DEPARTMENT OF NATURAL RESOURCES

Climate Summary for Watersheds: Supplemental Information

September 2019

Contents

Purpose

The Climate Summaries for Watersheds are based on climate data collected from 1895 through 2018. The focus is on reporting seasonal and annual temperature and precipitation recorded over this time period. By summarizing the data in a consistent way, climate can more easily be part of important discussions about managing Minnesota's natural resources and community infrastructure, so that climate adaptation and mitigation strategies are included and addressed.

- The Statewide Climate Summary provides context at the statewide scale and provide a starting point for a review of climate information.
- The Major Watershed Climate Summaries provide the same charts and tables at a scale that is useful for more local discussions about climate considerations.

Why is climate important to understand for managing the health of major watersheds?

Climate is a foundational ecological condition. Other natural processes evolve in response to local, regional and global climate conditions.

Why is it important to view climate change for major watersheds?

Climate measurements are showing a shift in foundational climate conditions. Other ecological processes are changing in response. Communities and individuals making decisions about managing land and water resources for infrastructure, flood protection, habitat protection, water supply, and other needs must be aware of this shift and consider its potential impacts.

Interpreting Climate Summary Data

These maps and charts provide a visualization of available long term climate data. The results should not be interpreted as statistically significant trends, but rather as a summary view of climate data over time. Additional statistical analysis would be required to measure the 'statistical significance' of perceived trends in the data.

Information about the source data

The maps and figures contained in this document are produced from the Global Historical Climatology Network Daily (GHCN-D) nClimGrid data. The foundational dataset of GHCN-D is a database of daily climate summaries from climate monitoring stations around the world. The GHCN-D staff interpolate observations from climate stations to create a continuous coverage of climate values, this derived product is called nClimGrid. Vose (et. al. 2014) assess the accuracy of nClimGrid for calculating average climate values for each of the 344 U.S. climate divisions; according to their estimates, errors are “likely less than 0.5°C for temperature and 20mm for precipitation at the start of the record, falling rapidly thereafter”.

While the quality of the input data is high, this Climate Summary is designed for exploration of climate trends at the statewide and major watershed scales. The GHCN-D Source Data is available for further analysis if users need measured observations for a specific climate monitoring station. NOAA Data Catalog

Limitations to using this data

- The maps and figures represent observed data only. These maps and charts should not be used to predict future climate conditions.
- The maps are created from 30 year averages and reflect the climate from that period. Patterns will not be constant when compared to a different 30-year period.
- The development of nClimGrid involves anomaly detection and spatial interpolation. Individual climate station data may be smoothed during this analysis, which can result in values that are slightly different than the original observations.
- Contour lines were developed to help illustrate and interpret climate patterns on the landscape. Contours creation involves the use of interpolation and smoothing.
- Given the above two points, some of the map’s precise details may reflect the mapping and display techniques, rather than true climatic variations.

For further information and guidance

The content of this document was developed by the Watershed Health Assessment Framework (WHAF) program staff, with guidance and feedback from the Minnesota Climatology Working Group.

For questions and guidance on managing for watershed health, or for information on the methods used to develop this document, contact the WHAF staff. whaf.dnr@state.mn.us

For questions and guidance on climatology data and its appropriate use, contact the Minnesota Climatology Working Group. climate@umn.edu

General Climate Observations

Statewide climate observations provide important context for interpreting the climate summaries.

Minnesota's climate has always been variable, but by examining the historical record (1895-2018), climate trends begin to emerge:

- Minnesota is getting warmer and wetter.
- Minnesota has fewer extreme cold temperatures; winter low temperatures are warming faster than other seasons.
- Minnesota is experiencing more extreme rainfall events, but this trend is not quantified in the Watershed Climate Summary at this time.

Minnesota's climate will continue to experience variability above and below the trend lines.

More on climate and climate trends can be found on the MN DNR website.

Temperature Observations

Minnesota Temperature Behavior and Seasonality

Minnesota's position near the center of the North American continent subjects it to a variety of air masses that determine its weather, and ultimately, its climate. Northerly winds provide access to Arctic air masses that dominate the winter season, occasionally replaced by somewhat milder from the west, south, and east. During the summer, southerly winds import warm and humid air from the Gulf of Mexico, with occasional, early-summer bouts of hot and dry air arriving on southwesterly winds. Spring often begins with winter-like temperatures and ends with summer-like ones, while fall works in the opposite direction.

The generally dry conditions associated with winter allow for dramatic temperature changes within the season, and also from one year to the next. For instance, cold northerly winds may drop temperatures well below 0°F for extended periods, but milder winds may boost temperatures well above freezing—often in the same month. Any persistent pattern favoring warmer or colder air can tilt a winter month heavily towards above-average or below-average temperatures. As a result, temperature variability is relatively high during the winter, when the average temperature of a given month commonly varies by double-digit margins from one year to the next.

By contrast, the higher moisture content of the air during summer limits temperature ranges, and as a result, temperature variability during summer is less than during winter. In the summer, the average temperature of a given month generally varies by 3-6 degrees from one year to the next, and double-digit temperature differences are rare.

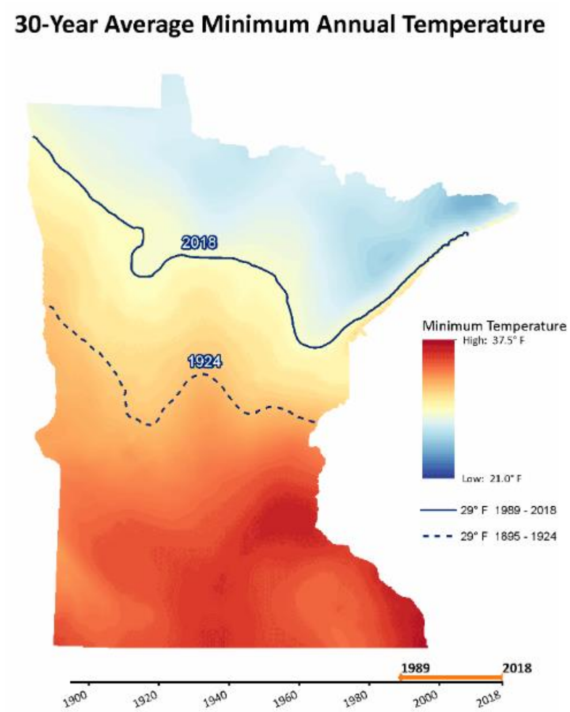
Baseline Temperature and Trends

Minnesota's statewide average annual temperature is approximately 40.2°F, based on the entire historical record (1895-2018). These temperatures, however, have been rising for several decades, meaning that period-of-record averages do not represent recent conditions adequately. When averaged over the entire period, Minnesota's annual temperatures have risen at a rate of almost a quarter of a degree (0.24°F) per decade; that rate has increased to over a half a degree (0.56°F) per decade since 1970.

