winter nights have warmed in all but one of the lower 48 states since 1970. Across the continent, winter nighttime temperatures have warmed about 30 percent faster than nighttime temperatures over the entire year. Since 1970, overnight winter temperatures in Wisconsin, Minnesota and Vermont have warmed



- Since 1912, states with average winter temperatures below 32°F warmed three times faster than states with average temperatures above 32°F. Since 1970, winter warming has accelerated almost everywhere and states that previously cooled began to warm in winter. Yet, the coldest states (below 32°F) have still warmed nearly twice as fast as the rest of the country on average. And during that time, winter nights in the coldest states warmed up to five times faster than those in warm states.
- The pattern of winter warming is different than the pattern of warming throughout the whole year, which was illustrated in Climate Central's June 2012 analysis of annual temperatures, The Heat is On. Some of the fastest-warming states overall, such as Arizona, New Mexico and Colorado, have had some of the slowest-warming winters, both since 1970 and over the past 100 years.

Introduction

In this report, we describe state-by-state differences in warming winter temperatures over the past century across the continental U.S. Regional differences and the rate of winter warming are more pronounced than changes in average annual temperatures, which we examined in our 2012 report, *The Heat Is On*. In general, seasonal temperatures are more variable than average annual temperatures, and winters tend to be the most variable season.

Winter warming trends depends on both the region and the timespan considered. Average winter temperatures in the coldest states have warmed faster than the rest of the country over all time frames. Some states experienced an overall cooling of winters since 1912, but since 1970 – the same time over which global warming accelerated – December, January, and February temperatures show a warming trend in all 48 states.

Warming Winters State-By-State

We collected records of daily high (maximum) and low (minimum) temperatures for winter (December, January, February) from the National Climatic Data Center's U.S. Historical Climatology Network of weather stations. Combining the averages of high and low temperatures from every station in every state,[1] we then calculated the average daily temperature from December through February each year. To gauge how average daily winter temperatures changed each decade, we computed linear trends from 1912-2012 and 1970-2012. Overnight temperature trends were similarly evaluated using only the daily low temperatures.

Based on these trends, Table 1 shows average winter temperature rates of change for the lower 48 states between 1912 and 2012. During this 101-year span, 35 states showed winter warming trends, while 13 showed no change or an overall cooling (trends in 21 states were not significant at the 10 percent level). Across the entire country, winters warmed at an average rate of 0.16°F per decade since 1912, about the same rate that average annual temperatures increased over the same time.[2]

The five fastest warming states since 1912 – North Dakota, Montana, Minnesota, Rhode Island, and New Jersey – showed winter warming rates faster than 0.310°F per decade time, compared to five states that cooled at nearly the same rate. the ten fastest warming and fastest cooling states are shown in Figure 1.

Winter warming increased significantly across the lower 48 states, since 1970. Every state showed warming-winter trends over this 43-year span (Table 2) and, on average, winters in the U.S. warmed more than four-and-a-half times faster than during the 101-year time span. The five fastest warming states have seen at least 4°F warming in winters since 1970.

Winters Warmed In Three Quarters of the States

Table 1. In most states, winters warmed over the past 101 years but several states have seen winters cool in that time.

Rank	State	Temperature Change (°F per decade)
1	North Dakota	0.424
2	Montana	0.367
3	Minnesota	0.338
4	Rhode Island	0.329
5	New Jersey	0.313
6	Vermont	0.312
7	Maine	0.302
8	South Dakota	0.296
9	Oregon	0.292
10	Arizona	0.287
11	Wyoming	0.283
12	Massachusetts	0.281
13	Connecticut	0.273
14	Utah	0.268
15	Idaho	0.255
16	Michigan	0.249
17	New Hampshire	0.249
18	Wisconsin	0.240
19	Colorado	0.236
20	Nevada	0.229
21	Washington	0.220
22	Delaware	0.218
23	New York	0.207
24	New Mexico	0.195
25	California	0.185
26	Pennsylvania	0.162
27	Maryland	0.148
28	Nebraska	0.140
29	Kansas	0.108
30	Iowa	0.059
31	Texas	0.055
32	Oklahoma	0.036
33	Missouri	0.021
34	Ohio	0.021
35	Virginia	0.016
36	Illinois	0
37	West Virginia	- 0.022
38	Indiana	- 0.026
39	North Carolina	- 0.034
40	Florida	- 0.042
41	South Carolina	- 0.069
42	Georgia	- 0.103
43	Arkansas	- 0.103
44	Tennesse	- 0.143
45	Kentucky	- 0.145
46	Mississippi	- 0.184
47	Louisiana	- 0.192
48	Alabama	- 0.245

