Assessment of Annual Contiguous U.S. Temperatures: 1895-2009

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U.S. Temperature Observations

Station data, including the standard observing stations, flight service stations, and the measurements provided by the Cooperative Observer Program (COOP) are the backbone for in situ monitoring of U.S. climate. The cooperative observing program was begun formally in 1890 by an act of Congress, and consists of over 10,000 volunteers who observe daily temperature, precipitation, and snowfall across the Nation. Many of these cooperative stations provide a long term and stable source of information for U.S. climate, sampling especially in the rural locations that are somewhat less covered by the standard observing stations.

Analyses of U.S. Temperature

There currently exist 6 widely available surface temperature analyses which can be used to assess contiguous U.S. surface temperature. Each involves different procedures to minimize inhomogeneities that arise for various reasons. These could involve station moves, changes in instrumentation, changes in neighboring environment. Not all inhomogeneities are known, nor have those that are known all been effectively addressed at this time. These and other factors can lead to temperature variations that are unrepresentative of weather and climate. The different processes of quality control seek to ensure that the resultant analysis meets specific requirements and that the product is dependable for climate monitoring purposes.

Also, analyses employ different gridding procedures. In these methods, the original station observations are used to generate calculated "observations" on a regularly spaced grid. Examples include the average of station data to generate regular latitude-longitude averages of the original data. Some statistical methods to generate high resolution grids yield a density of calculated observations that may exceed the original data. Also, some gridding may lead to non-regular spatial aggregations of the station data, for instance the production of 344 U.S. Climate Divisions have various sizes.

One implication of quality control procedures is that not all observations are retained in the final analysis, and different analyses retain a different collection of the original observations. For local climate analysis purposes in particular, it is desirable to retain stations having long and continuous records with minimal station and/or instrumental changes. For purposes of monitoring the area-averaged contiguous U.S. conditions, the attribute of high precision local observations needs to be weighed against the statistical problem of sub-sampling----estimates of the

error in estimating domain means from random sampling declines with 1/(sqrt(n)), where n is the number of observations.

Uncertainty Among the Analyses of U.S. Surface Temperature

Any single analysis, even after quality control has been applied to the original data, will retain some potential source(s) of error at the station level. These are not well quantified. Furthermore, for monitoring U.S. area-averages an additional source of error is due to the incomplete spatial coverage of the observations. Some analysis centers (e.g., NASA) have attempted to estimate this source of error in their analyses.

In this report, we calculate the spread among 6 different analyses of contiguous U.S. surface temperature. The question we address thereby is whether the methods themselves contribute to uncertainty. It should be noted that even if the 6 analyses were found to be identical to each other, an error in estimating the true contiguous U.S condition would still exist for the aforementioned reasons.

Implicit in the intercomparison conducted in this report is that each of the analyses is equally valid. We give identical weight to each data set as concerns annual values of contiguous U.S. surface temperature. It is possible that a selective weighting could be devised based on the rigor of quality control. Yet, we have insufficient information to judge, for instance, whether the stricter quality control applied to some analyses is outweighed by potential increases in sampling error resulting from the utilization of more precise, but less abundant, observations.

Data Set Access and Technical References

1. NOAA U.S. Climate Divisions
NCDC (National Climatic Data Center), 1994: Time Bias Corrected Divisional Temperature-Precipitation-Drought Index. Documentation for dataset TD-9640. National Climatic Data Center, NC, 12 pp.
http://www1.ncdc.noaa.gov/pub/data/documentlibrary/tddoc/td9640.pdf

NCDC Divisional Data Source
http://www.ncdc.noaa.gov/oa/climate/climatedata.html

2. NOAA U.S. Historical Climate Network (USHCN.v2)
Menne, M.J., C. N. Williams, and R. S. Vose, 2009: The United States Historical Climatology Network Monthly Temperature Data-Verson 2. *Bull. Amer. Met. Soc*., **90(7),** 993-1107.

USHCN Data Source
http://www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html

3. NOAA Global Historical Climate Network (GHCN.v2)

Peterson, Thomas C. and Russell S. Vose, 1997: An overview of the Global Historical Climatology Network temperature data base, *Bull. Amer. Met. Soc.*, **78**, 2837-2849.

NOAA GHCNv2 Data Source
http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcngrid.html

4. The PRISM Group Data
Daly, C., W. P. Gibson, G.H. Taylor, G. L. Johnson, P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. *Climate Research*, **22**: 99-113.