Additionally, Minnesota's temperature trends vary by time of day (that is, day versus night, or daily "high" versus "low" temperatures), by season, and by region of the state. For instance, since 1970:

- Daily minimum (low) temperatures are increasing 58% faster than daily maximum (high) temperatures.
- Winter temperatures are increasing more than eight times faster than summer temperatures.
    - → Winter minimum temperature are increasing fastest of all (+ 1.23°F per decade).
    - → Summer maximum temperatures have declined slightly (- 0.09°F per decade).
    - → Fall (and to a lesser extent spring) is warming faster than summer but slower than winter.
- Northern Minnesota is warming faster than southern Minnesota, by an average of 30%.

This map illustrates the northward movement of a line showing the average minimum temperature of 29 °F in 1924 (dotted blue line) and in 2018 (solid blue line). An animated version of this map showing the change over time is available here: [Minimum temperature trend over time.]



Topography Influence on Temperature

In general, low elevations are warmer than high elevations, but this relationship can be modified and altered by other factors, including time of day, wind direction, and proximity to water. For instance:

- Cold air tends to sink, and so on calm nights the lowest temperatures will be in low-lying areas.
- When air is blown up a slope, it will cool as it ascends.
- If the wind blows down-slope, it heats by compression and warms the low-lying areas more than similar areas at the same elevation that have little surrounding topography.
- Areas near lakes, particularly large lakes, may be cooled by lake breezes during the summer, but warmed by them during the late fall and early winter, before ice-in.

Precipitation Observations

Minnesota Precipitation Behavior and Seasonality:

The spatial pattern of annual precipitation in Minnesota is influenced heavily by access to deep sources of moisture. The Gulf of Mexico serves as Minnesota's primary moisture source, with smaller contributions coming from the Atlantic and Pacific Oceans, and an additional small, "microclimatic" influence from Lake Superior on portions of northeastern Minnesota.

Southeastern Minnesota, which is closest to the Gulf of Mexico and is most frequently influenced by air masses from that region, receives approximately 60% (12 inches) more precipitation than northwestern Minnesota.

Although Minnesota is best known for its distinct temperature seasonality—the unmistakable difference between winter and summer air mass conditions—it also has pronounced wet and dry seasons that closely follow temperature patterns. Summer months are typically 3-4 times wetter than winter months, and in an average year 65-70% of Minnesota's precipitation falls during the five months from May through September.

Baseline Precipitation and Trends:

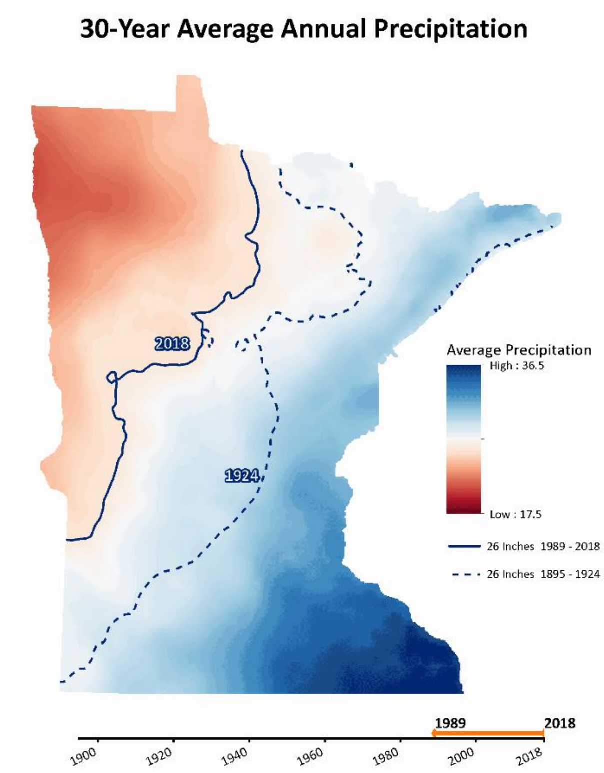
Minnesota's statewide average annual precipitation is 26.08 inches, based on the entire historical record (1895-2018). As with temperature, precipitation in Minnesota has been increasing for many decades. Part of this increase was the natural rebound expected after the major drought episode of the 1920s and 1930s, when annual precipitation decreased by 10-15% and reached the lowest levels on record. However, in the past few decades, precipitation has continued increasing beyond what would be expected from typical wet/dry variations. Since 1970 annual precipitation in Minnesota has increased at an average rate of 0.40" per decade. Rates of increase have been even faster in southern parts of the state. In northern areas, precipitation shows no recent increase.

The recent increases in precipitation have been concentrated from February through September. The other months have shown either no change, or slight drying. It should be noted that although the current wet regime has led to less total drought in Minnesota during parts of the 2010s than any other time on record, the entire state will continue to be susceptible to episodes of prolonged drying and drought.

Spatial Variability of Precipitation:

In southern and eastern portions of the state, the 2010s will finish as the wettest decade on record. In northern and northwestern areas, the precipitation of the 2010s has been closer to long-term averages. Indeed, it is common for Minnesota to experience precipitation surplus and deficit simultaneously, in different parts of the state. Thus, it will be possible for one area to experience record or near-record precipitation, while another experiences drought.

In general, during multi-year wet periods, Minnesota appears to "import" the wetter conditions from the southeast. This can be seen in animations of average precipitation and in change maps that show higher average precipitation values lifting northwestward across the state. This is especially noticeable presently, because the 1990s through 2010s have been so wet. Similarly, during periods of prolonged drying and drought, the lower average precipitation values can be seen surging eastward and southeastward across the state. Even if Minnesota continues the long-term trend towards more precipitation, significant dry episodes will halt or briefly reverse the apparent migration of wetter conditions.



This map illustrates the northwestward migration of average annual precipitation of 26 inches from 1924 (dotted blue line) to 2018 (solid blue line). This migration is in response to the increase in total annual precipitation occurring in southeastern Minnesota.