[a] *States ranked 26-48 -- excluding IL, LA, and AL -- have trends that are not statistically significant (at the 10 percent level).*

Winter-Warming Accelerated Every State But One Since 1970

Table 2. Every state but Nevada saw winter-warming trends increase in the past 43 years compared to trends since 1912

Rank	State	Temperature Change (°F per decade)	Rank	State	Temperature Change (°F per decade)
1	Minnesota	1.243	25	West Virginia	0.691
2	Wisconsin	1.144	26	Nebraska	0.654
3	North Dakota	1.142	27	Kansas	0.623
4	Vermont	1.119	28	Virginia	0.582
5	South Dakota	1.012	29	Oklahoma	0.579
6	Michigan	0.971	30	Texas	0.566
7	New Jersey	0.963	31	North Carolina	0.519
8	Massachusetts	0.941	32	Louisiana	0.511
9	Maine	0.925	33	Arkansas	0.478
10	New York	0.912	34	Wyoming	0.473
11	New Hampshire	0.908	35	South Carolina	0.455
12	Rhode Island	0.885	36	Mississippi	0.453
13	Illinois	0.880	37	Georgia	0.452
14	Connecticut	0.840	38	Alabama	0.438
15	Pennsylvania	0.822	39	Idaho	0.428
16	Iowa	0.808	40	Utah	0.417
17	Indiana	0.808	41	Arizona	0.376
18	Delaware	0.783	42	Florida	0.358
19	Montana	0.761	43	New Mexico	0.346
20	Missouri	0.752	44	Washington	0.339
21	Maryland	0.737	45	Colorado	0.335
22	Tennessee	0.735	46	Oregon	0.323
23	Ohio	0.715	47	California	0.249
24	Kentucky	0.707	48	Nevada	0.025

[a] *States ranked 16, 17, 19, 20, 23-29, 31-40, and 42-48 have trends that are not statistically significant (at the 10 percent level).*

Every state but Nevada saw winter-warming trends increase (or reverse from cooling trends) from 1970 compared to the 101-year rate. But while winter warming in Nevada didn't accelerate, the state's rate of annual temperature rise has accelerated in recent decades.[2]

All seven states that experienced a cooling trend over the 101-year period have seen dramatic winter warming, between 1.44°F – 3.24°F, in the past 30-40 years. And most states that were already warming consistently since 1912, like Minnesota and Vermont, saw even faster winter warming in the past few decades.

In many states, winters are warming much faster than the rest of the year. The 10 states with the fastest-warming winters since 1970 (Figure 1) each had warming trends at least one-and-a-half times faster than their rate of annual warming.[2] And the 10 fastest warming states over this time warmed over three times faster than the slowest 10 states.

