HENNEPIN COUNTY EMERGENCY MANAGEMENT

Extremes of Temperature in Hennepin County

History, Trends and Projections

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This document summarizes 115 years of temperature data at Minneapolis, and analyzes the state and trends of various extreme threshold occurrences.

Summary

The purpose of this report is to understand the trends and likely changes in extreme temperature events in Hennepin County. Many reports have suggested the area will see an increase in heat wave intensity and frequency as global warming proceeds[i]. The unusually cold winter of 2013-14 also prompted concerns about cold weather emergencies, related both to infrastructure, and to human health and safety. In light of the hazards posed by both temperature extremes, this report evaluates trends in both the warmest, and the coldest temperatures experienced each year at Minneapolis.

Highlights

Hot days not getting hotter

- The highest temperatures of summer are still well within historical bounds and have not exhibited an increase consistent with many predictions and warnings.

Warm summer nights not getting warmer

- The warmest nights of summer have exhibited some recent warming but are still well within historical bounds.

Rapid winter warming also not driven by warm temperatures

- The magnitudes of the warmest high and the warmest low temperatures of winter have remained remarkably constant since 1900, and have exhibited no warming.

The bottom is coming up

- The loss of cold conditions is driving the area's climate change signal. The coldest low temperatures of winter have warmed dramatically, as have the coldest high temperatures, and coolest low temperatures of summer have warmed more rapidly than any other variable examined.

Warming is being driven by less cold/cool air, as opposed to more hot/warm air

Overview

Background

Global warming is well underway, and this human-induced climate change is expected to continue for at least several more decades, even under the most optimistic greenhouse gas emissions scenarios[ii]. Minnesota has experienced some of the most pronounced warming nationally[iii], especially in winter[iv]. Even if the climate does stabilize (that is, even if it stops warming), scientists expect it to remain at a newly-warmer state thereafter. In other words, temperatures may stop rising, but they will remain warmer than at present for some time.

Countless reports from scientists, policymakers, and advocates, suggest that extreme heat events will increase as the climate warms. Minnesota's Environmental Quality Board, for instance, urges Minnesotans to expect more 100-degree events as the climate warms[v]. Peer-reviewed research submitted in 2010 and 2011 indicates that Minneapolis could reasonably expect the average annual number of excessive heat events to triple (from 8 to 23) by mid-century, with a 600% increase in heat-related mortality.[vi,vii] Such dramatic increases in heat emergencies and heat mortality would have obvious and significant implications for the entire emergency management infrastructure.

Despite the warming currently underway, the 2013-14 winter achieved a depth and persistence of cold that had not been experienced in several decades, and apart health and safety hazards, nearly led to a public works catastrophe, as frost depths reached many municipal water lines. Earlier analyses done by Hennepin County Emergency Management showed that the 2013-14 winter was more "abruptly cold" and more unlike the previous 30 winters than any other winter on record. On the heels of the period from summer 2011 through 2012, which had an exceptionally warm winter sandwiched in between two summers with higher than normal excessive heat events, the 2013-14 winter suggests the region is in a period of high variations, when both hot and cold extremes are common.

The purpose of this report, therefore, is to assess the current state and trends in extreme temperature events in Hennepin County, using the long-term Minneapolis record. Extremes of heat and cold will be examined, and compared to other observed trends in the Minneapolis temperature record.

It should be noted that this report focuses on temperatures only, and not heat index values, wind chill, dew point temperature, or any other variable related to apparent temperatures and comfort. A deeper investigation may be needed assessing trends in the combined effects of high temperatures and moisture/humidity levels at Minneapolis.

Observational record used

This report uses the "threaded" temperature record at Minneapolis, 1900-2014, to represent Hennepin County. Daily observations in this record were taken at downtown Minneapolis (1900-1938) and the Twin Cities International Airport (1938-2014).

Average Annual and Seasonal Temperatures

Average annual temperatures have increased by about 3 degrees (F) at Minneapolis since 1900, and have been increasing most sharply and persistently since 1970 (see Fig.1). The record exhibits an up-down-up pattern: temperatures rose until 1940, then dropped until 1970, when the current warming ensued. The dip is associated with the "benign climate" period of unprecedented agricultural success, during which many meteorological variables exhibited muted extremes and low-year-to-year variation[viii].

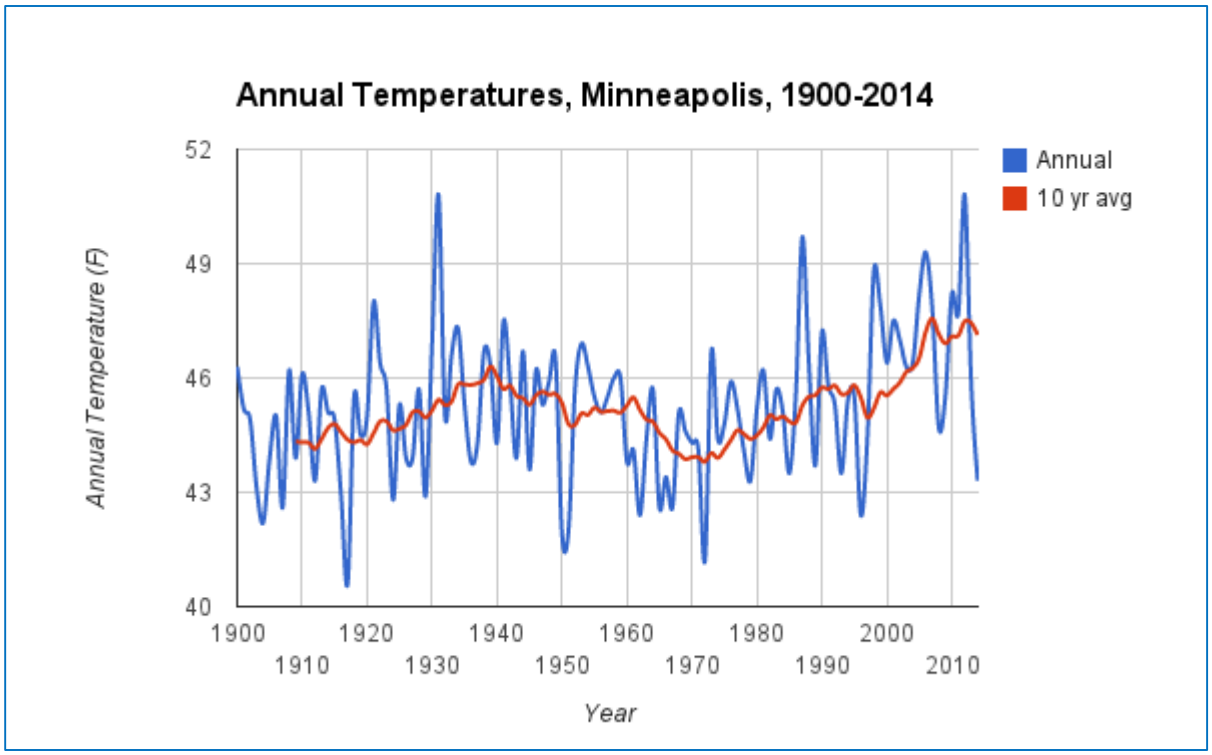

Figure 1. Annual temperatures, 1900-2014, at Minneapolis. Blue line shows annual values, red shows 10-yr averages.

Of particular note, temperatures since 2000 are outside the bounds of those experienced historically. This is especially noticeable when including a ten-year average of temperatures, running from 1909 through 1914.

The same period of record, but for summer only (June, July, August, see Fig. 2), reveals a similar pattern but with small and meaningful differences. First and foremost, summer temperatures are increasing rapidly, but are still within historical bounds, having peaked during the dust bowl period of the 1930s. Although the record does feature a roughly 3-degree beginning-to-end temperature rise, the most pronounced summertime warming is over the most recent 15 years or so (since 2000). Unlike the annual temperatures, 10-year-averaged summer temperatures fell during the 1990s, after an initial upward climb in the 1970s and 1980s. Though the warmest summer temperatures were in the 1930s, current trends suggest that period will be unseated by 2020.