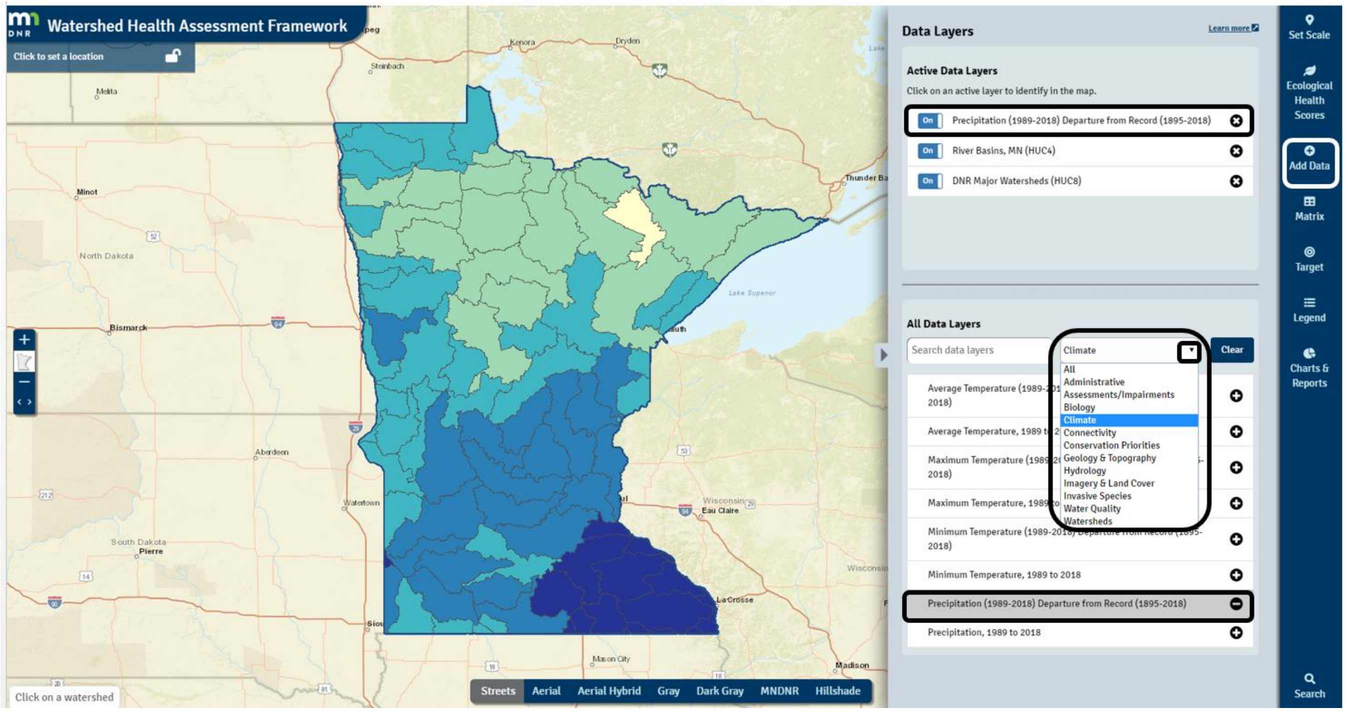
An animated version of this map showing the change over time is available here: [Annual Precipitation trend over time.]

More animated maps of seasonal and annual historic climate data can be found here:

https://www.dnr.state.mn.us/climate/historical/annual.html

Viewing Climate Data in the WHAF Map

The climate data layers developed for the Climate Summary for Watersheds are also available for viewing in the WHAF online map.



Steps:

- [Open WHAF Map 2.0]
- Click to open the ‘Add Data’ menu.
- Filter the data with the drop down list, select ‘Climate’.
- Click on the climate data layer you want to add.
- Use the ‘Active Data Layers’ to turn the layer on/off or drag to change which layer draws on top.

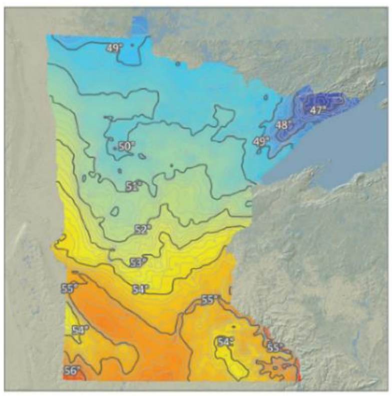
About Climate Charts and Maps

The example chart and maps are from the [Statewide Climate Summary] and the [Root River Watershed Climate Summary]. Climate Summaries for any major watershed in Minnesota can be [downloaded here].

Temperature

The temperature maps are based on the most recent 30 years of climate data (1989 – 2018). The statewide temperature maps show the expected gradient with the south being warmer than the north. Additionally, the northeast near Lake Superior is colder than other areas at the same latitude; and the Twin Cities urban area is warmer than other areas at the same latitude.

Example – Statewide Maximum Temperature Map



Average Maximum Temperature (°F), 1989-2018

46° 50° 54° 58°

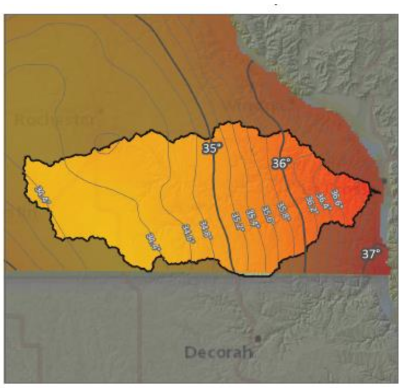
1° contour .2° contour

Statewide Average

Time period	Value
Annual	52.0°
Winter (Dec. - Feb.)	22.8°
Spring (March - May)	52.6°
Summer (June - Aug.)	78.0°
Fall (Sept. Nov.)	54.4°

This **statewide maximum temperature** map clearly shows the influence of topography. The highest temperatures are found in open low areas such as the Minnesota River Valley. The cooling effect of higher elevation can be seen along Buffalo Ridge in the southwest, and the Superior Uplands rising above Lake Superior.