Winters Warmed Fastest In the Coldest States Since Both 1912 and 1970

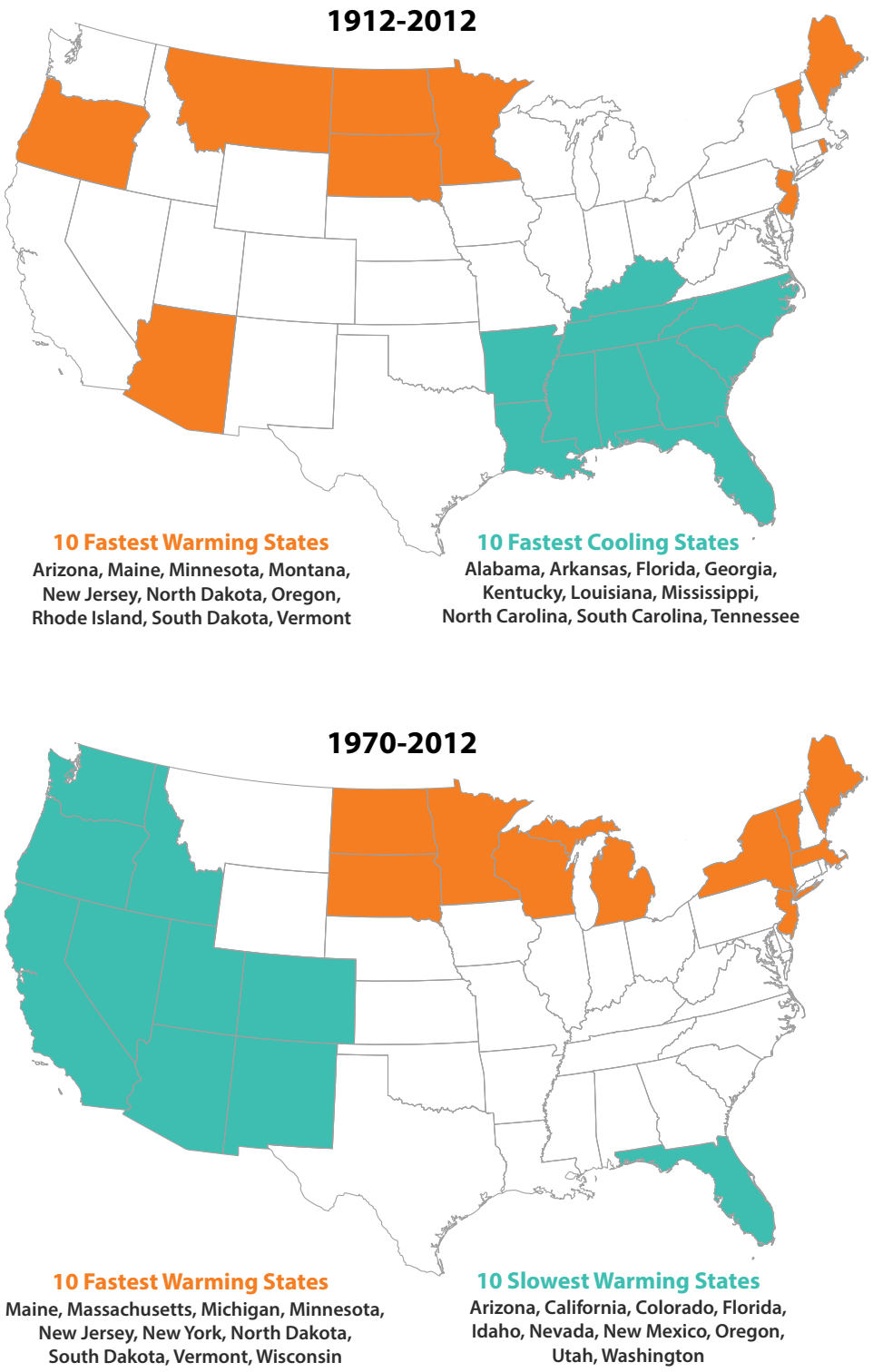


Figure 1. *From 1912-2012, the Southeast and Mississippi Valley cooled while the rest of the country experienced a warming trend, a phenomenon described as the Warming Hole. Winters warmed in every state since 1970, but the slowest warming states shifted to the West Coast and Southwest regions.*

Overnight Warming

Overnight winter temperatures have risen at about the same rate as daily temperatures, at a rate of 0.13°F per decade, since 1912 but in the past 43 years, overnight temperatures have been rising at an average rate of 0.61°F per decade,[3] nearly 30 percent faster than average annual overnight warming. Figure 2 illustrates the rate of overnight warming state-by-state.

The state rankings of average winter overnight warming since 1970 are in Table 4. The top three states since 1970 – Minnesota, Vermont and Wisconsin – have seen average overnight winter temperatures increase at least 1.29°F per decade, more than 5°F in the past 43 years.

