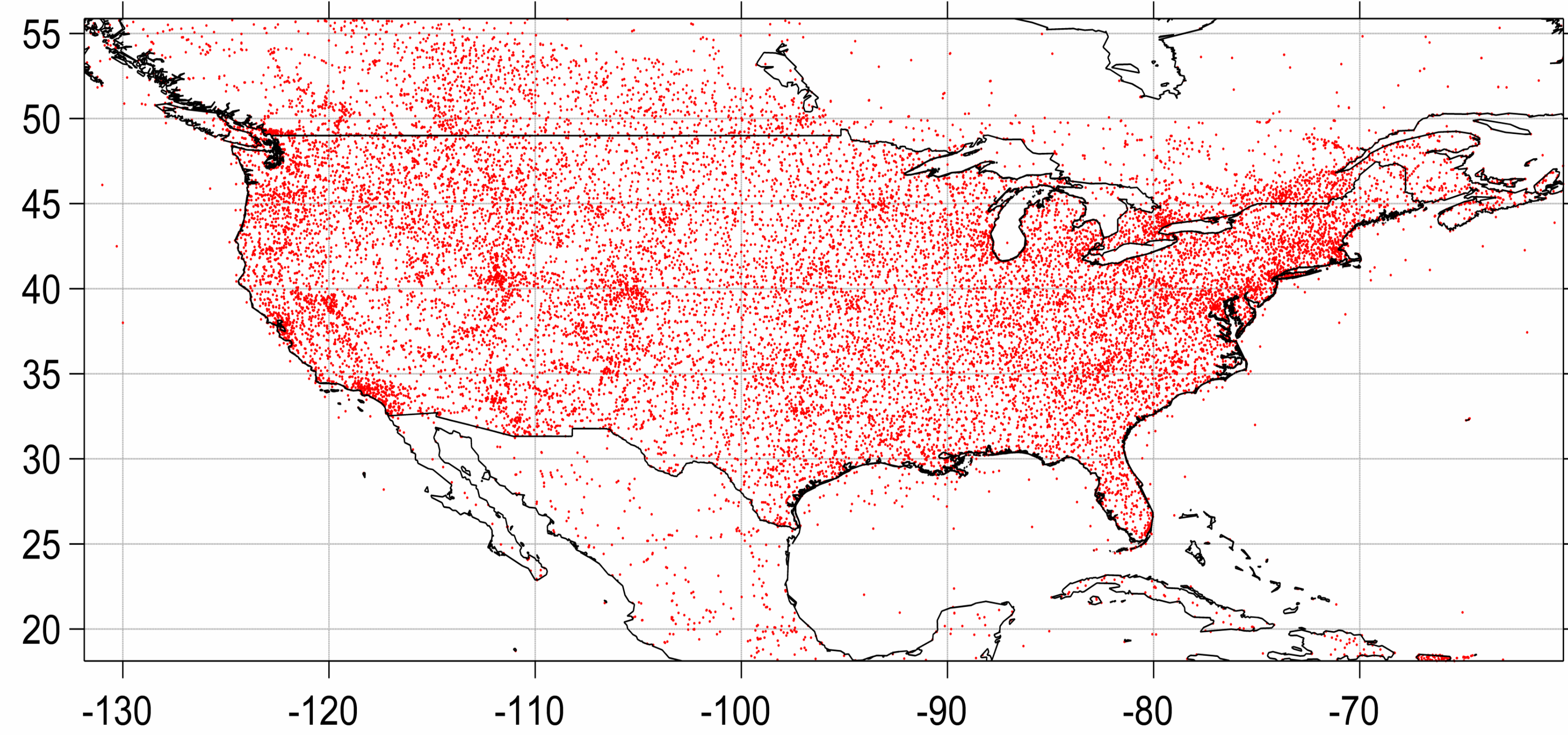


A High-Resolution Homogenized CONUS Temperature Dataset for Climate Analysis from 1850 to Present