Example - Root River Minimum Temperature Map



Average Minimum Temperature (°F), 1989-2018

24° 28° 32° 36°

1° contour .2° contour

Watershed Average

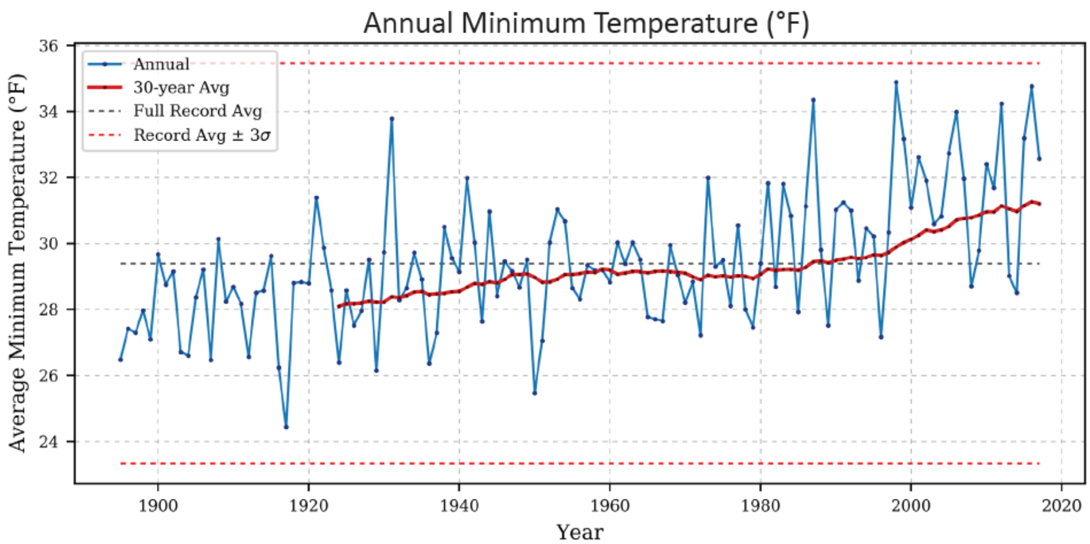
Time period	Value
Annual	35.1°
Winter (Dec. - Feb.)	10.3°
Spring (March - May)	34.3°
Summer (June - Aug.)	58.0°
Fall (Sept. Nov.)	37.5°

This map shows **average low temperature** for the most recent 30 years for the Root River Watershed. The annual average low was 35.1°, and seasonally the average low temperature ranged from 10.3° in the winter, to 58° in the summer. The minimum temperature also appears to warm by 3° from west to east. This gradient reflects the observed temperatures and the influence of a change in elevation.

Temperature Charts

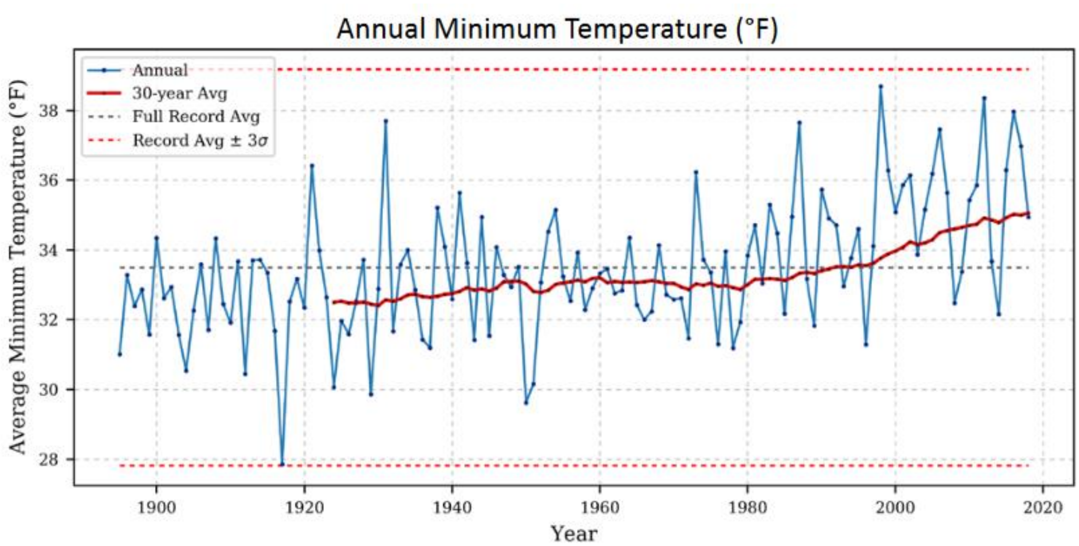
For each temperature chart, the blue line depicts the average annual minimum temperature for the entire record of climate data. The red line is a moving average based on each previous 30 years of data; beginning with the first 30-year period of 1898 – 1928. The dotted black line is the average minimum temperature for the entire climate record. The dotted red lines show three standard deviations from that average value.

Example – Statewide Minimum Temperature



This chart displays an increase in Minnesota's minimum temperatures, particularly over the most recent 20 years. This aligns with the recognized trend toward warmer winter nights across Minnesota.

Example – Root River Minimum Temperature

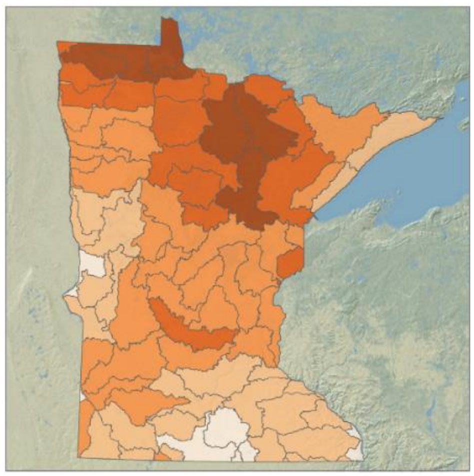


The Root River Watershed temperature charts display a similar pattern. The annual minimum temperature in the Root River Watershed also shows a consistent increase, particularly since the late 1990's.

Temperature Departure from Historic Average:

The temperature departure maps depict the difference between annual temperature based on the most recent 30 years of climate data (1989–2018), and annual temperature for the entire climate record (1895-2018). A greater difference or 'departure' of the recent average from the long-term average is displayed with a darker color.

Example – Statewide Minimum Temperature Departure

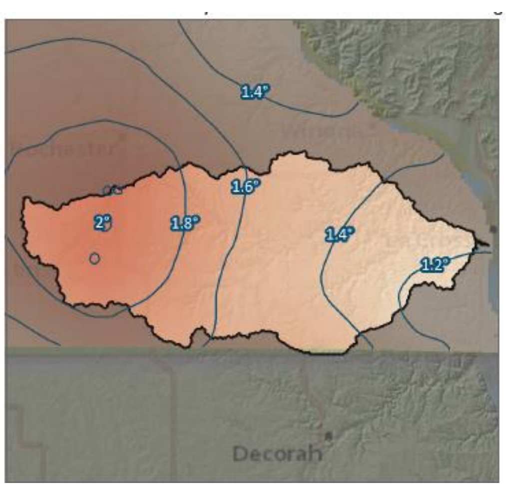


Statewide Average Departure

Time period	Value
Annual	1.8°
Winter (Dec. - Feb.)	3.2°
Spring (March - May)	1.4°
Summer (June - Aug.)	1.1°
Fall (Sept. Nov.)	1.4°

For Minnesota, the greatest departure is in the annual average minimum temperature. This value shows an upward deviation of 1.8^{o} degrees. The greatest departure occurred in north central Minnesota, with less change noted in the south. The greatest seasonal deviation has occurred in the winter, with minimum temperatures in the most recent 30 years averaging 3.2^{o} warmer than the average minimum for the entire climate record.