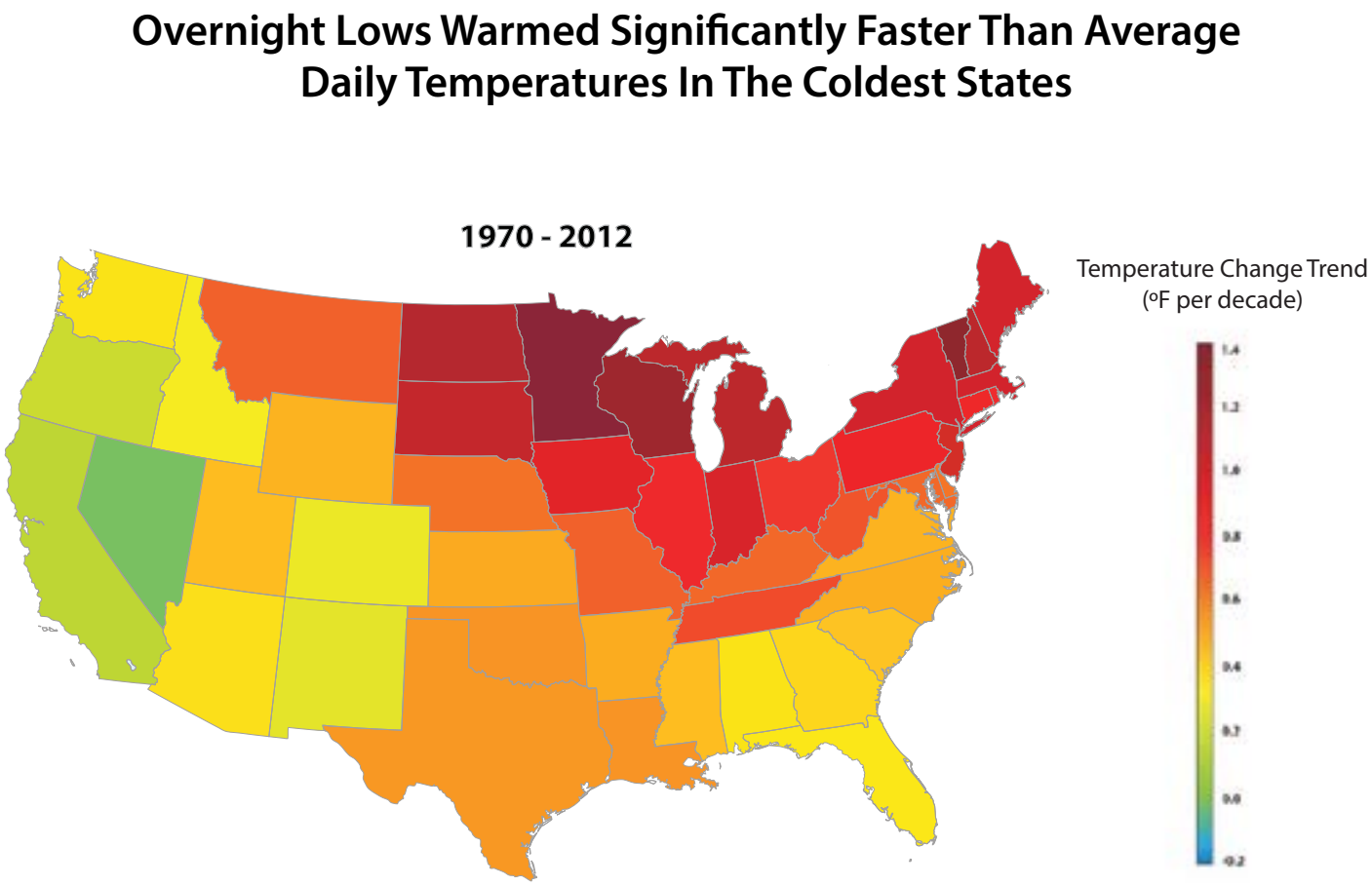


Figure 2. *Average overnight winter temperatures over the entire country warmed at the same rate as daily average winter temperatures, but in the coldest states overnight warming was more dramatic than daytime warming.*

Overnight Winter Temperatures Have Warmed In All But One State

Table 3. Since 1970, overnight low temperatures warmed everywhere in the winter except Nevada.

Rank	State	Temperature Change (°F per decade)
1	Minnesota	1.416
2	Vermont	1.372
3	Wisconsin	1.285
4	Maine	1.184
5	North Dakota	1.157
6	Michigan	1.116
7	New Hampshire	1.109
8	South Dakota	1.087
9	New York	1.020
10	New Jersey	1.015
11	Indiana	0.988
12	Massachusetts	0.982
13	Iowa	0.946
14	Pennsylvania	0.879
15	Connecticut	0.862
16	Illinois	0.848
17	Rhode Island	0.834
18	Ohio	0.796
19	Tennessee	0.742
20	West Virginia	0.714
21	Montana	0.689
22	Missouri	0.684
23	Kentucky	0.665
24	Maryland	0.661
25	Nebraska	0.642
26	Delaware	0.628
27	Louisiana	0.590
28	Oklahoma	0.560
29	Texas	0.550
30	Kansas	0.505
31	Arkansas	0.500
32	North Carolina	0.492
33	Wyoming	0.485
34	Virginia	0.482
35	Utah	0.452
36	Mississippi	0.448
37	South Carolina	0.444
38	Georgia	0.393
39	Arizona	0.361
40	Alabama	0.350
41	Washington	0.349
42	Florida	0.339
43	Idaho	0.311
44	Colorado	0.280
45	New Mexico	0.255
46	Oregon	0.190
47	California	0.150
48	Nevada	- 0.010