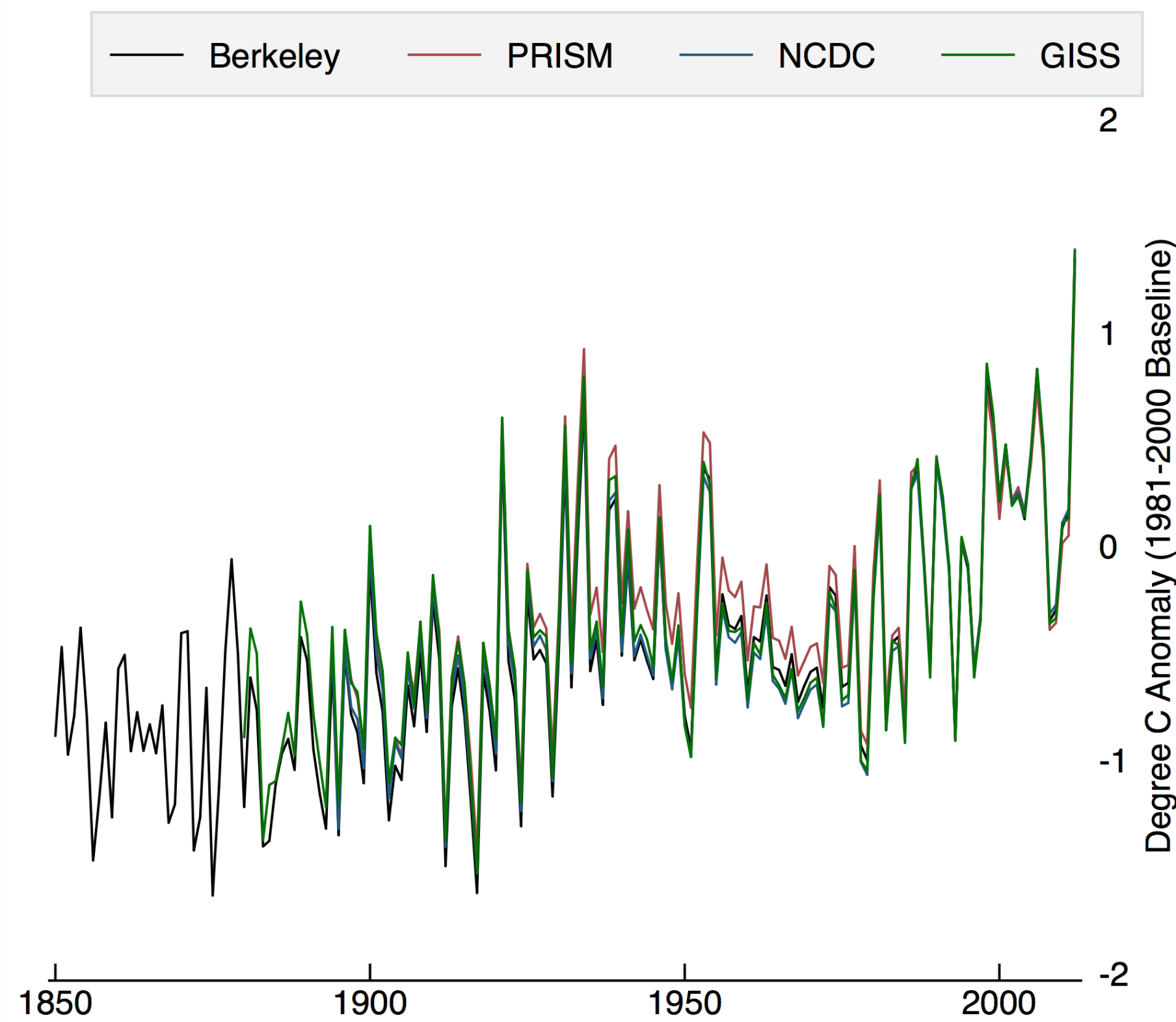
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Location of CONUS (and nearby) Temperature Stations used by Berkeley Earth