PRISM Data Source
http://www.prism.oregonstate.edu/

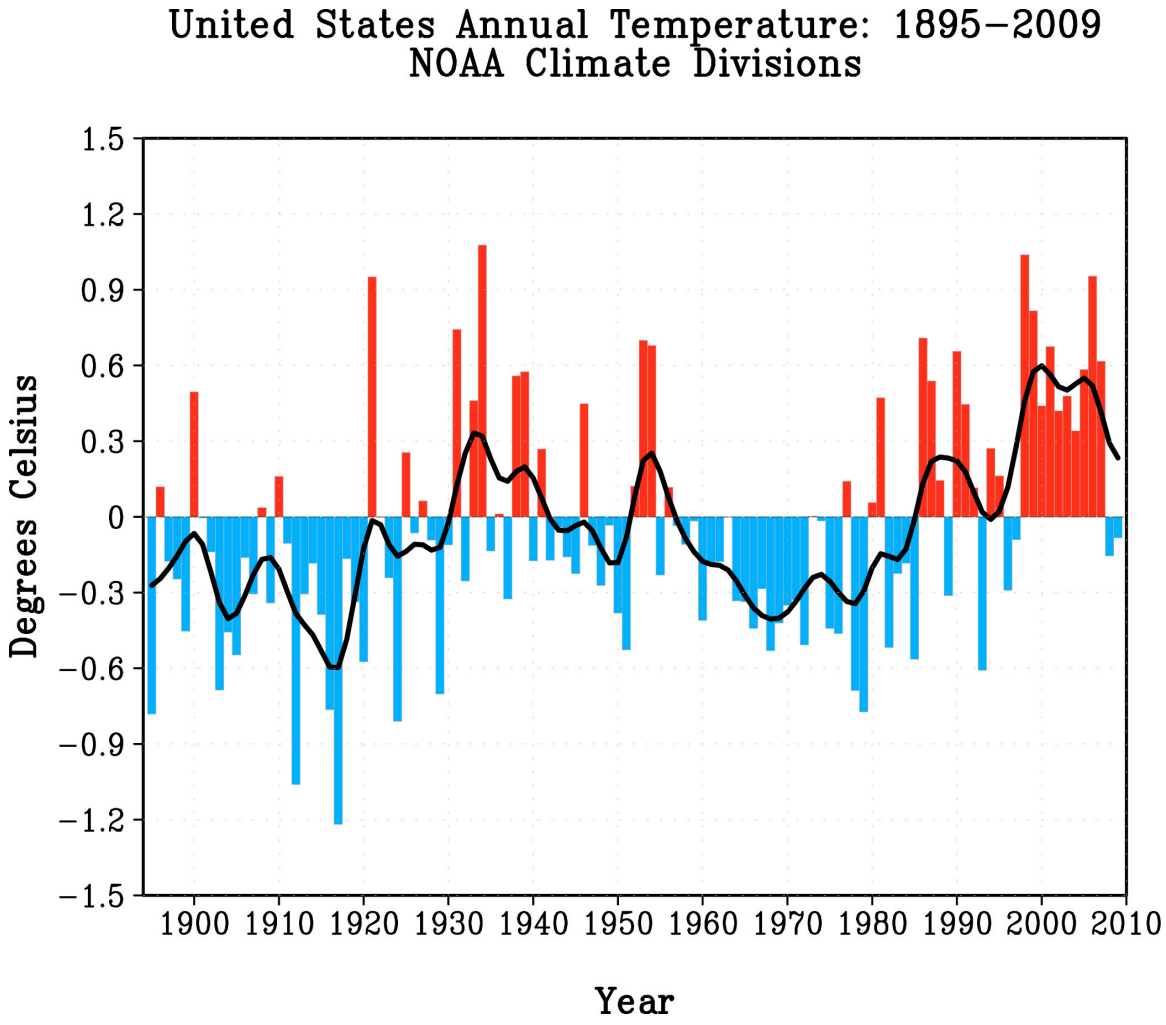
5. The UK Meteorological Office Hadley Center Global Data: HADCRUv3
Brohan, P., J. Kennedy, I. Harris, S. Tett, and P. Jones, 2006: Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. *J. Geophys. Res.* , **111**, D12106, doi:10.1029/2005JD006548.

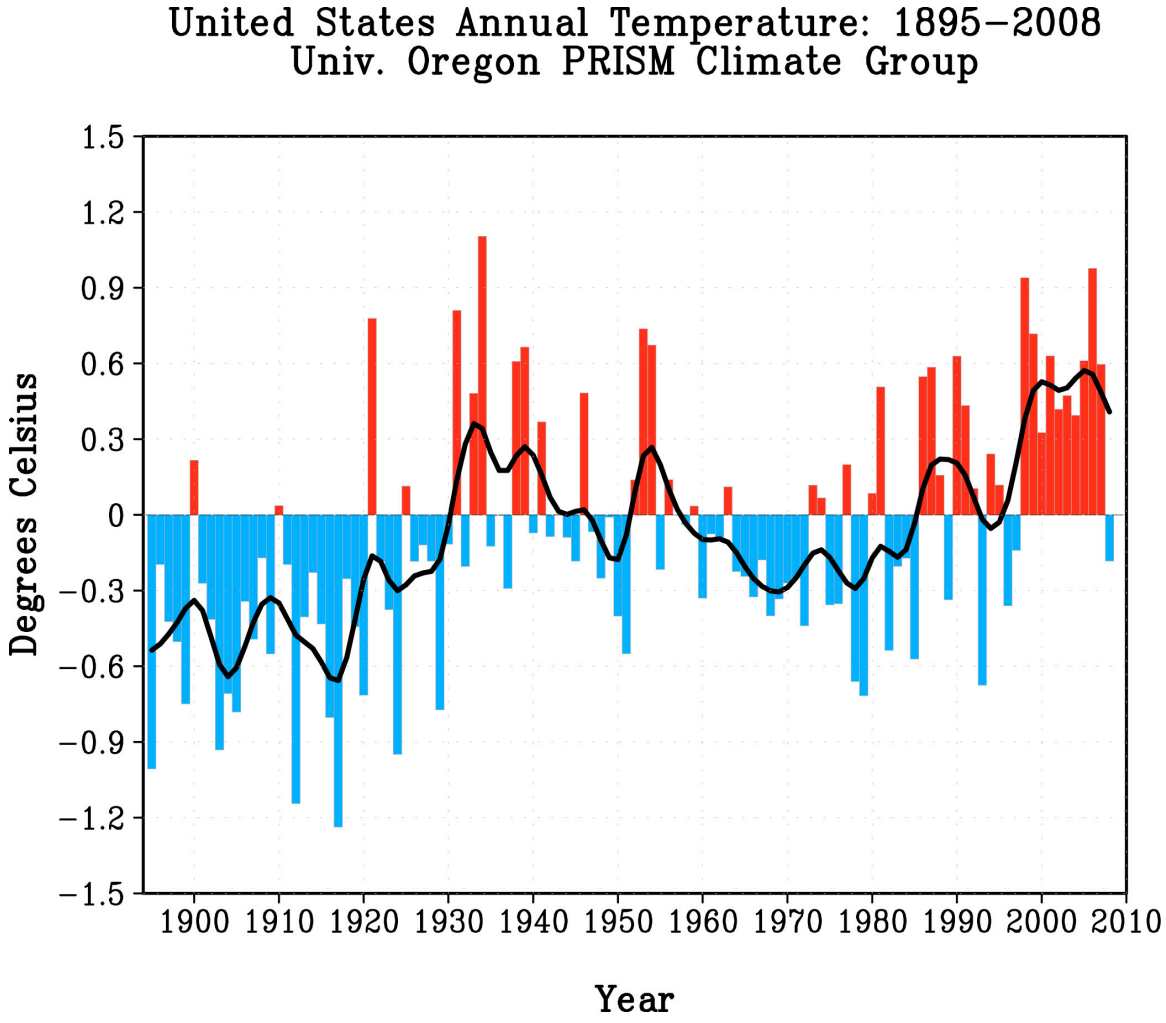
HadCRUv3 Data
http://www.cru.uea.ac.uk/cru/data/