[a] *States ranked 16, 18-28, and 30-47 have trends that are not statistically significant (at the 10 percent level).*

Regional Winter-Warming Trends

Our state-by-state analysis of winter warming trends in the U.S. reveals distinct regional differences in the rate of warming (Figure 3). Over both time periods, the fastest-warming states were in the Northeast and Upper Midwest. On the other hand, the Southeast, Southwest and West Coast have seen slower rates of winter warming. In some regions, the winter-warming rate is dramatically different than the rate at which the average annual temperature has increased.[2]

The coldest U.S. states have had the fastest-warming winters since both 1912 and 1970. Over the past 101 years, winter in states with average daily temperatures below 32°F (Figure 4) warmed an average of 0.22°F per decade, three times faster than the rest of the country. Since 1970, these cold states have seen average winter temperatures rise an average of 0.76°F degrees per decade, nearly double the rate of the warmer states.

See Table A1 in the Appendix for the coldest-to-warmest ranking of states, according to average winter temperature, from 1912-2012.

Several states in the Southeast and Lower Midwest experienced an overall cooling trend in winter months since 1912. This appears to be a magnification of the "warming hole" phenomenon we described in our analysis of average annual temperatures[2] and that others have analyzed,[4] noticing how it appears to be an eminently (but not uniquely) winter phenomenon. Considering only the time since 1970, however, winter temperatures across the Southeast have all warmed, and the warming hole disappears. In addition, states like Ohio, Indiana, North Carolina and West Virginia saw the rate of winter warming from 1970 increase by 15-30 times compared to 101-year rates.

Since 1970, the nine westernmost states have seen the slowest rates of winter warming. Even though these states are warming slower than the national average, their average winter temperatures are still increasing by an average of 0.32°F per decade. And though their winter temperatures haven't risen as rapidly as in other parts of the country, Southwestern states like Arizona, New Mexico and Colorado have experienced some of the most dramatic increases in average annual temperature.

See Table A2 in the Appendix for the coldest-to-warmest ranking of states, according to average winter temperature, from 1970-2012.

As we previously discussed in *The Heat is On*, others have documented these regional differences in warming trends. Some model simulations suggest that changing emission patterns of aerosol pollutants over past century may have influenced regional warming and cooling.[5] However, scientists have also detected these same patterns of differential warming and cooling in simulations without changing pollutants, an indication that the natural variability of the climate system is at least in part responsible for the differences we see across the country.[6,7] See our previous discussion and the references therein for a more detailed explanation.

As with our report on annual temperature trends, *The Heat Is On*, do not expect that future trends will be a simple extrapolation of current patterns, since natural variability and the future emissions – of both heat-trapping greenhouse gases and cooling aerosol pollutants – will shape future rates of warming. The rates of warming we've seen in various regions of the U.S. could be different in the future from what they've been in the past.