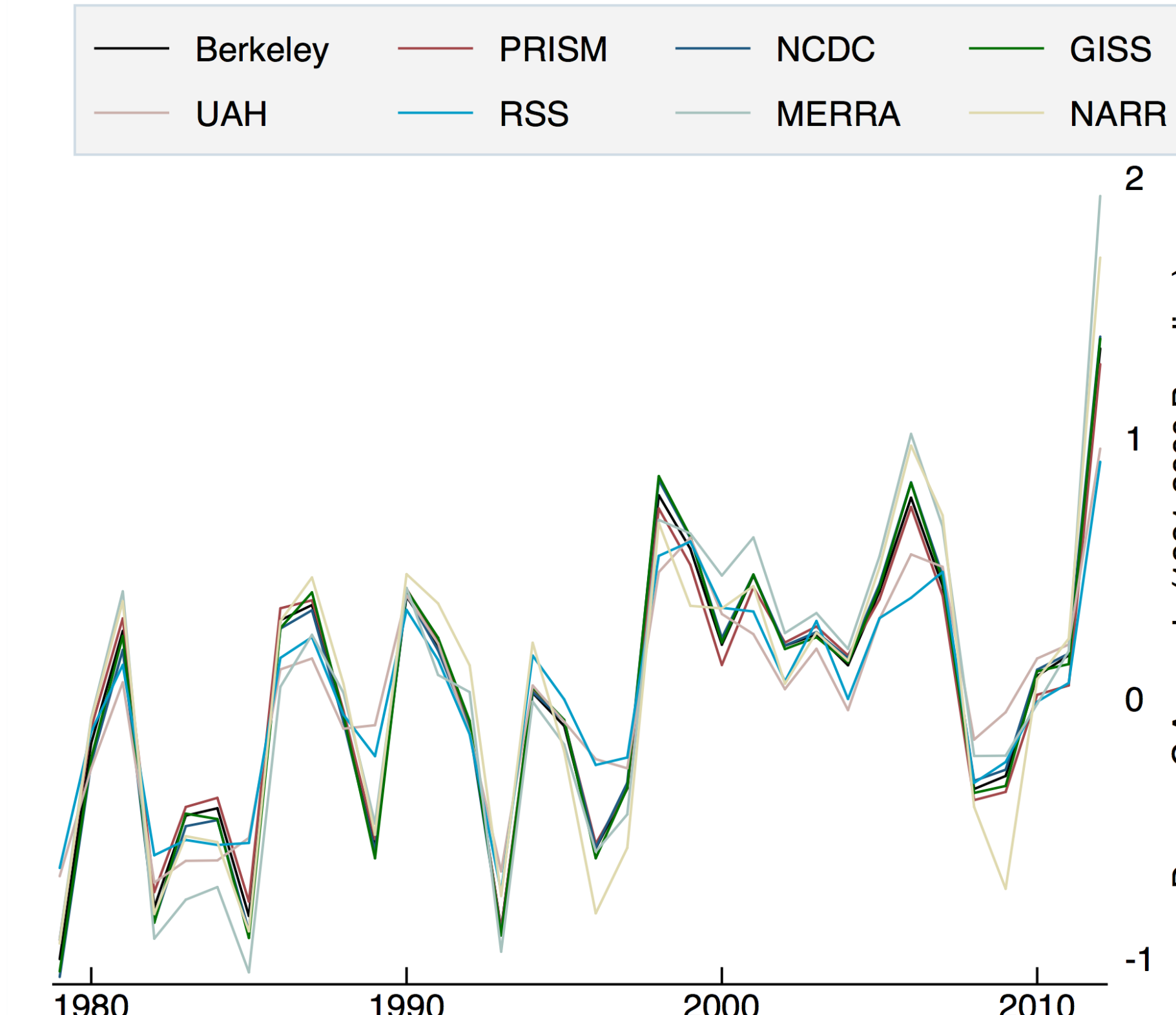


Location of all stations included in the Berkeley Earth CONUS dataset. Stations outside U.S. borders are also used in detecting inhomogenities and in the construction of temperature fields.