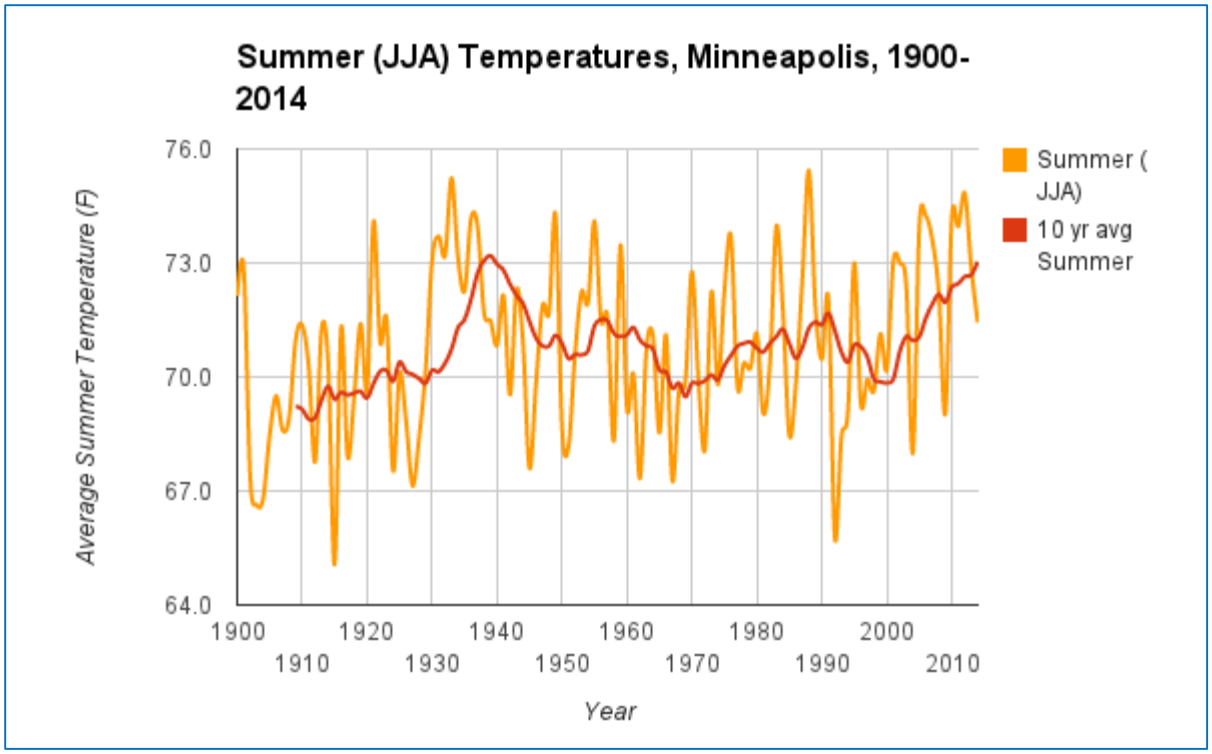

Figure 2. Same as Figure 1, but for summer (JJA). Note that warming since 2000 is consistent and sharp, but at a not-yet-unprecedented level.

Winter temperatures (December through February) have increased faster than annual temperatures, and also faster and more persistently than summer temperatures (see Fig. 3). Of particular note, although 1930-31 remains the warmest single winter on record, the increase in temperatures beginning in the late 1970s and accelerating from the late 1980s onward, is without historical precedent. The 10-year-average temperatures increased by more than 6 degrees over a roughly 20-year period, beginning in 1986. The rate and persistence of winter warming during this time is unlike anything else seen in the record. A potential cessation in warming set in beginning with the 2007-08 season, though was interrupted notably with the 2011-12 season, which was the third warmest on record. The 2013-14 December-February period—just two seasons later—was the 9th coldest on record at Minneapolis [ix]. The proximity of these two extreme winters, in combination with the large high-to-low spread seen from the 1980s onward, suggests even as winters warm, the area is in a period of high inter-annual (i.e., year-to-year) variability. Without inspecting any other information, this trend suggests that even as average winter temperatures increase, we should expect wide variations around that average.

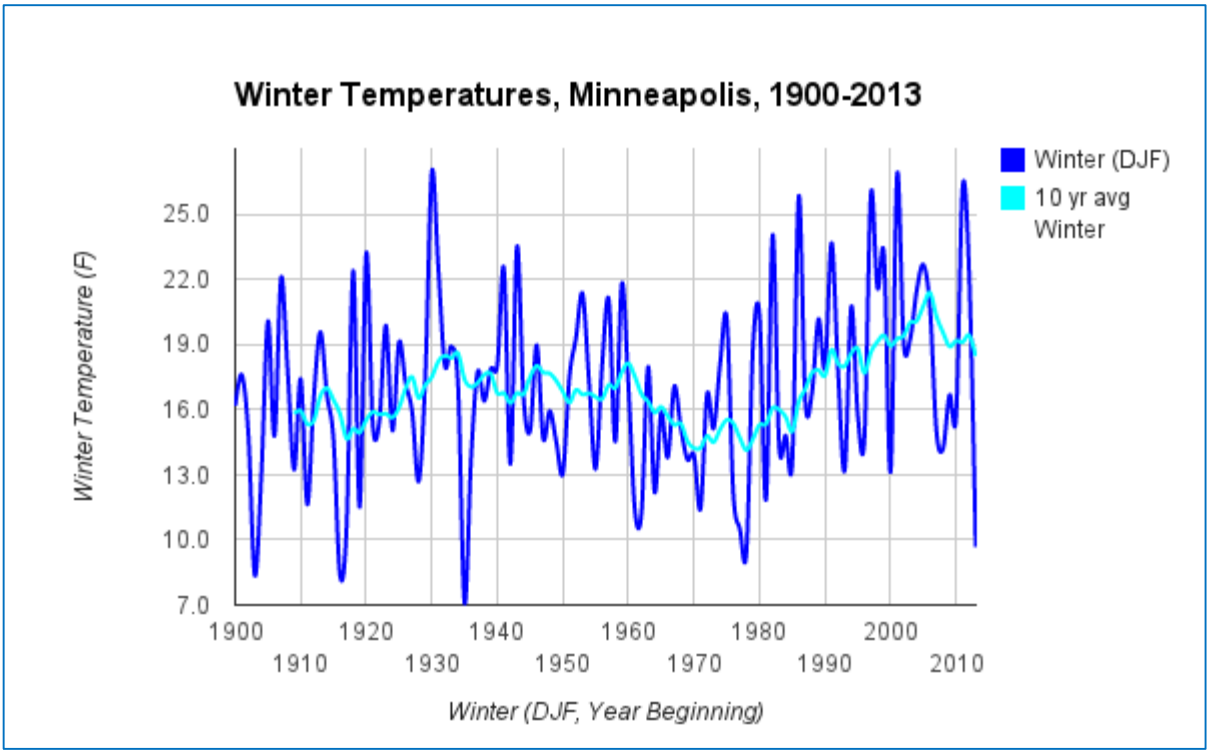

Figure 3. Winter temperatures at Minneapolis. Royal blue shows annual values, and the light blue trace shows ten year average values. Note both the rapid/prolonged upward trend beginning in the late 1970s, along with the high inter-annual variability during the same time.

Key Takeaways

1. A long-term increase in average annual temperatures has been punctuated by a particularly rapid increase since 1970, rendering Minneapolis warmer than any other time on record.
2. Recent significant warming signals are present in both summer and winter, though the two seasons exhibit differences in the onset of that warming
3. Winter warming has been longer and more pronounced than summer and has no historical precedent.

Temperature Extremes

The Minneapolis temperature records examined above show clear and obvious signatures annually, and in both summer and winter , that global warming is affecting the Twin Cities area (spring and fall are out of scope for this project, because the focus is on extremes of temperature, which are less common during the transition seasons). One vital question for emergency managers, planners, and resource agencies is: what does climate change mean for extremes of temperature?

Hot Temperatures

The US National Climate Assessment has stated Minnesota will experience more numerous and intense heat waves (see p. 2, third bullet)[x], and as indicated earlier, the Minnesota Environmental Quality Board expects more days above 100 degrees (F). From the perspective of high temperatures, however, neither of these statements are borne out by the record at Minneapolis (see Fig. 4). The hottest temperatures of the year (the warmest high temperature of summer) exhibit a nearly flat pattern since the about 1950, with only a subtle increase noticeable since 2000 that is entirely within the bounds of historical temperature fluctuations. Because the values associated with the hottest single day of the year may vary independently from larger climatic and seasonal signals, the warmest 15 high temperatures are also examined, and they, too, show a flat, or slight downward pattern since 1950 (also on Fig 4).