Winter Warming Accelerated Almost Everywhere Since 1970

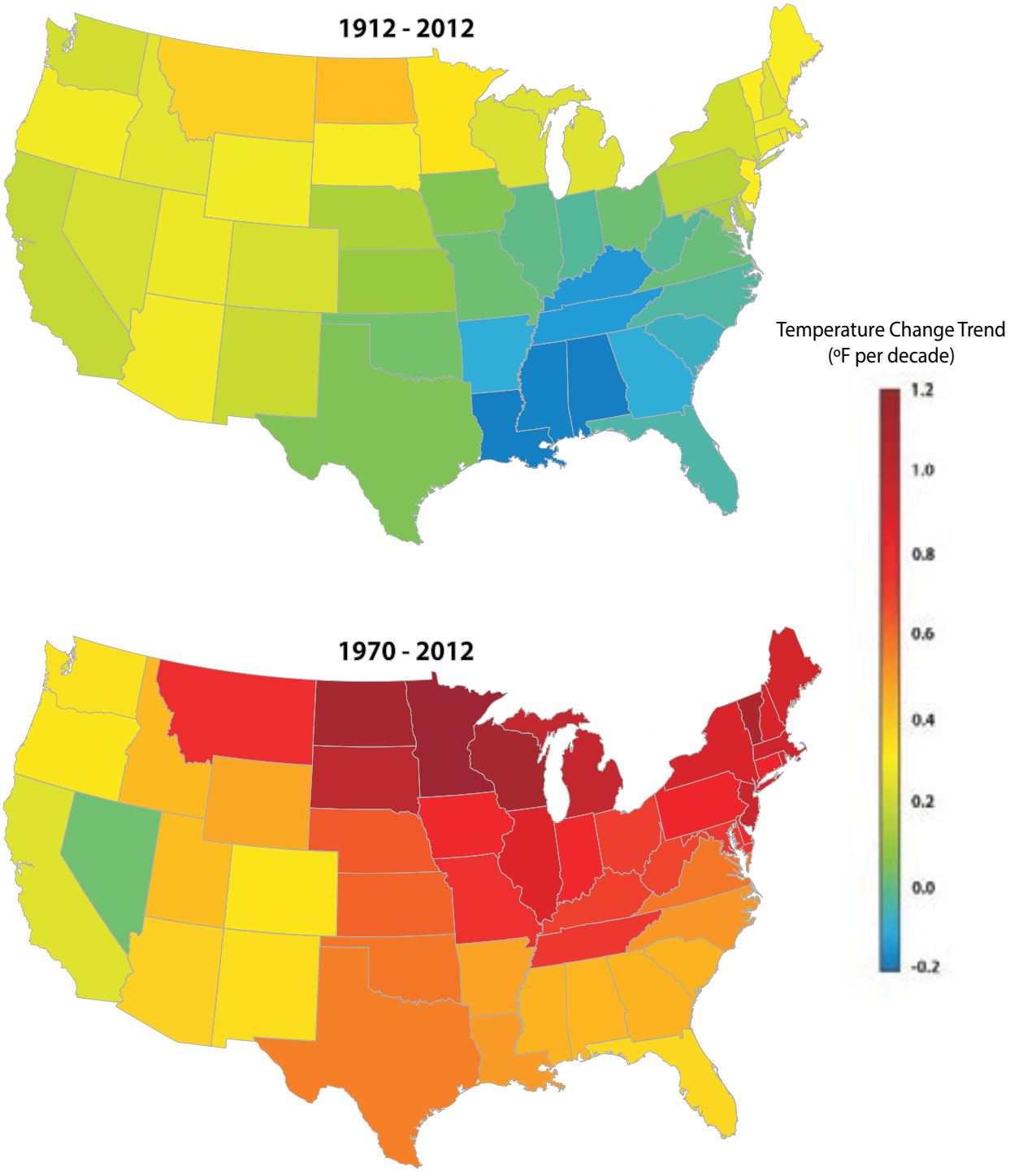


Figure 3. *Rates of warming for average winter (Dec.-Feb.) temperatures (degrees Fahrenheit per decade) for each state: 1912-2012 (top) and 1970-2012 (bottom).*