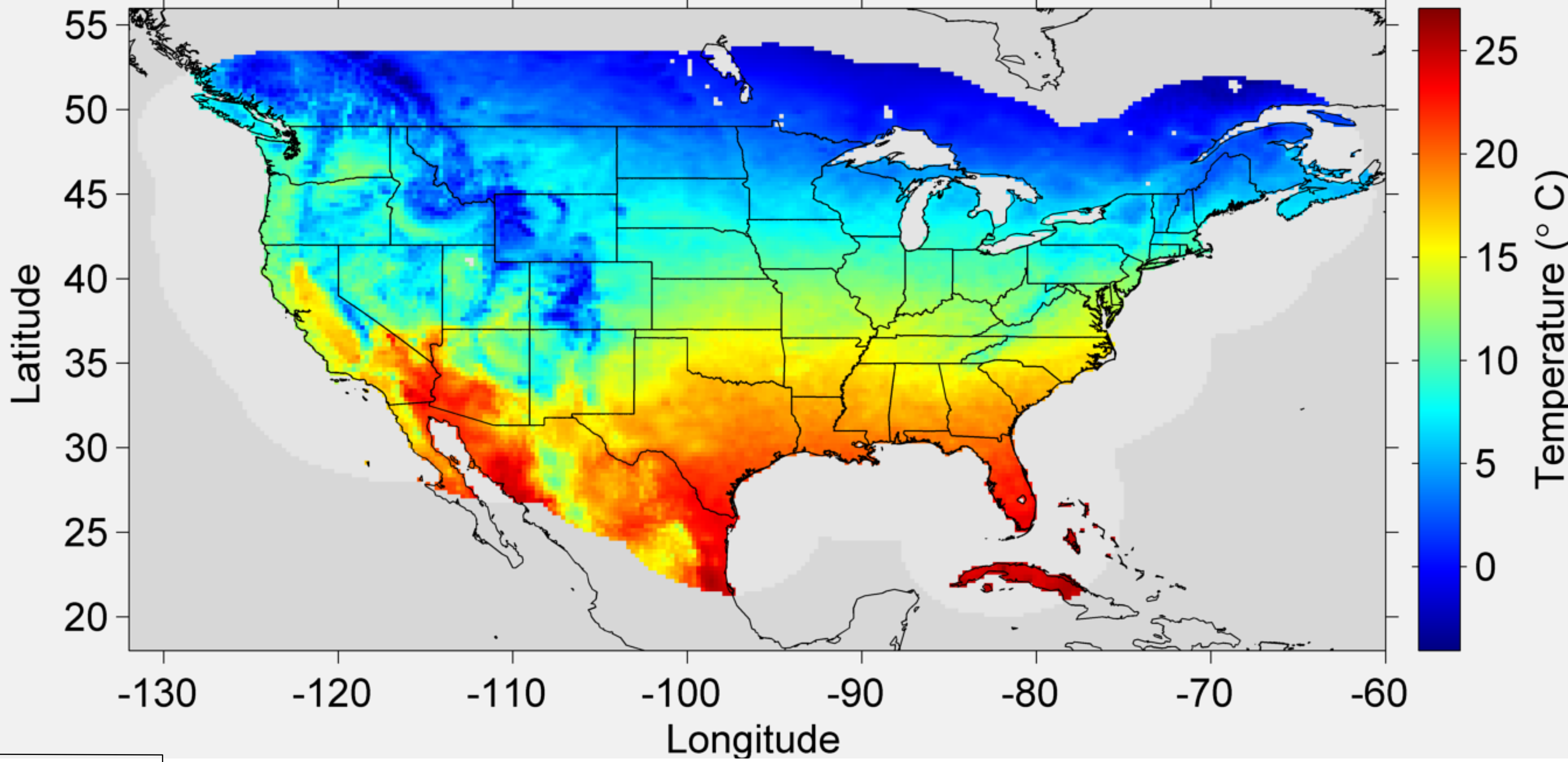
CONUS Temperature Records, 1850-2012



CONUS Temperature Records, 1979-2012



Annual Average Temperature (1951-1980)



Annual average absolute temperatures over the period from 1951-1980.