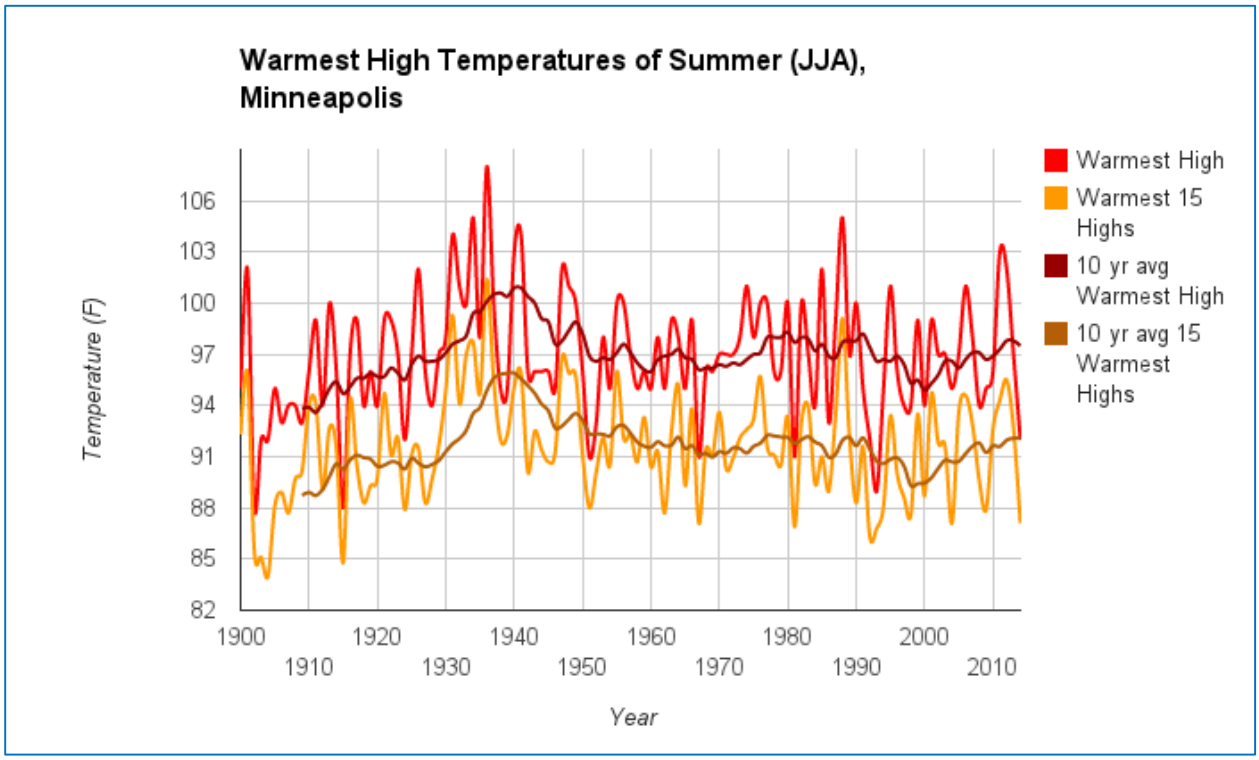

Figure 4. Highest temperature of summer (red), and average of 15 warmest high temperatures of summer (orange), with maroon and brown traces showing respective 10-year averages. Note nearly flat trajectories since 1950.

Another way to examine summer high temperature extremes is to assess the frequency that a given threshold is met or exceeded. Minneapolis has only equaled or exceeded 100 degrees 62 times since 1900, and half of those occurred between 1930 and 1941. In other words, 100-degree days are exceptionally infrequent. Instead, the threshold of 95 degrees is high enough to connote a significant and unusual temperature event, and low enough to occur with reasonable frequency. An examination of 95-degree days since 1900 shows a similar pattern to the hottest temperatures of the summer: a significant peak occurred in the 1930s and early 1940s, with no discernible trend thereafter (see Fig. 5).

The upward trend since 2000 mimics that seen in Figure 4, and though worthy of notice, is still well within the bounds of historical variability.

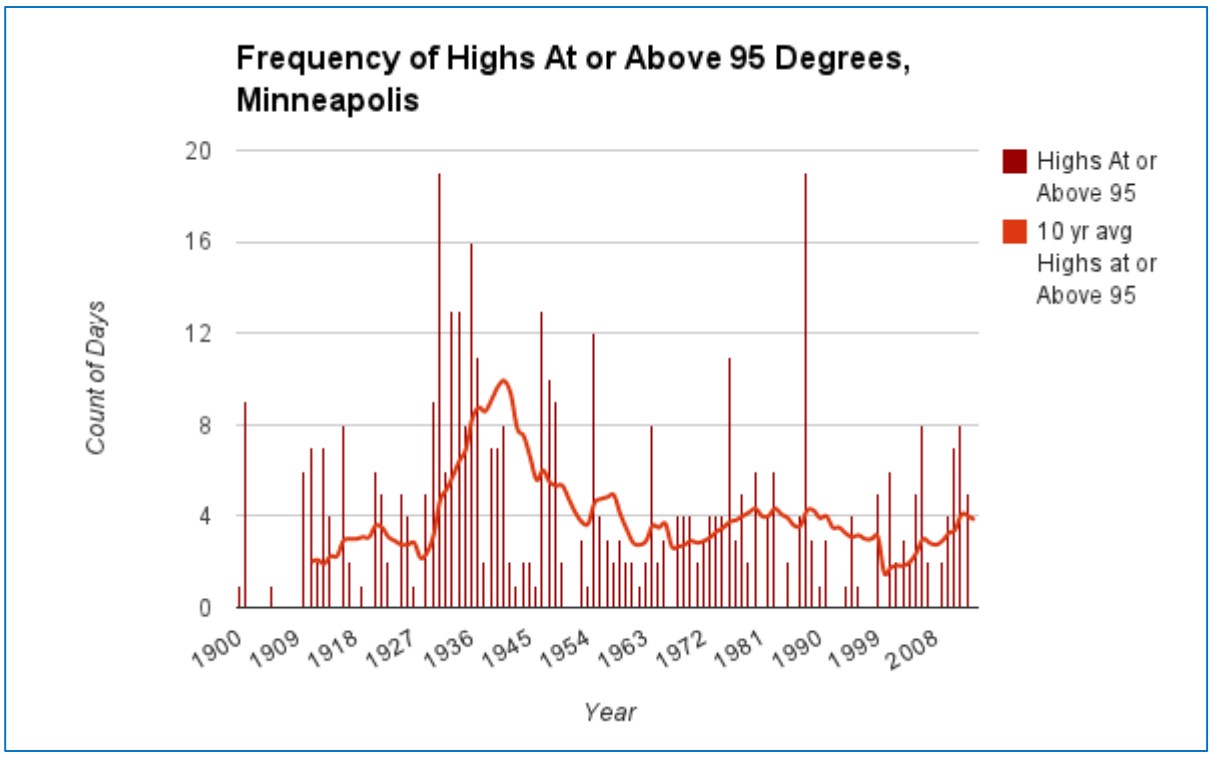

Figure 5. Frequency of highs at or above 95 degrees, with red trace showing 10-year average. Note flat trajectory, similar to Fig. 4, since 1950, with only subtle increases since 2000.

The pattern of hottest summertime temperatures, and the frequency of days above 95 degrees both suggest that ***while Hennepin County may indeed be warming, it is not getting hotter*.** It is important to note that this is only an examination of temperatures, and not dew points or heat indices. Higher dew points would indeed increase the apparent temperatures, even if the temperatures themselves did not rise. The Minnesota State Climatology Office has shown that evening summertime dew points in Minneapolis exhibit the same general flattening-out since 1950 that was seen in the extreme high temperature charts , although with some added variability since the early 1990s (see Fig. 6). Despite the lack of a trend, the vast majority of rare, 80-degree dew point hours in Minneapolis have been from the 1990s onward. Dr. Mark Seeley has also shown a gradual increase in the frequency of dew point readings above 70 degrees (F)[xi]. Thus, hidden in the flat-looking dew point record are some historically unusual extremes, along with a subtle upward trend in frequencies of higher dew point values. Further research is needed to determine whether and how extreme heat index values have changed in Hennepin County.