Example - Root River Minimum Temperature Departure



Watershed Average Departure

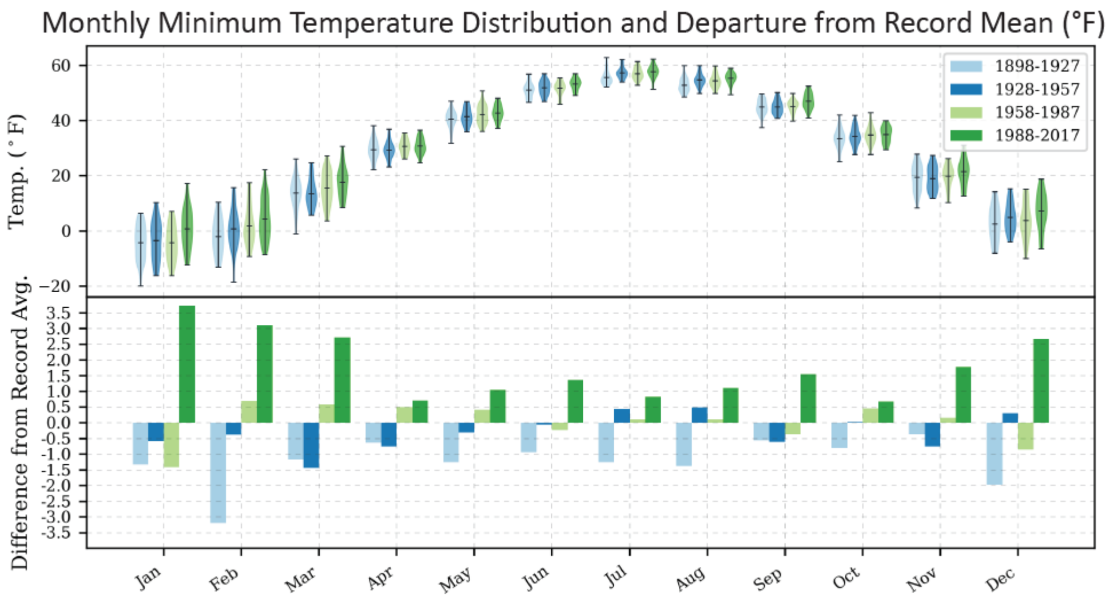
Time period	Value
Annual	1.6°
Winter (Dec. - Feb.)	2.8°
Spring (March - May)	1.2°
Summer (June - Aug.)	1.1°
Fall (Sept. Nov.)	1.1°

Additional spatial analysis at the major watershed scale provides more detailed results within each watershed. The departure for annual average minimum temperature for the Root River watershed shows an upward deviation of 1.6^{o} degrees. The greatest seasonal deviation has occurred in the winter, with minimum temperatures in the most recent 30 years averaging 2.8^{o} warmer than the average minimum for the entire climate record.

Monthly Temperature Departure from Climate Record:

Temperature values for each month are summarized into four adjacent 30-year periods. This reveals seasonal patterns in the range of temperature values, and indicates some change in those values over time.

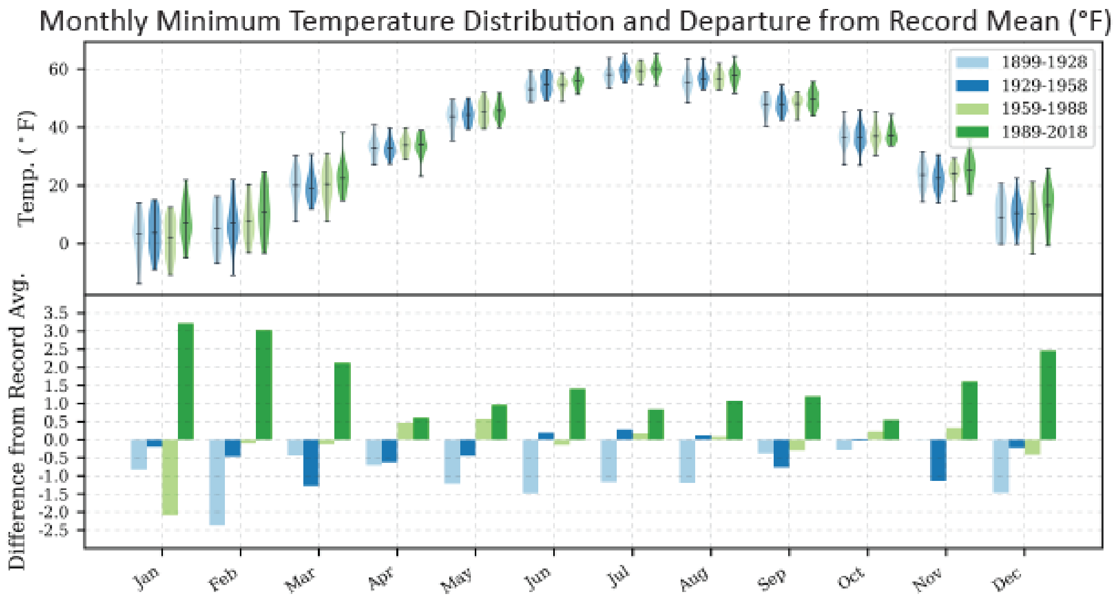
Example – Statewide Monthly Minimum Temperature Departure



Minnesota's climate experiences its greatest variability in temperature during the winter. The top chart shows that the greatest range of minimum temperatures has consistently occurred during winter months.

The bottom chart shows which months are experiencing the greatest change in low temperatures. Each bar represents the degrees above or below the long term average low. The earliest 60-years (blue bars, 1898 -1957) are below or near the average low, while the more recent 60 years (green bars, 1958-2017) are consistently near or above the average low. The most recent 30-year period (dark green) shows that minimum temperatures were warmer than the long term average every month of the year, with an increase nearing 3° during January and February. This is in line with the observation that in Minnesota 'it doesn't get as cold as it used to, especially winter nights'.