Introduction

Here we present a new high-resolution homogenized CONUS dataset spanning the period from 1850 to 2012, produced using 17,311 temperature stations within CONUS and an additional 4334 stations within 500 km of the border. The dataset is currently available for monthly minimum, maximum, and mean absolute temperatures and anomalies at a quarter degree (~25 km) resolution, though the approach supports even higher resolution estimates.

The Need for High-Resolution Homogenized Datasets for Climate Analysis

Homogenization is necessary to account for shifts in the station-based data caused by historical changes in the circumstances behind surface temperature measurement (e.g., changes in instrument type, station relocations, time of observation changes, urbanization, and other land-use changes) rather than by true changes in the climate. The artifacts caused by these kinds of changes have large, systematic impacts on temperature trends in the Conterminous United States (CONUS) [Menne and Williams 2009; Williams et al. 2012; Hausfather et al. 2013]. Homogenization of CONUS temperature data results in century-scale Tavg trends (0.07 C per decade) that are nearly double the magnitude of unhomogenized trends (0.04 C per decade). Existing high-resolution datasets (e.g. PRISM and some reanalysis products) use data with significant uncorrected inhomogenities, resulting both in physically unrealistic patterns of adjacent warming and cooling trends as well as biases in the magnitude of trends.

High resolution datasets are increasingly important for the study of local climate changes and the evaluation of regional climate models. Unfortunately, the lack of homogeneity considerations in many modern climate datasets, such as PRISM, can make some datasets unsuitable for the study of long-term climate trends.

Methods

The Berkeley Earth temperature analysis framework (Rohde et al. 2013a) was developed to conduct studies of global climate change from surface instrumental data. The method was designed from the beginning to tolerate noisy, incomplete, and inhomogeneous weather data, and consequently makes use of several times more observations than other comparable systems. Unlike most methods of analyzing climate data, the Berkeley approach does not rely on gridding, but rather uses Kriging-based techniques to define a spatially continuous temperature field that interpolates across available observations.