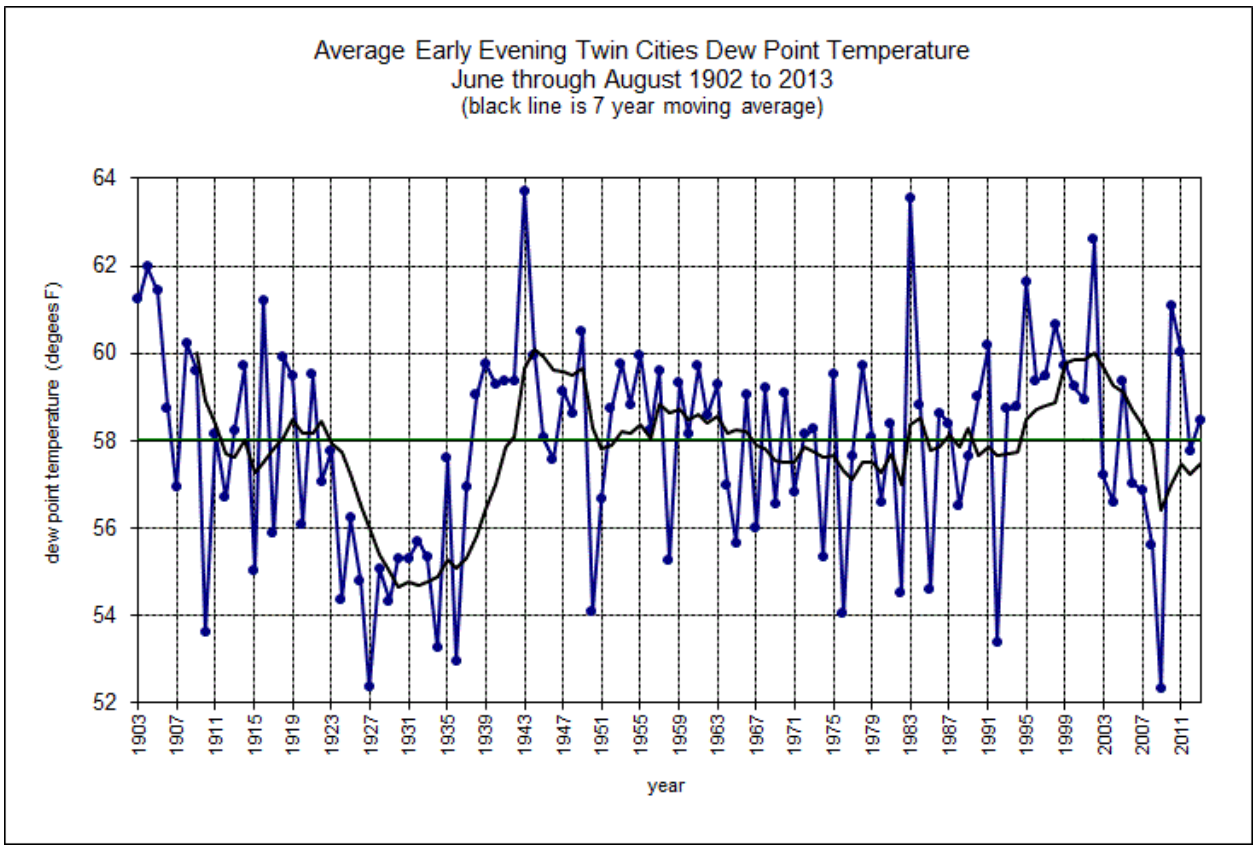

Figure 6. Historical record of evening dew points at Minneapolis. Courtesy of Minnesota Climatology Office[xii]

Key Takeaways

1. **The hottest days of the year are not getting hotter and have, in fact, essentially been flat since 1950.**

2. **The 15 hottest days of the year show almost exactly the same trend.**

3. **From the standpoint of temperature alone, there is no evidence that extreme daytime heat events have increased in Hennepin County.**

4. **The currently minor uptick in the hottest temperatures of summer and the frequency of days at or above 95 degrees will need to persist before it can be deemed an actual trend.**

5. **Further examination of dew point extremes in combination with high temperatures will be needed to understand trends in excessive heat events.**

Warmest Nights of Summer (Warmest Low Temperatures of Summer)

Climate change is caused in large part by the buildup of greenhouse gases that trap outgoing "longwave" radiation and prevent the earth from cooling itself. The earth sheds the majority of longwave radiation at night, and thus, much of the global warming signal has been observed and also theorized to occur at night. The result is an increase in overnight low temperatures. One question is, "are all nights getting warmer, or just some?" It would be of particularly high impact if the warmest nights of summer were getting warmer, because heat stress events are tied as much to warm nights as they are to hot days.

Like the hottest days of summer, the warmest nights of summer (both the single warmest low and the 15 warmest low temperatures) have not yet warmed beyond the bounds of normal historical variations (see Fig. 7). Like Figures 4 and 5, the warmest low temperatures occurred in the1930s. A general upward trend is once again noted since the year 2000, but is not yet larger than other fluctuations since the era of warm summers in the 1930s and 40s. It is clear on this image, however, that both the decade-scale variability and the recent warming are more significant and closer to historical limits than what was found with the hottest temperatures of summer.

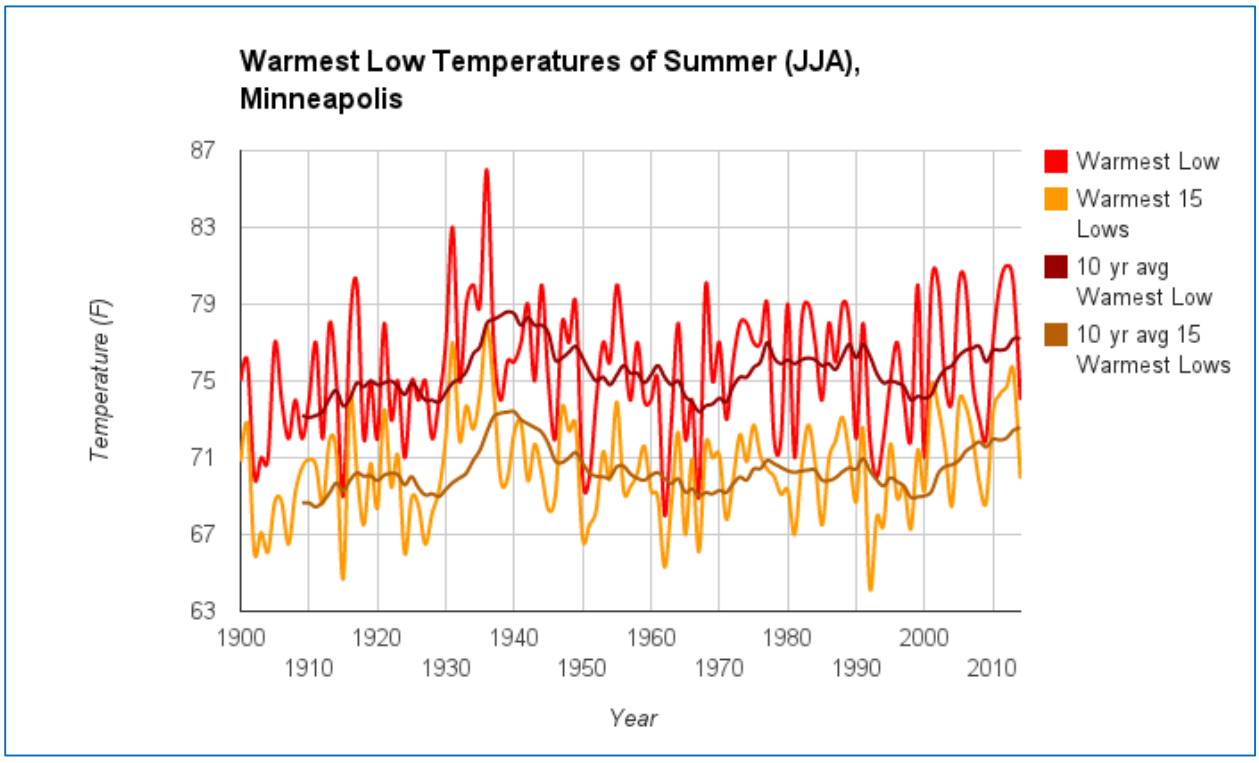

Figure 7. Warmest low temperature of summer (red), and average of 15 warmest low temperatures of summer (orange), with maroon and brown traces showing the respective 10-year averages.

The number of low temperatures equal to or exceeding 75 degrees also shows an upward trend that, while not yet historically unique, is more significant than was found for highs equal to or exceeding 95 degrees (see Fig. 8). Indeed, the 10-year average of the number of nights remaining at or above this

threshold has increased steadily since 2000 and would, on the current trajectory, become historically unique by 2025 or 2030. Considering that summer 2014 failed to exceed that threshold even once, it remains to be seen whether the recent increase is a climatic signal, as opposed to the "noise" associated with normal variations.

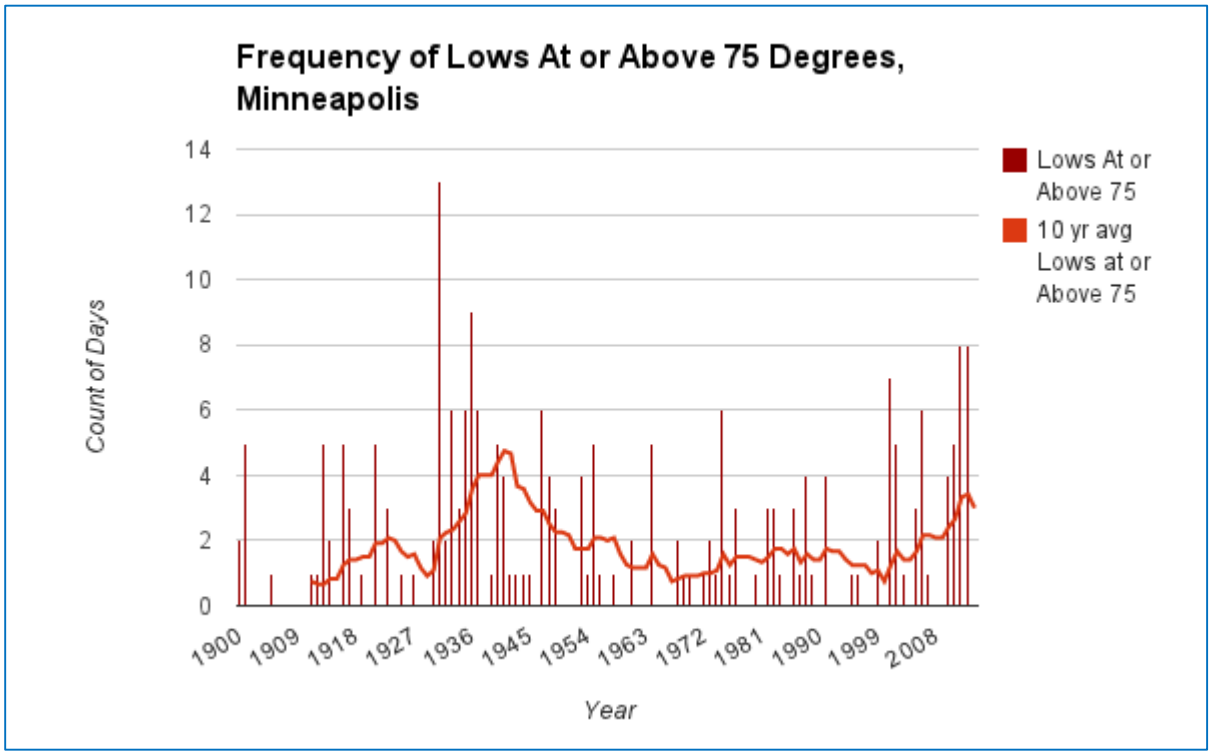

Figure 8. Number of low temperatures at or above 75 degrees, with red trace showing 10-year average.