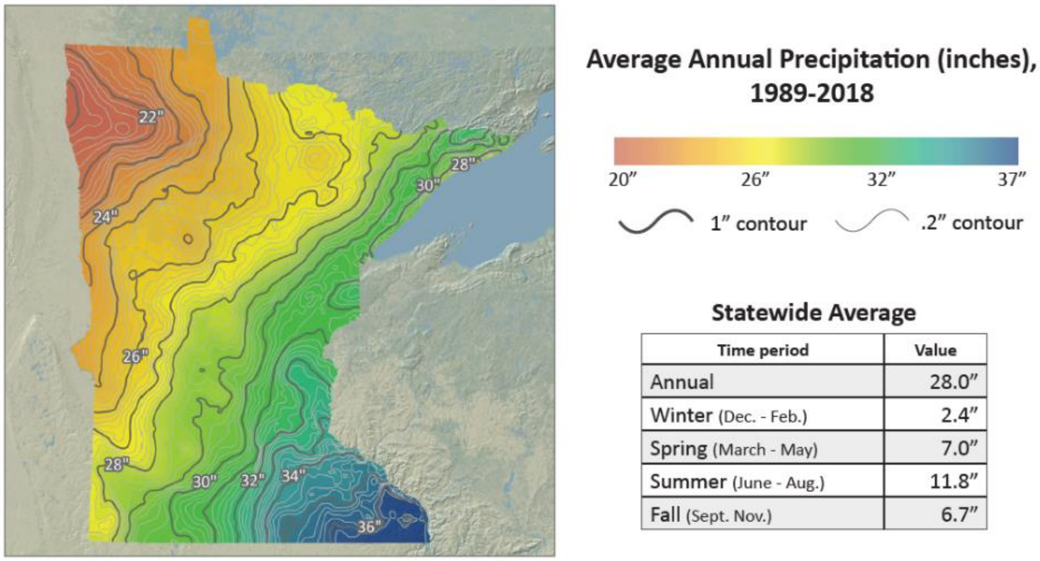
Example – Root River Monthly Minimum Temperature Departure



The same pattern is shown in this chart for the Root River Watershed. The top chart shows that the greatest range of minimum temperatures has occurred during the winter months. The bottom chart shows which months are experiencing the greatest change in low temperatures. The most recent 30-year period (dark green) shows that minimum temperatures were warmer than the long term average every month of the year, with an increase nearing 3° F during January and February.

Precipitation

Example – Statewide Recent Average Annual Precipitation

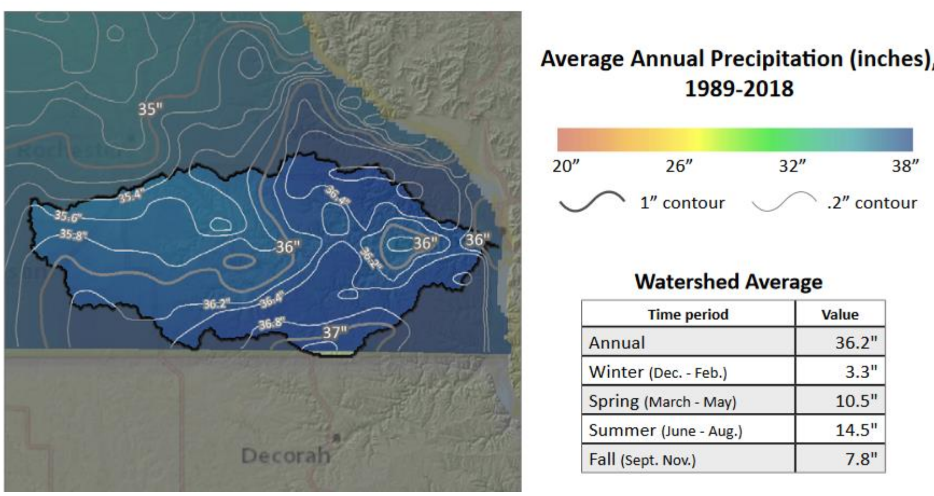


Statewide Average

Time period	Value
Annual	28.0"
Winter (Dec. - Feb.)	2.4"
Spring (March - May)	7.0"
Summer (June - Aug.)	11.8"
Fall (Sept. Nov.)	6.7"

The precipitation map depicts average precipitation based on the most recent 30-years of climate data. For Minnesota, the annual average precipitation total is 28 inches. The seasonal totals range from an average of 11.8 inches in the summer to 2.4 inches in the winter. Snowfall amounts are converted to their water content equivalent. The precipitation gradient across Minnesota from drier in the northwest to wetter in the southeast has been consistent over the historic record; but the extreme values have been getting further apart.

Example – Root River Recent Average Annual Precipitation



Watershed Average

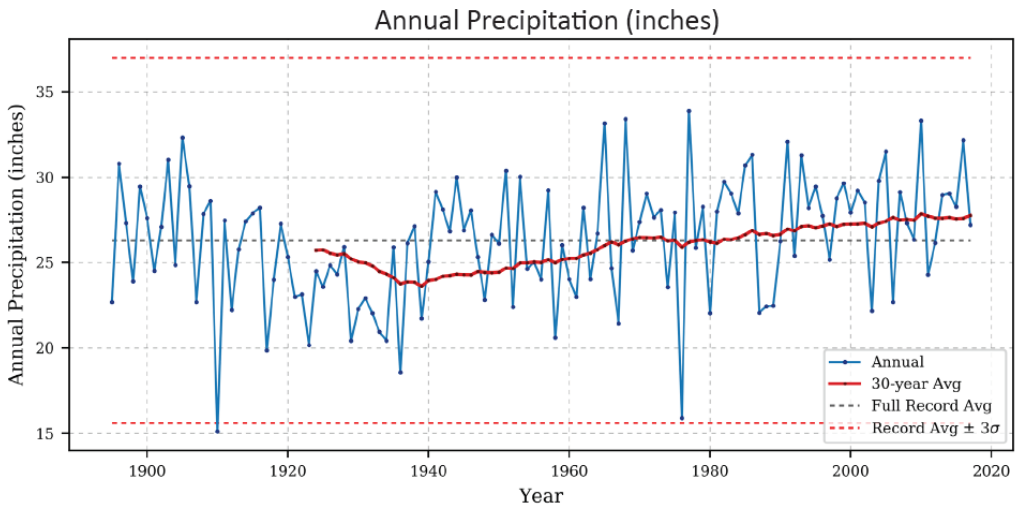
Time period	Value
Annual	36.2"
Winter (Dec. - Feb.)	3.3"
Spring (March - May)	10.5"
Summer (June - Aug.)	14.5"
Fall (Sept. Nov.)	7.8"

This map depicts average precipitation based on the most recent 30-years of climate data. The Root River Watershed is found in southeastern Minnesota, a part of the state that consistently receives more precipitation than other parts of the state. For this major watershed, the annual average precipitation total is 36.2 inches. The seasonal totals range from an average of 14.5 inches in the summer to 3.3 inches in the winter including snowfall amounts that are converted to their water content equivalent.