6. NASA-GISS Data
Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl, 2001: A closer look at United States and global surface temperature change. *J. Geophys. Res.* , **106(D20)**, 23947-23963.

NASA GISS Data Source
http://data.giss.nasa.gov/gistemp/

Time Series of Annual Contiguous Surface Temperature. Departures Relative to 1971-2000 Reference. Black Curve is a 9-point Gaussian Filter of the Annual Values.

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Univ. Oregon PRISM Climate Group
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1.2
0.9
0.6
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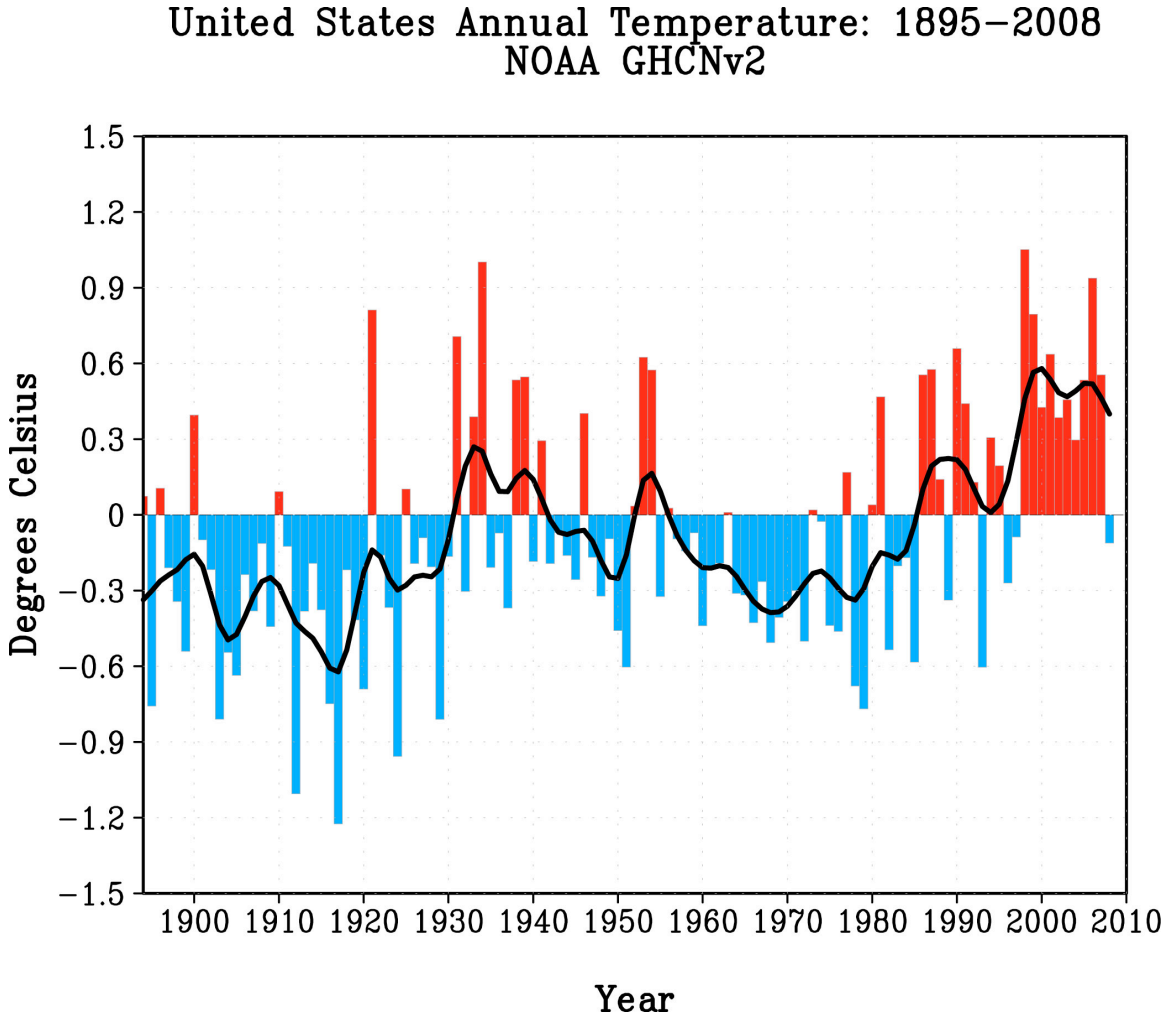
−1.2
−1.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year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NOAA GHCNv2
Degrees Celsius
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1.2
0.9
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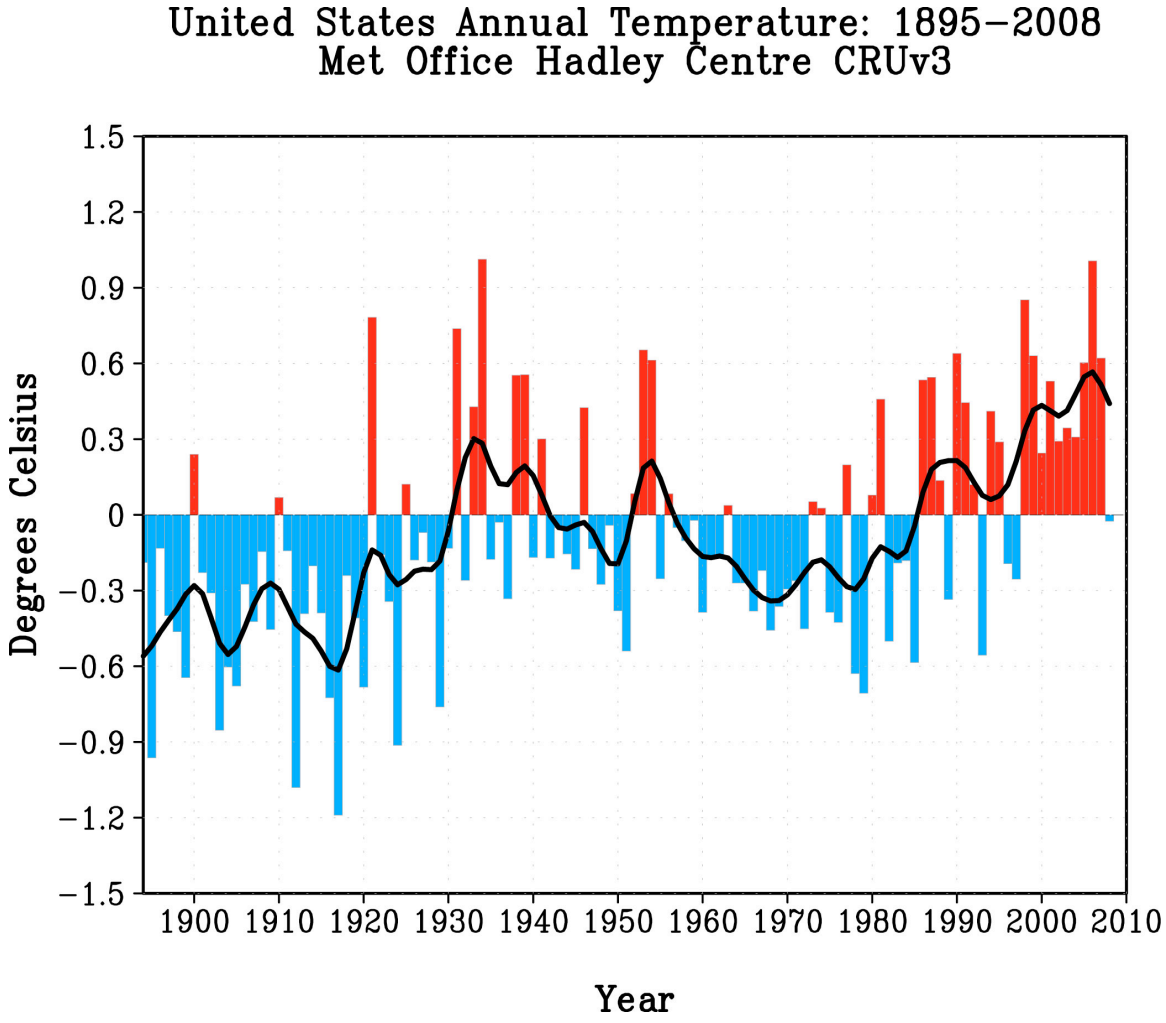
−1.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year