Key Takeaways

1. **The warmest nights of summer also peaked in the 1930s and have been more or less flat since 1950, although with more variation than was observed with the hottest temperatures of summer.**

2. **The number of low temperatures at or above 75 degrees (F) appears to be increasing significantly but is not yet outside the bounds of normal variability.**

3. **Climate change is registering more of an effect on warm nights than on hot days.**

Warmest High Temperatures of Winter

Perhaps more than any other extreme temperature variable examined, warm winter temperatures (Decmeber through February) lack any semblance of a trend, or any period of peak magnitudes (see Fig. 9). Both the warmest high temperature of winter, and the 15 warmest high temperatures of winter

exhibit muted variability. The warmest high temperature is typically around 50 degrees, although readings at or above 60 have been observed seven times, and have failed to climb above 40 degrees with the same frequency.

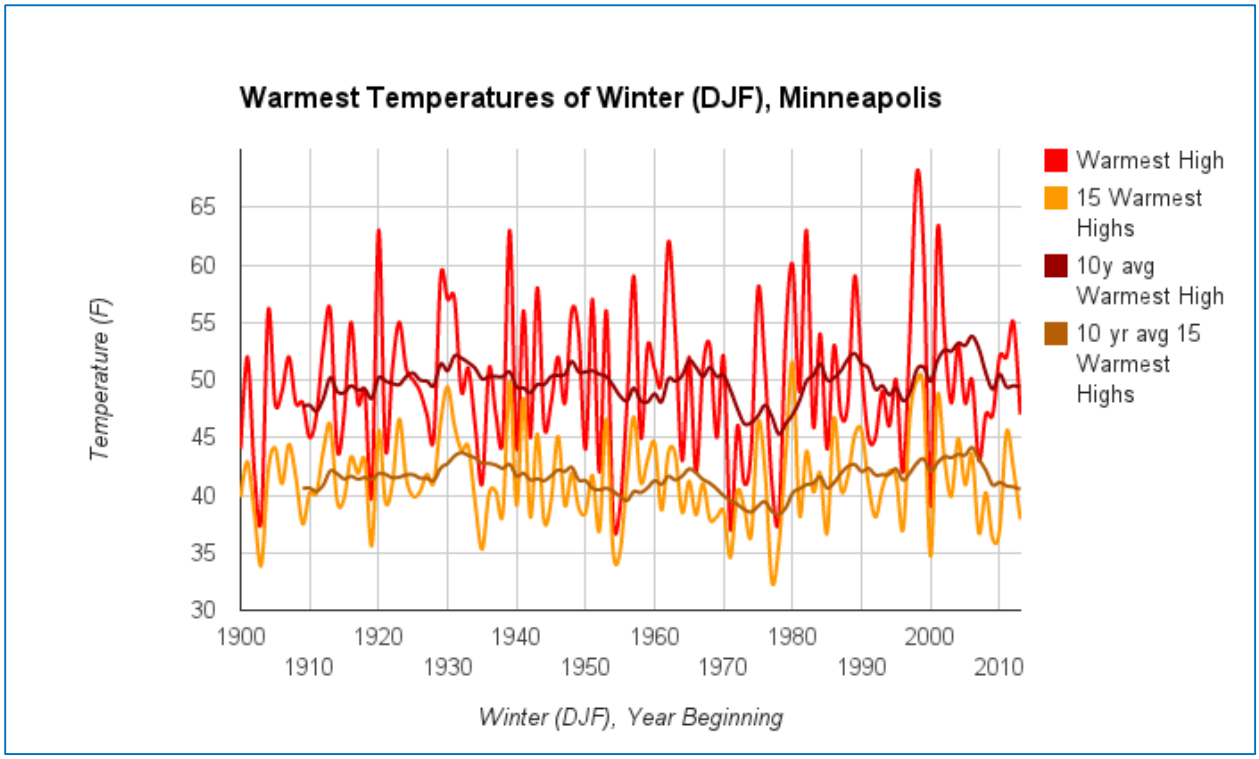

Figure 9. Warmest high temperature of winter (red) and warmest 15 high temperatures of winter, with maroon and brown traces showing respective 10-year averages. Note lack of any discernible trend, along with lack of any period of peak winter high temperatures, as had been found with summertime temperatures.

This finding is especially startling given the extent of warming observed during recent winters. With the exception of very warm high temperatures observed in 1998 and 2001 (both of which were in very early December), the warmest temperatures of winter in recent years have not varied appreciably from the historical record.

Key Takeaways

1. **The warmest days of winter have not gotten warmer, and currently cannot be projected to in the foreseeable future.**

2. **Therefore, winter is indeed warming, but not because of any change in the character of its warmest days.**

Warmest Nights of Winter (Warmest Low Temperatures of Winter)

The warmest low temperatures observed during winter also exhibit no trend with time whatsoever (see Fig. 10). Like the warmest high temperatures of winter, with the exception of a few isolated "spikes," no period on record stands out as the warmest.

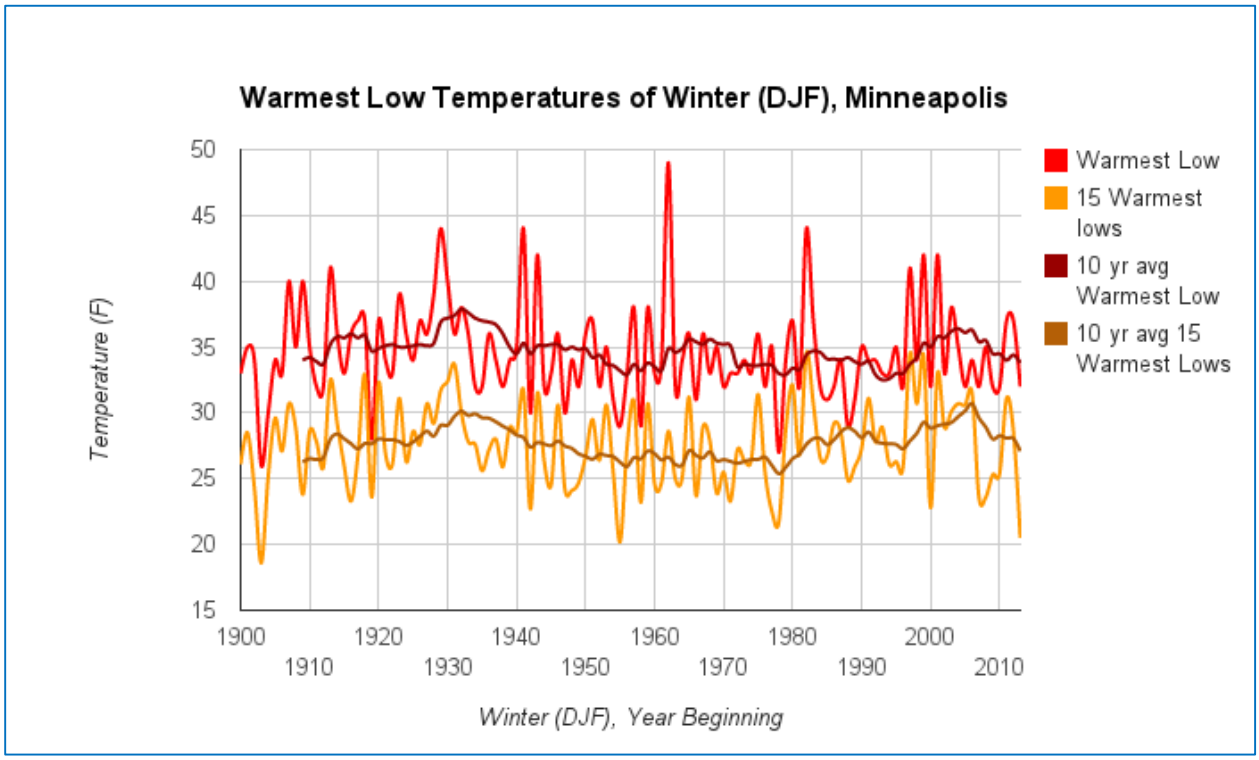

Figure 10. Warmest low temperature of winter (red) and 15 warmest low temperatures of winter (orange), with red and brown traces showing the respective 10-year averages. Note the lack of any discernible trend.