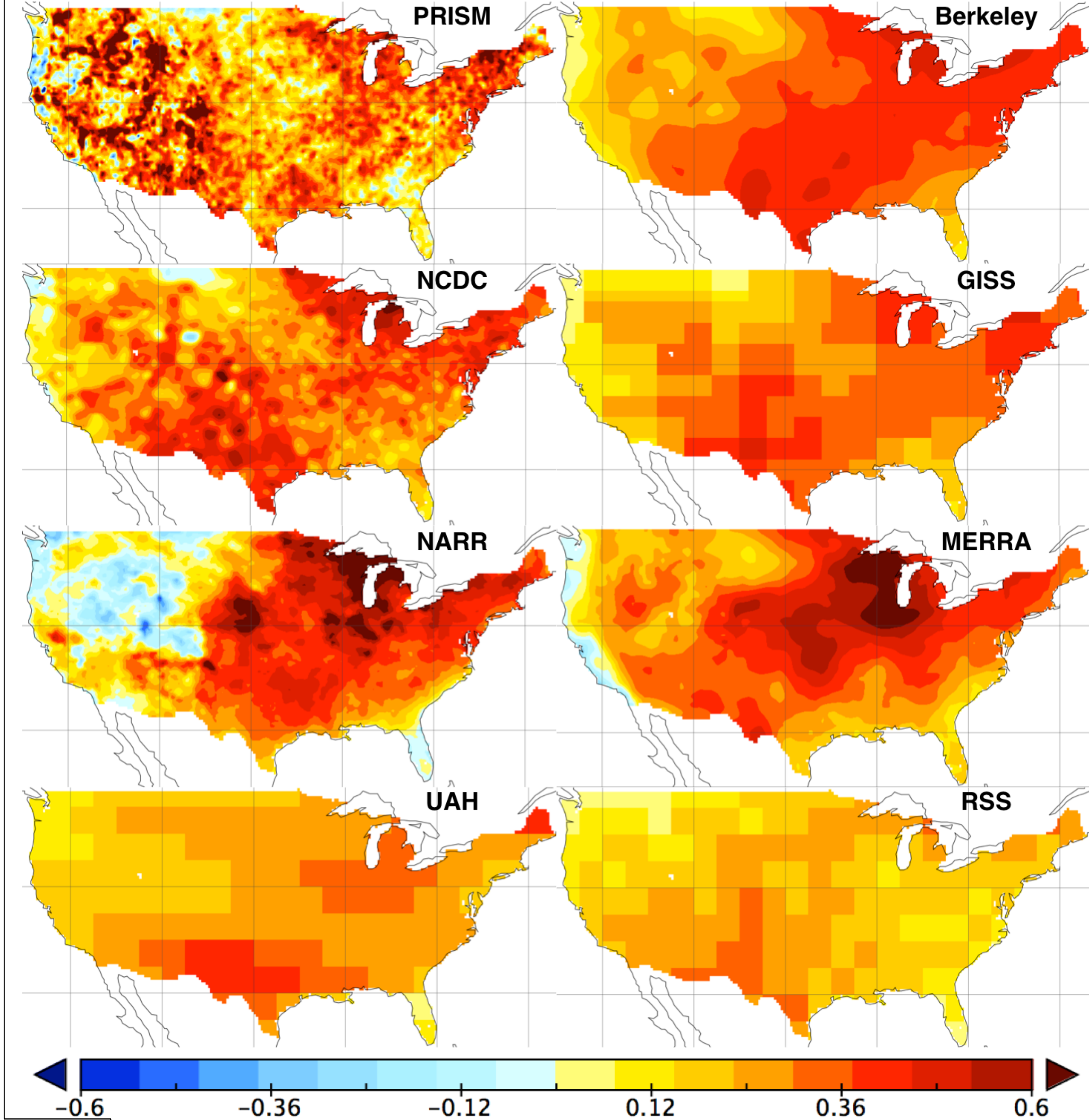
$$W(\vec{x}, t) = \sum K_i(\vec{x}, t) * (d_i(t) - b_i - \bar{T}(t))$$

$$\begin{pmatrix} K_1(\vec{x}, t) \\ \vdots \\ K_N(\vec{x}, t) \end{pmatrix} = \begin{pmatrix} R(\vec{x}_1, \vec{x}_1) & \cdots & R(\vec{x}_1, \vec{x}_N) \\ \vdots & \ddots & \vdots \\ R(\vec{x}_N, \vec{x}_1) & \cdots & R(\vec{x}_N, \vec{x}_N) \end{pmatrix}^{-1} \begin{pmatrix} R(\vec{x}_1, \vec{x}) \\ \vdots \\ R(\vec{x}_N, \vec{x}) \end{pmatrix}$$

In principle, this means the Berkeley methodology can be used to study climate at arbitrary resolutions, though in practice the usefulness of this analysis is limited by the density of the underlying weather data and computational expense of sampling the field. For previous large-scale studies (e.g. Rohde et al. 2013a, 2013b), we have used a globally-complete sampling of the underlying field at moderate resolution (e.g. 1.25-degree).