United States Annual Temperature: 1895–2008
Met Office Hadley Centre CRUv3
Degrees Celsius
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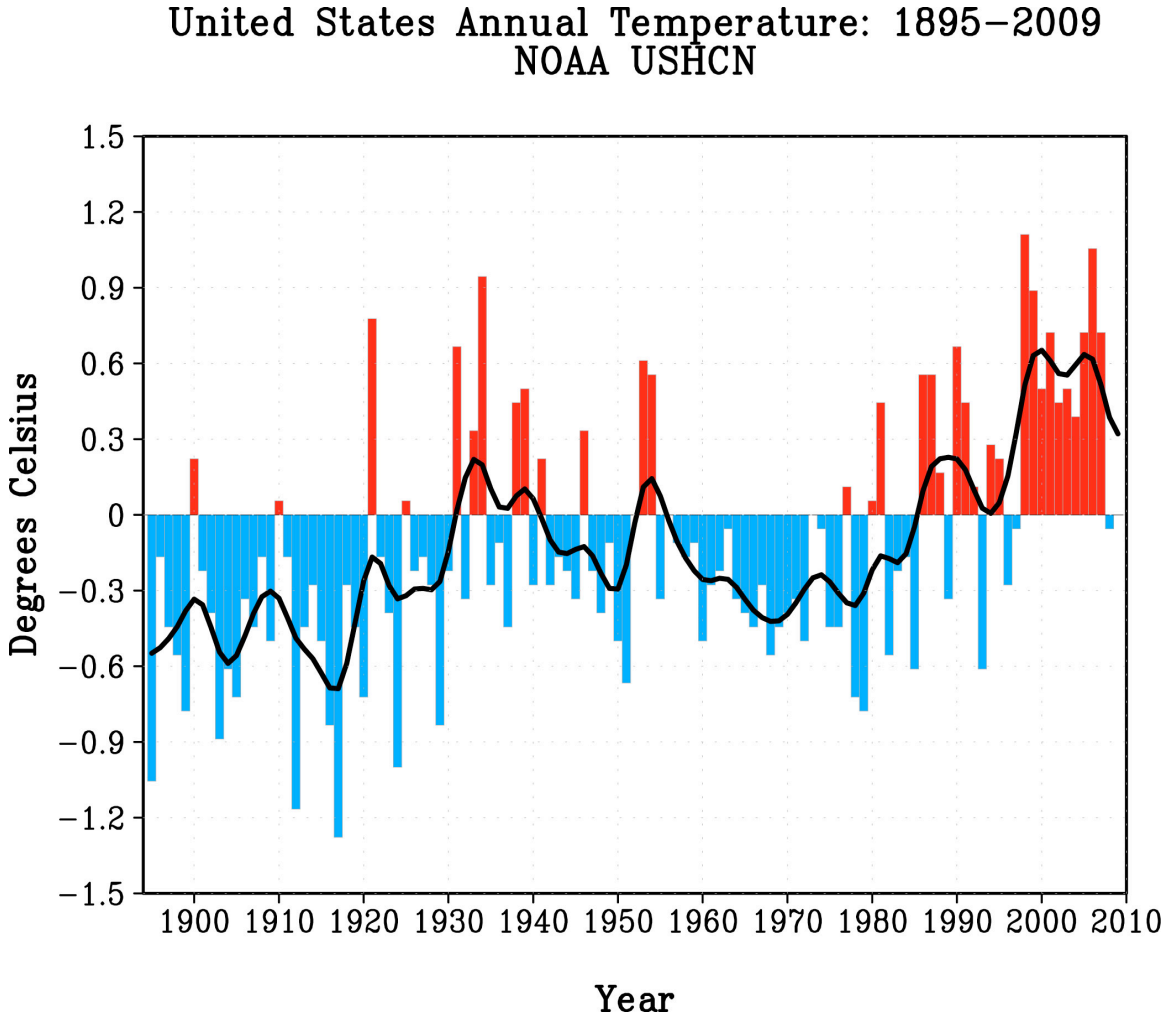
1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
−1.2
−1.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year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NOAA USHCN
Degrees Celsius
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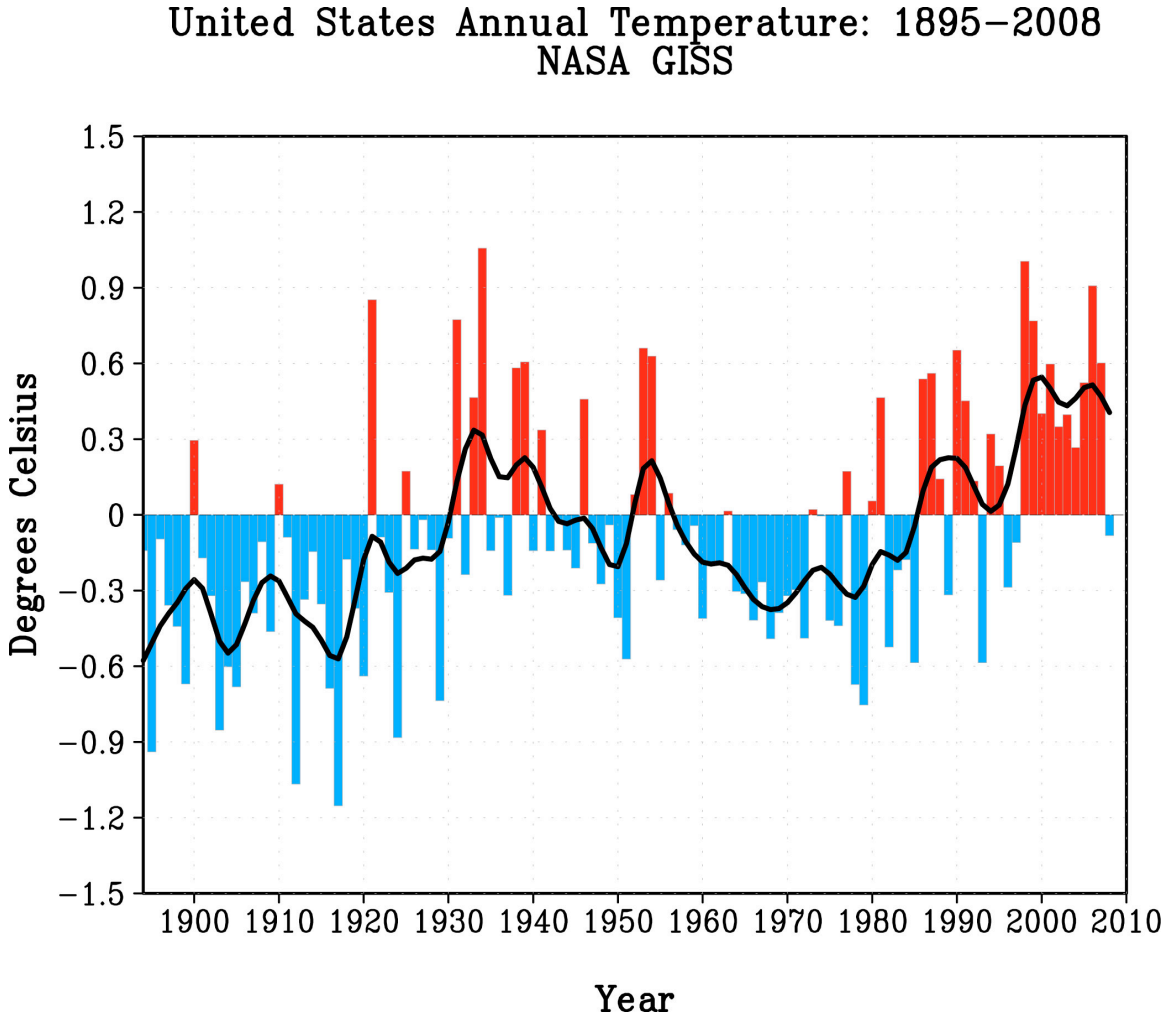
1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
−1.2
−1.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year