Despite a prominent warming signal during winter, and despite that observations and forecasts suggest warming should be greatest during the winter *and at night*, the warmest low temperatures of winter do not appear to register an influence of the intensified greenhouse effect.

Key Takeaways

1. **The warmest nights of winter have not gotten warmer, and currently cannot be projected to in the foreseeable future.**

2. **Therefore, winter is indeed warming, but not because of any change in the character of its warmest nights**

Coldest Nights of the Year (Coldest Winter Low Temperatures)

In Hennepin County, the most obvious temperature signal of climate change is the loss of formerly-normal cold temperatures. The coldest day of the year has warmed by about 8 degrees (F) since the early 20th century, and the 15 coldest days have warmed by about 7 degrees over that same period. However, as seen in Fig. 11, the coldest temperatures became much colder between 1956 and 1962, and appeared to reset the warming trend seen up until that point. A cold regime persisted until 1970 when a rapid warming of the coldest temperatures ensued. Between 1970 and winter of 2013-14, the 10-year average of both the coldest temperature of winter, and the 15 coldest low temperatures of winter, rose by more than 10 degrees. No analogous period—or anything even resembling it—of such rapid and pronounced warming exists anywhere within the record.

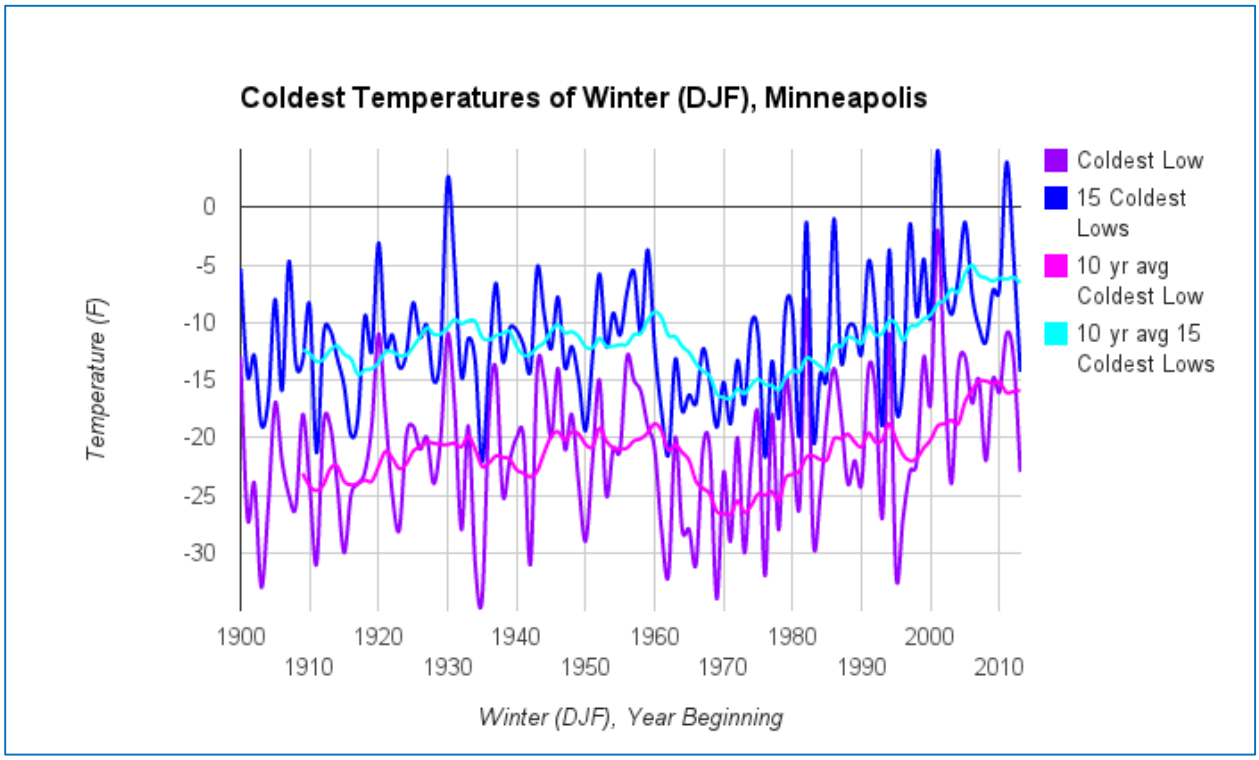

Figure 11. Coldest temperature of winter (purple) and 15 coldest low temperatures of winter (blue), with magenta and light blue traces showing the respective 10-year averages. Note the pattern of gradual warming between 1900 and the late 1950s, followed by a sharp drop, and then the most rapid and intensive warming on record from 1970 through 2013.

With the coldest temperatures of winter warming so rapidly, it should not be surprising that the number of nights falling to -10 or colder have dropped off dramatically in recent years also (see Fig. 12). Since 1972, the 10-year average of the annual frequency of low temperatures equal to or colder than -10 (F) has fallen by over 11 days per year (from 17.6 down to 6.1). A nearly identical pattern, only with different magnitudes, could be seen for thresholds of -5, -15, -20 and -25 (not shown). Indeed, Minneapolis has not fallen to -25 or colder since the 1996-97 winter. No period of that length without reaching -25 (F) occurs anywhere within the Minneapolis temperature record.

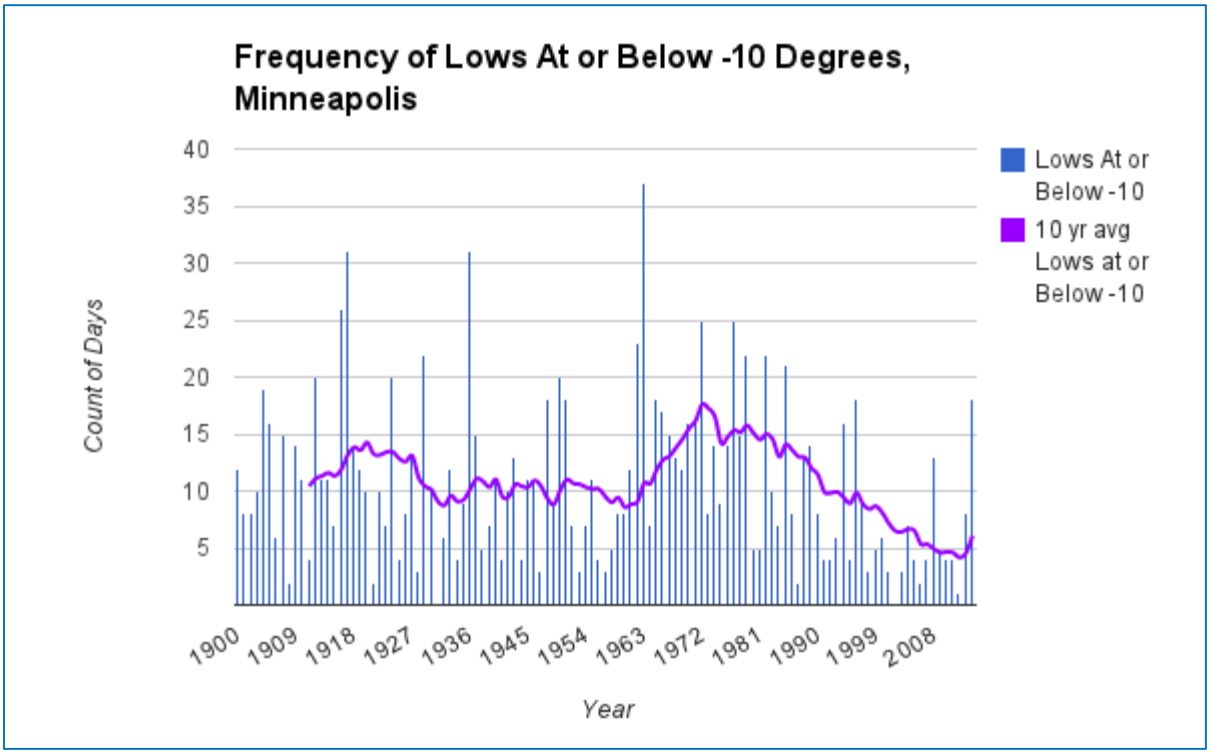

Figure 12. Count of days with low temperatures equal to or colder than -10 (F), with 10-year average shown in purple. Note sharp downward trend since 1970.

Key Takeaways

1. **The coldest temperatures of the year have warmed rapidly, and are now significantly warmer than at any other time on record. Hennepin county simply does not get as cold as it once did.**

2. **Accordingly, the frequency of lows at or below -10 (F), and virtually all cold-temperature thresholds, has decreased dramatically since 1970.**

3. **The loss of formerly-common is one of the area's key climate change "symptoms."**

Coldest Days of the Year (Coldest Winter High Temperatures)

The coldest high temperatures of the year (the coldest highs of winter) exhibit a pattern that is largely similar to the coldest lows of winter, though with a slightly less pronounced magnitude and rate of warming (though still significant, see Fig. 13). A gradual warming of the coldest high temperatures was observed between 1900 and 1960, followed by a drop, and then an uptick in 1970, and again in the late 1990s. Whereas the coldest high temperature of the year historically has been around -7 degrees, since the early 2000s the 10-year average has been much closer to zero degrees (F). Like the coldest low temperatures of the year, the coldest high temperatures of the year have warmed to a level not previously experienced at any time in the historical record.