Precipitation Chart

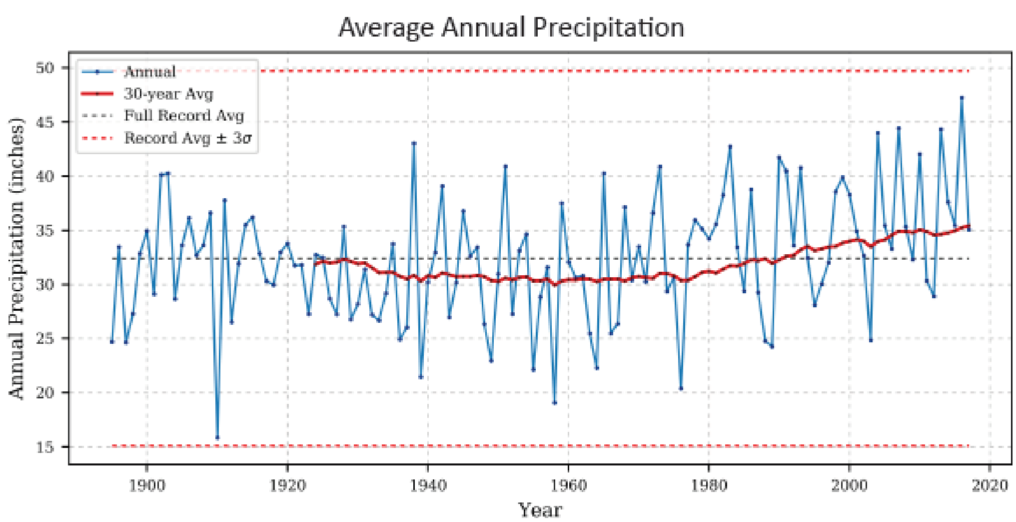
The blue line on these charts depicts the average annual precipitation for the entire record of climate data. The red line is a moving average based on each previous 30 years of data; beginning with the first 30-year period of 1898 – 1928. The dotted black line is the average annual precipitation for the entire climate record. The dotted red lines show three standard deviations from that average value.

Example – Statewide Annual Precipitation



This chart displays a slight increase in statewide annual precipitation, with annual precipitation above the long term record beginning around 1990 and continuing over the most recent 30 years.

Example – Root River Annual Precipitation

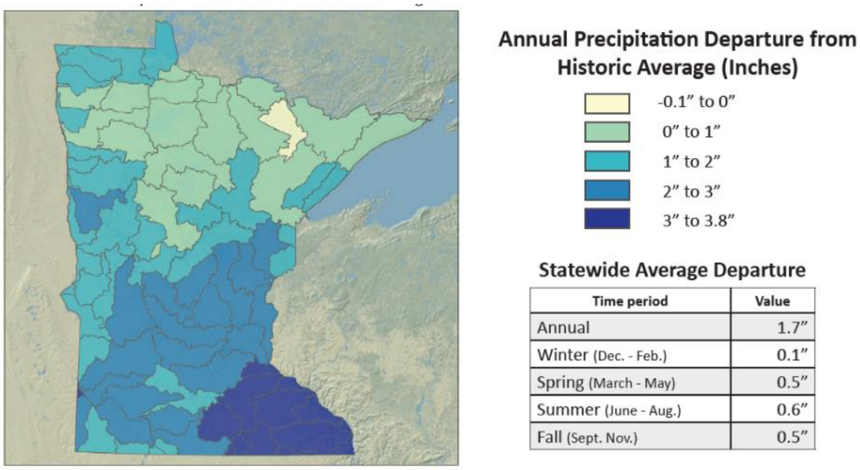


For the Root River Watershed, the chart displays a similar pattern of increase in annual precipitation, but the magnitude of the change is greater. This observation is consistent with other observations of precipitation throughout the southeastern quadrant of the state.

Annual Precipitation Departure from Historic Average

These maps depict the difference between the average precipitation for the most recent 30 years of climate data and the average precipitation for the entire climate record.

Example – Statewide Annual Precipitation Departure

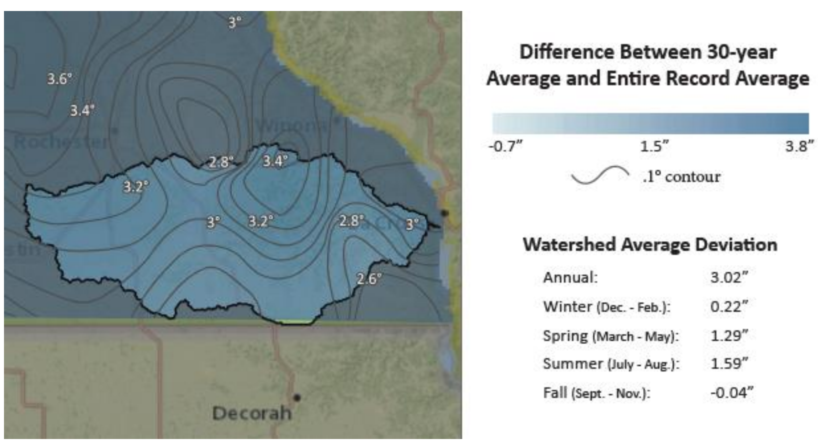


Statewide Average Departure

Time period	Value
Annual	1.7"
Winter (Dec. - Feb.)	0.1"
Spring (March - May)	0.5"
Summer (June - Aug.)	0.6"
Fall (Sept. Nov.)	0.5"

For Minnesota, the average annual precipitation show an upward deviation of 1.7 inches. The greatest seasonal deviation has occurred in the summer, with precipitation in the most recent 30 years averaging .6 inches greater than the average for the entire climate record. In contrast, the winter months (Dec.-Feb.) have experienced minimal deviation from the climate record. This map also shows that the increase in precipitation is notably higher in southeastern Minnesota.