United States Annual Temperature: 1895–2008
NASA GISS
Degrees Celsius
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1.2
0.9
0.6
0.3
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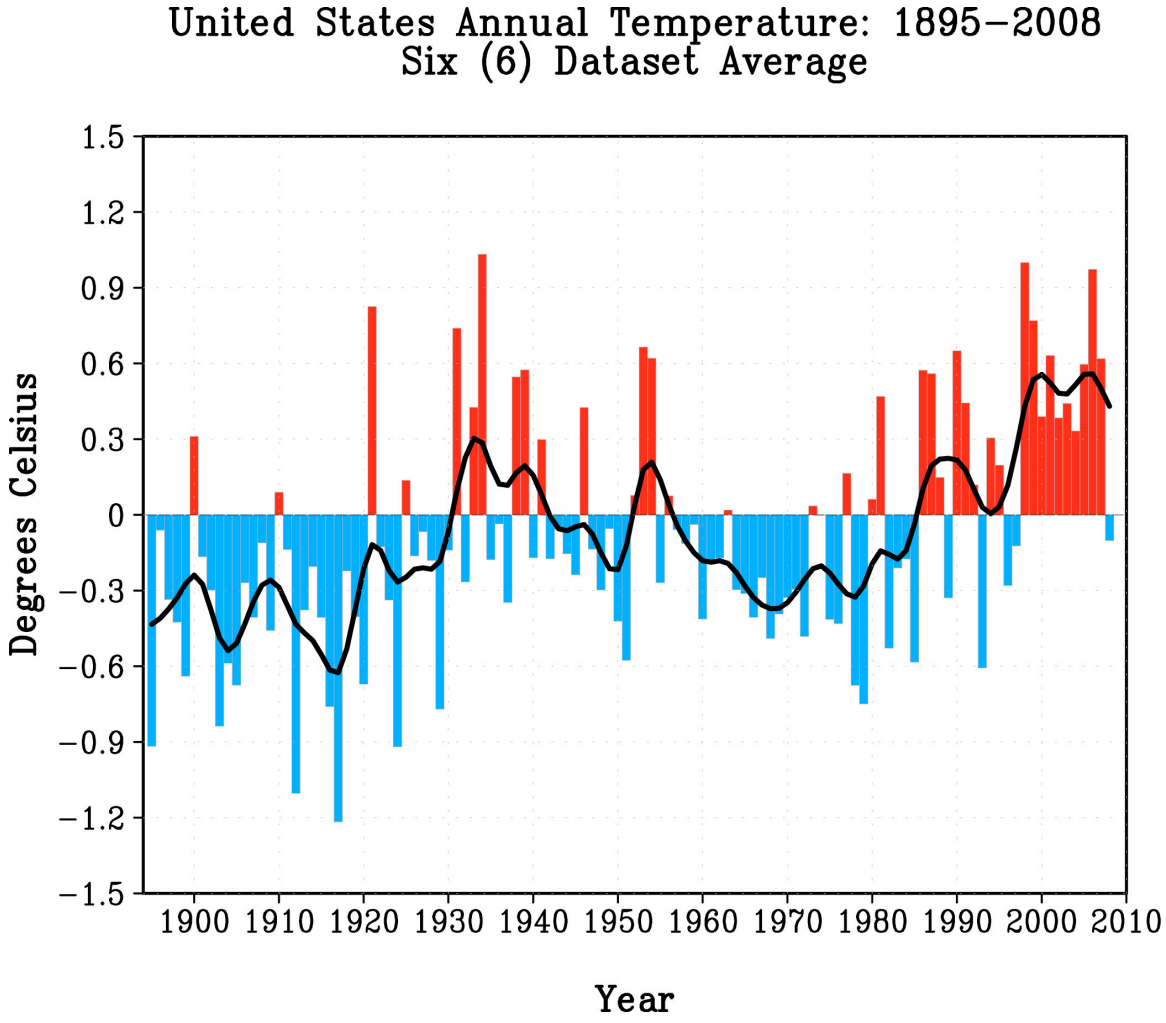
−0.9
−1.2
−1.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year