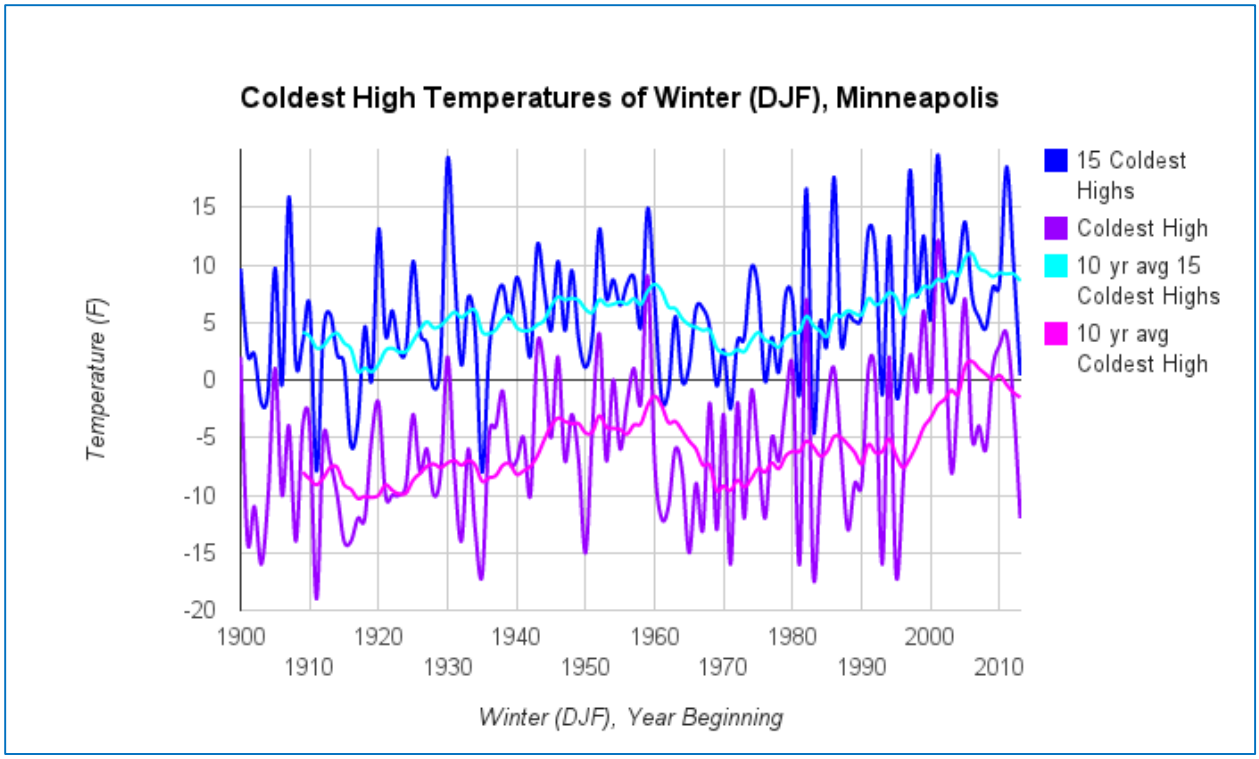

Figure 13. Coldest high temperature of winter (purple) and 15 coldest high temperatures of winter (blue), with magenta and light blue traces showing the respective 10-year averages. Note the pattern of gradual warming between 1900 and the late 1950s, followed by a sharp drop, and then the most rapid and intensive warming on record from 1970 through 2013.

Not surprisingly, the frequency of days with temperatures equal to or below zero degrees (F) also has been in sharp decline since 1970 (see Fig 14). Through 1997, the average number of zero or subzero highs annually was 4.4. From 1998-2014, the average has fallen to just 1.3 days per year, and no year during that time has exceeded the old average. From 1998 through 2014, eight out of 17, or 47% of years failed to have a zero or subzero high temperature, up from 11% (11 out of 98) for the 1900-1997 period. Whereas high temperatures at or below zero were once commonplace, it appears the time is approaching when they will become the exception rather than the rule.

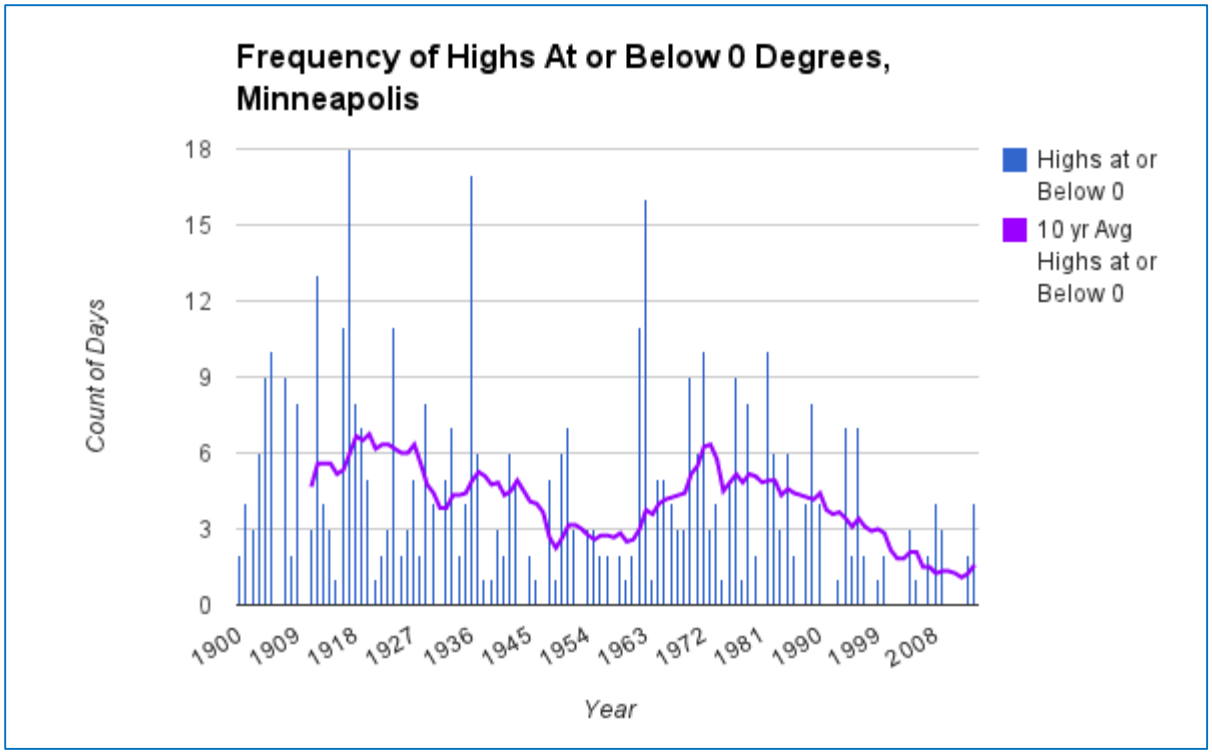

Figure 14. Count of days with high temperatures equal to or colder than 0 (F), with 10-year average shown in purple. Note sharp downward trend since 1970.

Key Takeaways

1. **The coldest high temperatures have warmed dramatically since 1970 and are now warmer than at any other time on record.**

2. **High temperatures at or below zero have become much less common in recent years and may soon be the exception, rather than the rule.**

Coolest Low Temperatures of Summer

Despite a slight cooling trend for the majority of the record, the lowest temperatures observed during summer have exhibited exceptional warming since the turn of the millennium (see Fig. 15). In fact, the 10-year average of the coolest temperatures of summer had been at an all-time low (just below 42 degrees) from the late 1990s into the early 2000s, but then rose to the warmest levels on record within five years, with rapid and persistent warming of the coolest summer temperatures continuing since that time. The trend has been anchored by multiple occurrences of temperatures failing to fall below 50 degrees at any time during the entire June-August period, which had not been observed before 2005.

The 15 coolest low temperatures of summer have shown a slightly less pronounced, but still significant warming during the same interval. They too are now beyond the bounds of normal historical variability, and their 10-year average recently climbed above 54 degrees (F) for the first time in recorded history.