Example – Root River Annual Precipitation Departure



Watershed Average Deviation

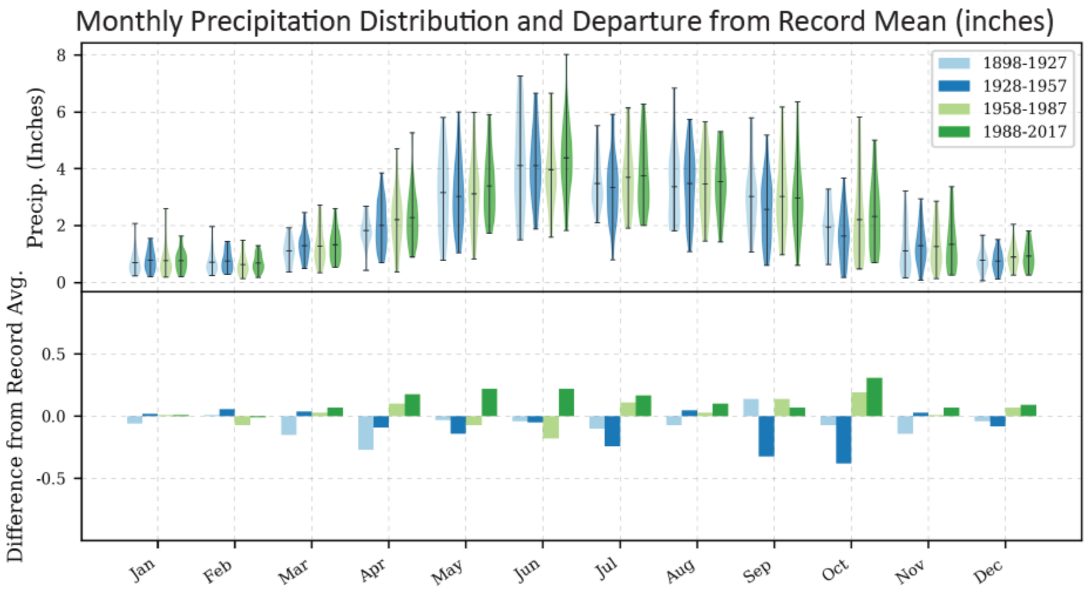
Annual:	3.02"
Winter (Dec. - Feb.):	0.22"
Spring (March - May):	1.29"
Summer (July - Aug.):	1.59"
Fall (Sept. - Nov.):	-0.04"

Additional spatial analysis at the major watershed scale provides more detailed results within each watershed. For the Root River Watershed, the average precipitation totals show an upward deviation of 3.02 inches. The greatest seasonal deviation has occurred in the summer, with precipitation in the most recent 30 years averaging 1.59 inches greater than the average for the entire climate record. In contrast, the fall months of September-November have experienced no deviation from the climate record. This deviation toward greater seasonal precipitation is consistent with the regional trend in southeastern Minnesota.

Monthly Precipitation Departure from Historic Record

These charts displays the distribution of monthly precipitation values for four adjacent 30-year periods.

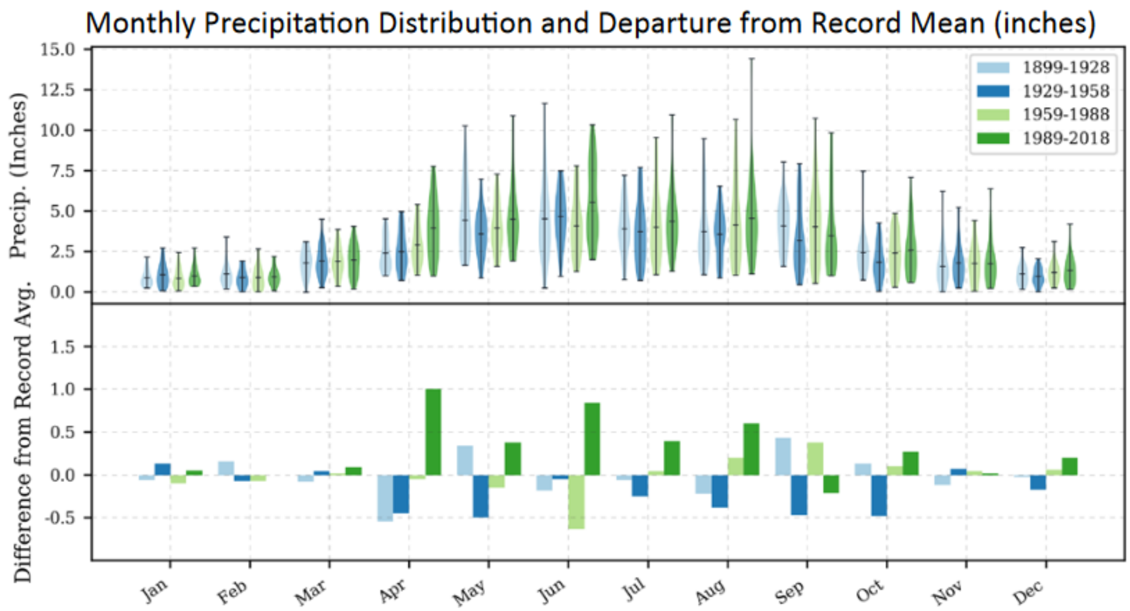
Example – Statewide Monthly Precipitation Departure



The top figure shows the range of precipitation totals observed for each month, during the four different 30 year data 'snapshots'. There appears to be an increase in the variability of precipitation during the most recent (dark green) climate period.

The lower figure shows which months are experiencing the greatest change when compared to the average precipitation for the entire climate record. Each bar represents the inches above or below the long term average for each 30-year period. There is a trend toward monthly averages at or above the long term average, particularly for the most recent (dark green, 1988-2017) thirty year period. The greatest deviation has occurred during the months of April through July, and in October.

Example – Root River Watershed Monthly Precipitation Departure



Similar to the statewide pattern, the top figure shows an increase in the variability of precipitation during the most recent (dark green) climate period.

The lower figure shows which months are experiencing the greatest change when compared to the average precipitation for the entire climate record. Each bar represents the inches above or below the long term average for each 30-year period. The monthly averages are at or above the long term average, particularly for the most recent (dark green, 1988-2017) thirty year period. The greatest upward deviation has occurred during the months April, June, July and August, with the largest downward deviation occurring in September.

For further information on Climate Change in Minnesota:

Additional information on Climate and Climate Change is available on the MN DNR website

Climate of Minnesota

Climate change and Minnesota

Impacts of Climate Change

Climate Change Resources

References:

Climate Trends - Minnesota DNR. www.dnr.state.mn.us/climate/climate_change_info/climate-trends.html. Accessed 1 July 2019.

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. DOI: 10.7930/NCA4.2018.

Vose, R.S., Applequist, S., Durre, I., Menne, M.J., Williams, C.N., Fenimore, C., Gleason, K., & Arndt, D. (2014). Improved Historical Temperature and Precipitation Time Series For U.S. Climate Divisions. Journal of Applied Meteorology and Climatology, 53(May), 1232–1251. DOI: 10.1175/JAMC-D-13-0248.1

Data Sources:

National Centers for Environmental Information (NOAA-NCEI). (2019). Global Historical Climatology Network Daily nClimGrid. Retrieved from https://www.ncdc.noaa.gov/land-based-station-data/global-historical-climatologynetwork-ghcn