United States Annual Temperature: 1895–2008
Six (6) Dataset Average
Degrees Celsius
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1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
−1.2
−1.5
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Year

The Values of Annual U.S. Surface Temperature and Issue of Ranking

Overall, the agreement between annual values, interannual variations, and trends in the annual contiguous US surface temperature is very high. For the period 1895-2008, the standard deviation of annual values among the 6 analyses is 0.05°C.

Despite the robustness among the analyses, the uncertainty among them is sufficiently large to render a definitive assessment of the warmest US year problematic. As indicated in Table 1, the 6-dataset average departure for 1934 is +1.03°C and +1.00°C for 1998. Given the standard error based on spread of +0.05°C, our assessment judges these two years to be statistically indistinguishable.

Table1. Annual Contiguous US Surface Temperature Departures For 6 Different Analyses, The Average Departure of the Six, and the Standard Deviation. Departures Relative to a 1971-2000 Reference.

YR	DIV	PRISM	GHCN	HADCRU	NASA	USHCN	MEAN	STD
1895	-0.78	-1.01	-0.76	-0.96	-0.94	-1.06	-0.92	0.11
1896	0.12	-0.20	0.11	-0.13	-0.10	-0.17	-0.06	0.13
1897	-0.18	-0.42	-0.21	-0.40	-0.36	-0.44	-0.34	0.10
1898	-0.25	-0.50	-0.34	-0.46	-0.44	-0.56	-0.43	0.10
1899	-0.45	-0.75	-0.54	-0.65	-0.67	-0.78	-0.64	0.11
1900	0.49	0.22	0.40	0.24	0.29	0.22	0.31	0.10
1901	-0.00	-0.27	-0.10	-0.23	-0.17	-0.22	-0.17	0.09
1902	-0.14	-0.41	-0.22	-0.31	-0.32	-0.39	-0.30	0.10
1903	-0.69	-0.93	-0.81	-0.85	-0.85	-0.89	-0.84	0.08
1904	-0.46	-0.71	-0.55	-0.60	-0.60	-0.61	-0.59	0.08
1905	-0.55	-0.78	-0.64	-0.68	-0.68	-0.72	-0.67	0.07
1906	-0.16	-0.34	-0.24	-0.28	-0.27	-0.33	-0.27	0.06
1907	-0.31	-0.49	-0.38	-0.42	-0.39	-0.44	-0.41	0.06
1908	0.04	-0.17	-0.11	-0.15	-0.11	-0.17	-0.11	0.07
1909	-0.34	-0.55	-0.44	-0.45	-0.46	-0.50	-0.46	0.06
1910	0.16	0.04	0.09	0.07	0.12	0.06	0.09	0.04
1911	-0.11	-0.20	-0.13	-0.14	-0.09	-0.17	-0.14	0.04
1912	-1.06	-1.14	-1.11	-1.08	-1.07	-1.17	-1.10	0.04
1913	-0.31	-0.40	-0.38	-0.39	-0.34	-0.44	-0.38	0.05
1914	-0.18	-0.23	-0.19	-0.20	-0.15	-0.28	-0.21	0.04
1915	-0.39	-0.43	-0.38	-0.39	-0.35	-0.50	-0.41	0.05
1916	-0.76	-0.80	-0.75	-0.73	-0.69	-0.83	-0.76	0.05
1917	-1.22	-1.24	-1.22	-1.19	-1.15	-1.28	-1.22	0.04
1918	-0.17	-0.25	-0.22	-0.24	-0.18	-0.28	-0.22	0.04
1919	-0.34	-0.44	-0.42	-0.41	-0.37	-0.44	-0.40	0.04
1920	-0.57	-0.71	-0.69	-0.68	-0.64	-0.72	-0.67	0.05
1921	0.95	0.78	0.81	0.78	0.85	0.78	0.83	0.06
1922	-0.00	-0.18	-0.16	-0.16	-0.09	-0.17	-0.13	0.06
1923	-0.24	-0.38	-0.37	-0.34	-0.31	-0.39	-0.34	0.05
1924	-0.81	-0.95	-0.96	-0.91	-0.88	-1.00	-0.92	0.06
1925	0.25	0.11	0.10	0.12	0.17	0.06	0.14	0.06
1926	-0.06	-0.18	-0.19	-0.18	-0.14	-0.22	-0.16	0.05
1927	0.06	-0.12	-0.09	-0.07	-0.02	-0.17	-0.07	0.07
1928	-0.09	-0.18	-0.21	-0.19	-0.14	-0.28	-0.18	0.06
1929	-0.70	-0.77	-0.81	-0.76	-0.74	-0.83	-0.77	0.04
1930	-0.11	-0.12	-0.16	-0.13	-0.09	-0.22	-0.14	0.04
1931	0.74	0.81	0.71	0.74	0.77	0.67	0.74	0.05
1932	-0.25	-0.20	-0.30	-0.26	-0.24	-0.33	-0.27	0.04
1933	0.46	0.48	0.39	0.43	0.47	0.33	0.43	0.05
1934	1.08	1.10	1.00	1.01	1.06	0.94	1.03	0.05
1935	-0.14	-0.12	-0.21	-0.18	-0.14	-0.28	-0.18	0.05
1936	0.01	-0.00	-0.07	-0.03	-0.01	-0.11	-0.04	0.04
1937	-0.33	-0.29	-0.37	-0.33	-0.32	-0.44	-0.35	0.05
1938	0.56	0.61	0.53	0.55	0.58	0.44	0.55	0.05
1939	0.58	0.66	0.55	0.56	0.61	0.50	0.57	0.05
1940	-0.17	-0.07	-0.18	-0.17	-0.14	-0.28	-0.17	0.06
1941	0.27	0.37	0.29	0.30	0.34	0.22	0.30	0.05