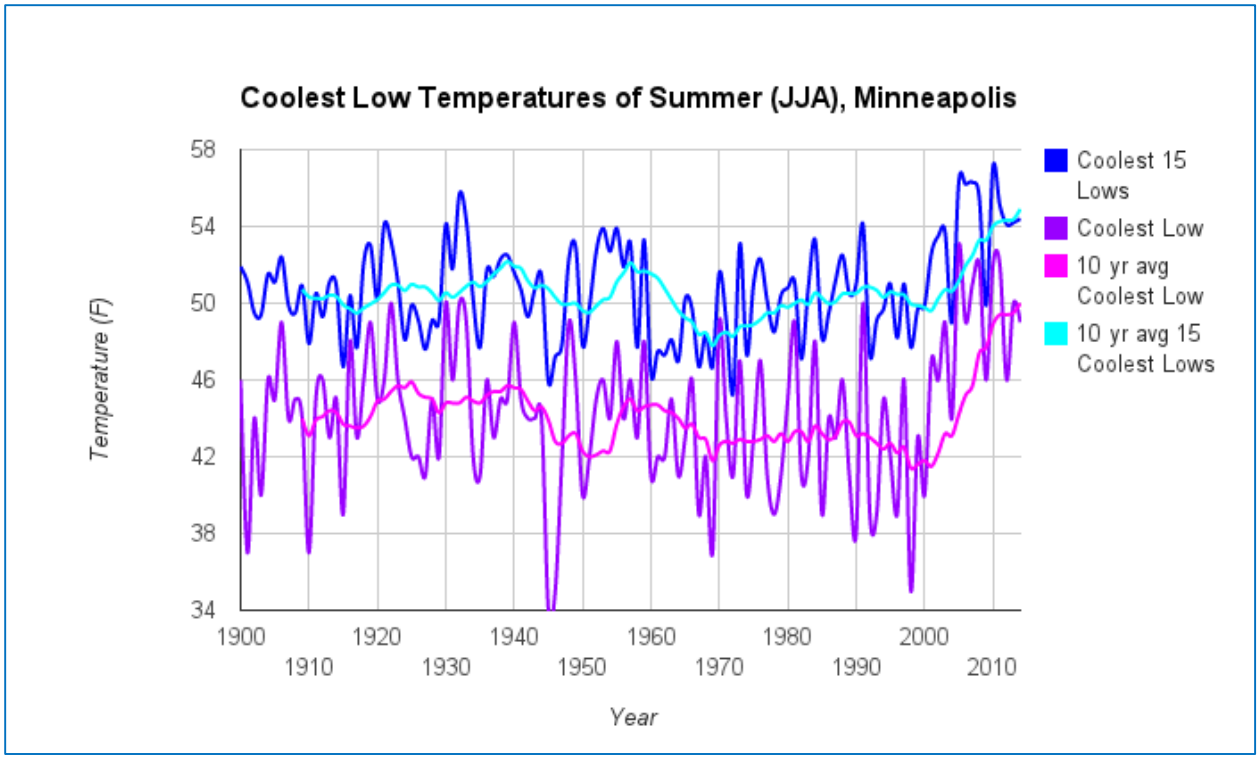

Figure 15. . Coldest temperature of summer (purple) and 15 coldest low temperatures of summer (blue), with magenta and light blue traces showing the respective 10-year averages. Note downward trend in the purple and magenta traces, followed by an unprecedented rise after 2000.

Key Takeaways

1. **The coldest temperatures of summer have warmed dramatically and rapidly since the year 2000, and are now without historical precedent.**

2. **A continuation of this trend suggests that summertime temperatures in the 40s will become increasingly rare.**

Coolest High Temperatures of Summer

The coolest high temperatures have risen only slightly during the record amid frequent fluctuations, and are currently still within historical bounds (see Fig 16). Unlike the coolest low temperatures of summer, the current upward trend seen here is indistinguishable from the numerous other upward trends seen in the record. A continuation of this currently minor trend would indicate that summertime high temperatures below 60 degrees will become less common. At present however, there is little basis for such a prediction.

The coolest 15 high temperatures of summer, on the other hand, show a gradual upward trend through the record, without any major inflection points beyond the small multi-decade-scale fluctuations seen

in the 10-year averages. Unlike the absolute-coolest high temperature of summer, the 10-year average of the 15 coolest high temperatures of summer have now left the left the bounds of historical variability and are the warmest on record (see Fig. 16). The gradual, persistent nature of this particular trend makes it unique among the other extreme temperature variables examined in this report.

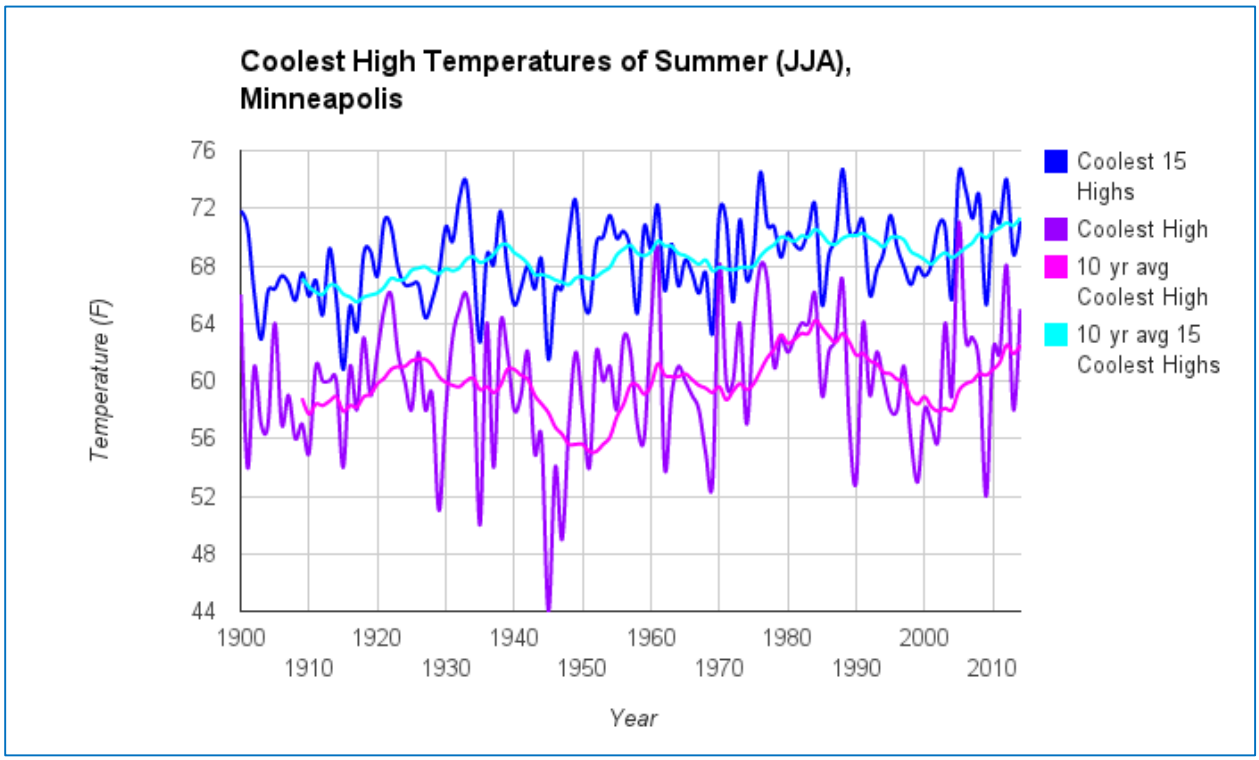

Figure 16. Coolest high temperature of summer (purple) and 15 coolest high temperatures of summer (blue), with magenta and light blue traces showing the respective 10-year averages.

Key Takeaways

1. **The absolute-coolest high temperature of summer is exhibiting long-term warming but is still undergoing large inter-annual and decadal fluctuations and is currently within the bounds of normal historical conditions.**

2. **The 15 coolest high temperature readings of summer have also exhibited long-term warming, but have done so with less fluctuation and are now warmer than at any other time on record.**

Summary and Conclusions

The above analyses lead to the following conclusions:

- **Hot days are not getting hotter.** The highest temperatures of summer are still well within historical bounds and have not exhibited an increase consistent with many predictions and warnings.
- **Warm summer nights are not getting warmer (yet).** The warmest nights of summer have exhibited some recent warming but are still well within historical bounds
- **Rapid winter warming is not driven by warm temperatures**. The magnitudes of the warmest high and the warmest low temperatures of winter have remained remarkably constant since 1900, and have exhibited no warming.
- **The bottom is coming up.** The loss of cold conditions is driving the area's climate change signal. The coldest low temperatures of winter have warmed dramatically, as have the coldest high temperatures. The coolest low temperatures of summer have warmed more rapidly than any other variable examined.
- **In summary, our warming is being driven by less cold and cool air, as opposed to more warm and hot air.**

The following table summarizes the seasonal extreme temperature patterns, and assesses the likelihood a climate change signal is present, using the designators no climate change signal;

	Warmest High Temperatures	Warmest Low Temperatures	Coolest Low Temperatures	Coolest High Temperatures
Summer	No increase; no climate change signal	Some increase; climate change signal possible	Unprecedented and major increase; climate change signal virtually certain	Gradual and significant increase; climate change signal likely
Winter	No increase; no climate change signal	No increase; no climate change signal	Unprecedented and major increase; climate change signal virtually certain	Unprecedented and major increase; climate change signal highly likely

References

[i] US Global Change Research Program, Third National Assessment, Midwest Chapter http://nca2014.globalchange.gov/report/regions/midwest

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