States With Average Winter Temperatures Below 32°F

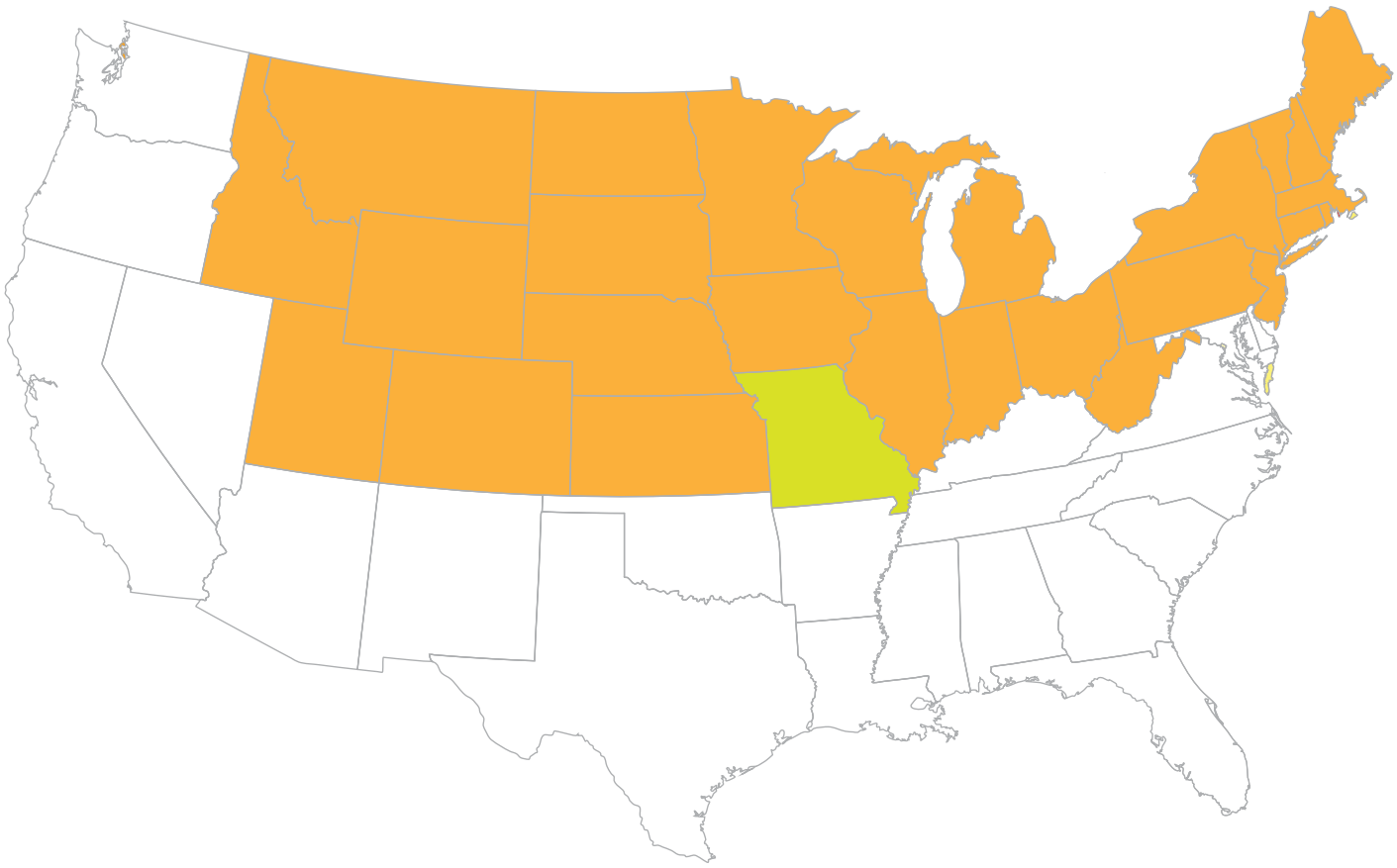


Figure 4. *States with average winter temperatures below 32°F. Between 1912-2012, Missouri's average winter temperature was below 32°F, but the average winter temperature in Missouri between 1970-2012 is above 32°F.*

Methodology

This analysis is based on data collected from stations that make up the United States Historical Climatological Network (USHCN). These stations, covering the contiguous U.S., are maintained by the National Climatic Data Center and contribute to the Global Historical Climatology Network (GHCN). Stations from Hawaii and Alaska are not included in the USHCN and thus we have excluded them from our discussion to keep our analysis consistent among all states considered.

From this network of 1221 American stations, we collected minimum and maximum daily temperature records for December, January and February. Mean temperatures (ie. average daily winter temperatures) were calculated by averaging the daily minimum and maximum temperatures. We then aggregated all the stations in a given state to form state average values.

Using state average values, we computed linear trends for annual averages of mean temperatures and minimum (overnight low) temperatures. Given the long record at our disposal, we computed trends using two different starting points. The oldest date available with sufficiently complete coverage across the contiguous U.S. was 1912, which conveniently covered the past 101 years, so our first set of analyses cover the time between 1912 and 2012. Our second set of analyses spans 1970-2012.

We chose the latter 43-year period guided by the knowledge of a well known acceleration of warming, at the global level, that began in the seventies. This accelerated global warming has been attributed to a concurrence of natural factors (changes in ocean temperatures according to intrinsic multi-decadal variability of the system) and the effect of clean-air regulation in countries of the industrialized world, reducing the amount of pollution particles (aerosols) in the air, known to have a cooling effect (see above).

Within the *Warming Winters* state-by-state interactive, the smoothed trend is obtained by a quadatic curve modeled using local fitting (akin to computing a moving average along the time series). The fit is performed using the loess() function in the R statistical software package (freely available at http://www.r-project.org/).

Statistical significance was computed assuming an autoregressive process of order 1 for the residuals of the linear regression, applying Generalized Least Squares. When we rank states according to the values of their respective trends, however, we do not consider the statistical significance of their differences. Rather, we use the trend magnitudes at their face value.

References and Notes

(1) The U.S. Historical Climatology Network does not include Hawaii and Alaska, so we've excluded them from this analysis to avoid inconsistent comparison between states.