1942	-0.17	-0.09	-0.19	-0.17	-0.14	-0.28	-0.17	0.06
1943	-0.04	0.00	-0.07	-0.05	-0.02	-0.17	-0.06	0.05
1944	-0.16	-0.09	-0.16	-0.16	-0.14	-0.22	-0.15	0.04
1945	-0.23	-0.18	-0.26	-0.22	-0.21	-0.33	-0.24	0.05
1946	0.45	0.48	0.40	0.42	0.46	0.33	0.43	0.05
1947	-0.11	-0.07	-0.17	-0.13	-0.11	-0.22	-0.14	0.05
1948	-0.27	-0.25	-0.32	-0.28	-0.27	-0.39	-0.30	0.05
1949	-0.03	-0.01	-0.09	-0.04	-0.04	-0.11	-0.06	0.04
1950	-0.38	-0.40	-0.46	-0.38	-0.41	-0.50	-0.42	0.04
1951	-0.53	-0.55	-0.60	-0.54	-0.57	-0.67	-0.58	0.05
1952	0.12	0.14	0.04	0.08	0.08	-0.00	0.08	0.05
1953	0.70	0.74	0.62	0.65	0.66	0.61	0.66	0.04
1954	0.68	0.67	0.57	0.61	0.63	0.56	0.62	0.05
1955	-0.23	-0.22	-0.32	-0.25	-0.26	-0.33	-0.27	0.04
1956	0.12	0.14	0.03	0.08	0.09	-0.00	0.08	0.05
1957	-0.04	-0.00	-0.10	-0.05	-0.06	-0.11	-0.06	0.04
1958	-0.11	-0.04	-0.14	-0.10	-0.12	-0.17	-0.11	0.04
1959	-0.02	0.04	-0.07	-0.02	-0.04	-0.11	-0.04	0.05
1960	-0.41	-0.33	-0.44	-0.39	-0.41	-0.50	-0.41	0.05
1961	-0.18	-0.08	-0.21	-0.17	-0.20	-0.28	-0.18	0.06
1962	-0.18	-0.09	-0.19	-0.16	-0.19	-0.22	-0.17	0.04
1963	-0.00	0.11	0.01	0.04	0.01	-0.06	0.02	0.05
1964	-0.33	-0.23	-0.31	-0.27	-0.30	-0.33	-0.30	0.04
1965	-0.34	-0.24	-0.32	-0.27	-0.31	-0.39	-0.31	0.05
1966	-0.44	-0.33	-0.43	-0.38	-0.42	-0.44	-0.41	0.04
1967	-0.28	-0.18	-0.26	-0.22	-0.27	-0.28	-0.25	0.04
1968	-0.53	-0.40	-0.51	-0.46	-0.49	-0.56	-0.49	0.05
1969	-0.42	-0.33	-0.41	-0.36	-0.39	-0.44	-0.39	0.04
1970	-0.35	-0.27	-0.34	-0.29	-0.32	-0.39	-0.33	0.04
1971	-0.33	-0.25	-0.30	-0.26	-0.30	-0.33	-0.29	0.03
1972	-0.51	-0.44	-0.50	-0.45	-0.49	-0.50	-0.48	0.03
1973	0.00	0.12	0.02	0.05	0.02	-0.00	0.04	0.04
1974	-0.02	0.07	-0.03	0.03	-0.01	-0.06	-0.00	0.04
1975	-0.44	-0.36	-0.44	-0.39	-0.42	-0.44	-0.41	0.03
1976	-0.46	-0.35	-0.46	-0.43	-0.44	-0.44	-0.43	0.04
1977	0.14	0.20	0.17	0.20	0.17	0.11	0.17	0.03
1978	-0.69	-0.66	-0.68	-0.63	-0.67	-0.72	-0.68	0.03
1979	-0.77	-0.72	-0.77	-0.71	-0.75	-0.78	-0.75	0.03
1980	0.06	0.09	0.04	0.08	0.06	0.06	0.06	0.02
1981	0.47	0.51	0.47	0.46	0.46	0.44	0.47	0.02
1982	-0.52	-0.54	-0.54	-0.50	-0.52	-0.56	-0.53	0.02
1983	-0.22	-0.20	-0.20	-0.19	-0.22	-0.22	-0.21	0.01
1984	-0.18	-0.17	-0.17	-0.18	-0.18	-0.17	-0.18	0.01
1985	-0.56	-0.57	-0.58	-0.59	-0.59	-0.61	-0.58	0.01
1986	0.71	0.55	0.55	0.53	0.54	0.56	0.57	0.06
1987	0.54	0.58	0.58	0.54	0.56	0.56	0.56	0.02
1988	0.14	0.16	0.14	0.14	0.14	0.17	0.15	0.01
1989	-0.31	-0.34	-0.34	-0.34	-0.32	-0.33	-0.33	0.01
1990	0.66	0.63	0.66	0.64	0.65	0.67	0.65	0.01
1991	0.45	0.43	0.44	0.44	0.45	0.44	0.44	0.01
1992	0.12	0.10	0.13	0.12	0.13	0.11	0.12	0.01
1993	-0.61	-0.68	-0.60	-0.56	-0.59	-0.61	-0.61	0.04
1994	0.27	0.24	0.31	0.41	0.32	0.28	0.30	0.05
1995	0.16	0.12	0.19	0.29	0.19	0.22	0.20	0.05
1996	-0.29	-0.36	-0.27	-0.19	-0.29	-0.28	-0.28	0.05

1997	-0.09	-0.14	-0.09	-0.25	-0.11	-0.06	-0.12	0.06
1998	1.04	0.94	1.05	0.85	1.00	1.11	1.00	0.08
1999	0.82	0.72	0.80	0.63	0.77	0.89	0.77	0.08
2000	0.44	0.33	0.43	0.24	0.40	0.50	0.39	0.08
2001	0.67	0.63	0.64	0.53	0.60	0.72	0.63	0.06
2002	0.42	0.42	0.39	0.29	0.35	0.44	0.38	0.05
2003	0.48	0.47	0.46	0.34	0.40	0.50	0.44	0.05
2004	0.34	0.39	0.30	0.31	0.27	0.39	0.33	0.05
2005	0.58	0.61	0.53	0.60	0.52	0.72	0.60	0.07
2006	0.95	0.98	0.94	1.01	0.91	1.06	0.97	0.05
2007	0.62	0.60	0.56	0.62	0.60	0.72	0.62	0.05
2008	-0.15	-0.18	-0.11	-0.03	-0.08	-0.06	-0.10	0.05