(2) Tebaldi, C., Adams-Smith, D. and N. Heller, **2012:** The Heat Is On: U.S. Temperature Trends. *Climate Central,* http://www.climatecentral.org/news/the-heat-is-on/.

(3) An earlier version of this report mistakenly reported the average overnight winter warming rate from 1970 to be 0.78°F.

(4) Meehl, G. A., Arblaster, J. M., and G. Branstator, 2012: Understanding the U.S. East-West differential of heat extremes in terms of record temperatures and the warming hole. *Journal of Climate*. 25: 6394-6408.

(5) Leibensperger, E.M., Mickley, L. J., Jacob, D. J., Chen, W.-T., Seinfeld, J. H., Nenes, A., Adams, P. J., Streets, D. G., Kumar, N., and D. Rind, 2012: Climatic effects of 1950-2050 changes in US anthropogenic aerosols – Part 2: Climate response. *Atmospheric Chemistry and Physics*. 12: 3349-3362.

(6) Meehl, G. A., Washington, W. M., Amman, C., Arblaster, J. M., Wigley, T. M. L., and C. Tebaldi, 2004: Combinations of natural and anthropogenic forcings and 20th century climate. *Journal of Climate*, 17: 3721–3727.

(7) Kunkel, K., Liang, X.-Z., Zhu, J., and Y. Lin, 2006: Can CGCMs simulate the twentieth-century "warming hole" in the central United States? *Journal of Climate*, 19: 4137–4153.

Appendix

Table A1. Average Winter Temperatures, 1912-2012 (coldest to warmest)

Rank	State	Average Winter Temperature (°F)
1	North Dakota	11.2
2	Minnesota	12.4
3	Wisconsin	17.8
4	South Dakota	18.8
5	Vermont	19.3
6	Maine	19.4
7	New Hampshire	19.9
8	Iowa	20.9
9	Michigan	21.6
10	Montana	21.6
11	Wyoming	21.8
12	New York	24.0
13	Nebraska	25.4
14	Colorado	25.9
15	Idaho	26.2
16	Utah	28.0
17	Pennsylvania	28.2
18	Connecticut	28.4
19	Massachusetts	28.5
20	Illinois	28.5
21	Ohio	28.7
22	Indiana	29.9
23	Rhode Isand	31.2
24	New Jersey	31.5
25	Kansas	31.8
26	Missouri	32.0
27	West Virginia	32.3
28	Nevada	33.8
29	Washington	34.6
30	Delaware	34.8
31	Maryland	35.2
32	Kentucky	35.7
33	Oregon	35.7
34	Viginia	36.2
35	New Mexico	36.5
36	Oklahoma	38.6
37	Tennessee	38.8
38	Arkansas	40.4
39	North Carolina	41.2
40	Arizona	43.7
41	South Carolina	45.9
42	Mississippi	46.6
43	California	46.7
44	Alabama	46.7
45	Texas	47.6
46	Georgia	47.8
47	Louisiana	51.8
48	Florida	60.1

Table A2. Average Winter Temperatures, 1970-2012 (coldest to warmest)

Rank	State	Average Winter Temperature (°F)
1	North Dakota	12.4
2	Minnesota	13.2
3	Wisconsin	18.5
4	South Dakota	19.5
5	Maine	20.0
6	Vermont	20.1
7	New Hampshire	20.5
8	Iowa	20.9
9	Michigan	22.0
10	Wyoming	22.5
11	Montana	22.6
12	New York	24.6
13	Nebraska	25.6
14	Colorado	26.4
15	Idaho	26.8
16	Illinois	28.2
17	Ohio	28.6
18	Pennsylvania	28.6
19	Utah	28.7
20	Connecticut	29.1
21	Massachusetts	29.2
22	Indiana	29.6
23	Missouri	31.9
24	Kansas	31.9
25	Rhode Island	32.1
26	West Virgina	32.2
27	New Jersey	32.4
28	Nevada	34.4
29	Washington	35.1
30	Kentucky	35.2
31	Delaware	35.4
32	Maryland	35.6
33	Virginia	36.2
34	Oregon	36.5
35	New Mexico	37.1
36	Tennessee	38.3
37	Oklahoma	38.5
38	Arkansas	39.9
39	North Carolina	41.1
40	Arizona	44.6
41	South Carolina	45.8
42	Alabama	46.0
43	Mississippi	46.0
44	California	47.3
45	Georgia	47.5
46	Texas	47.7
47	Louisiana	51.2
48	Florida	60.1

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