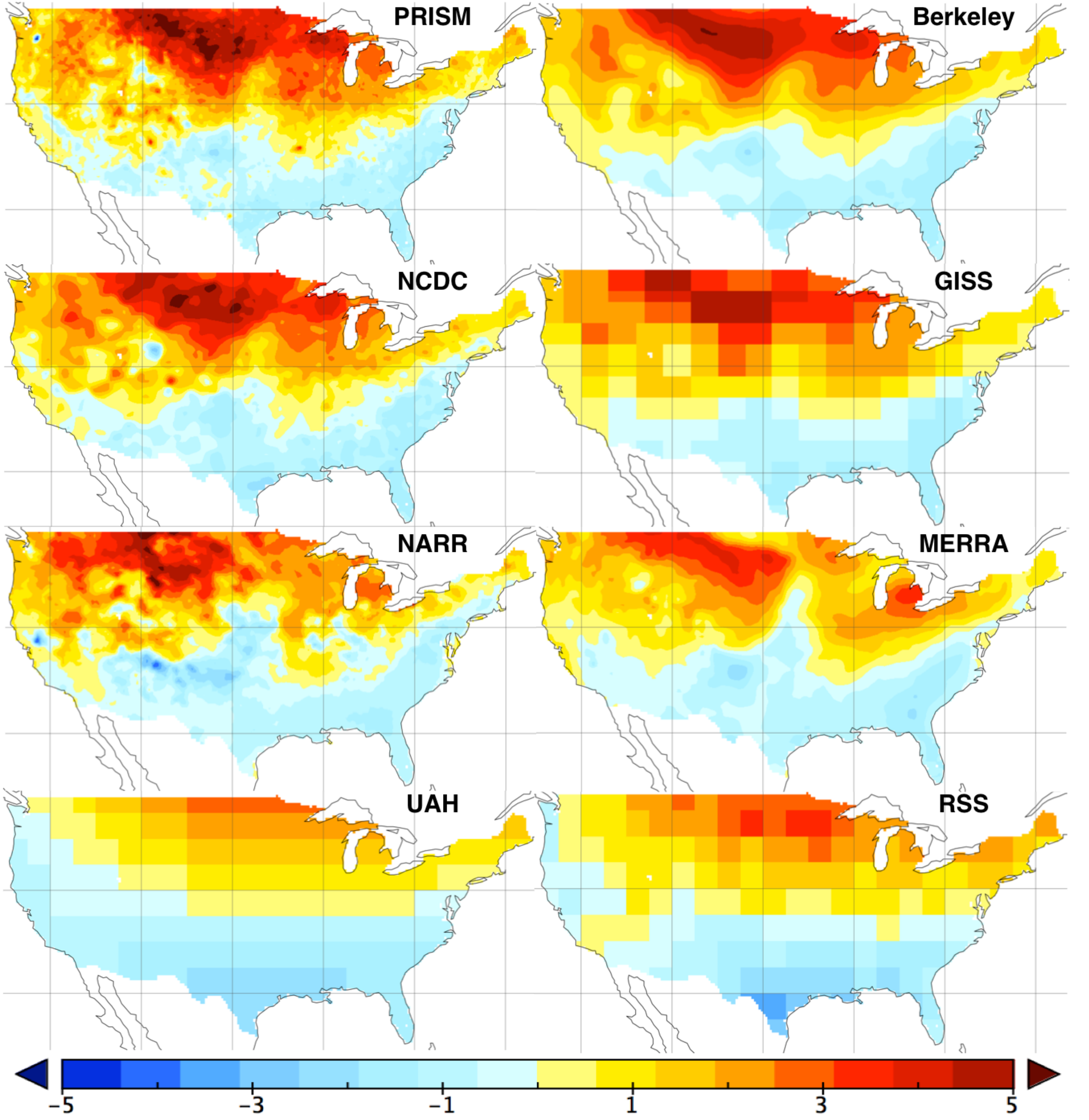
Here, we adapt the same algorithms to sample the United States at 0.25-degree resolution (an approximately 25 km linear scale). The algorithms were run by embedding a high resolution sampling field over the continental US (+ 500 km of adjacent territories) within a low-resolution field of the rest of the world. This is practical as the United States is the most densely instrumented country on Earth with 17311 weather stations in our data base, roughly one every 20 km, with an additional 4334 stations within 500 km of the border. This is augmented with high-resolution elevation and coastline data. Further, by comparing each station to its neighbors, the Berkeley algorithms have integrated corrections for noise, quality control, and inhomogenization issues that allow the resulting field of the United States to avoid many of the problems that otherwise arise when using raw weather data.

Monthly Mean Temperature Trends, 1979-2012



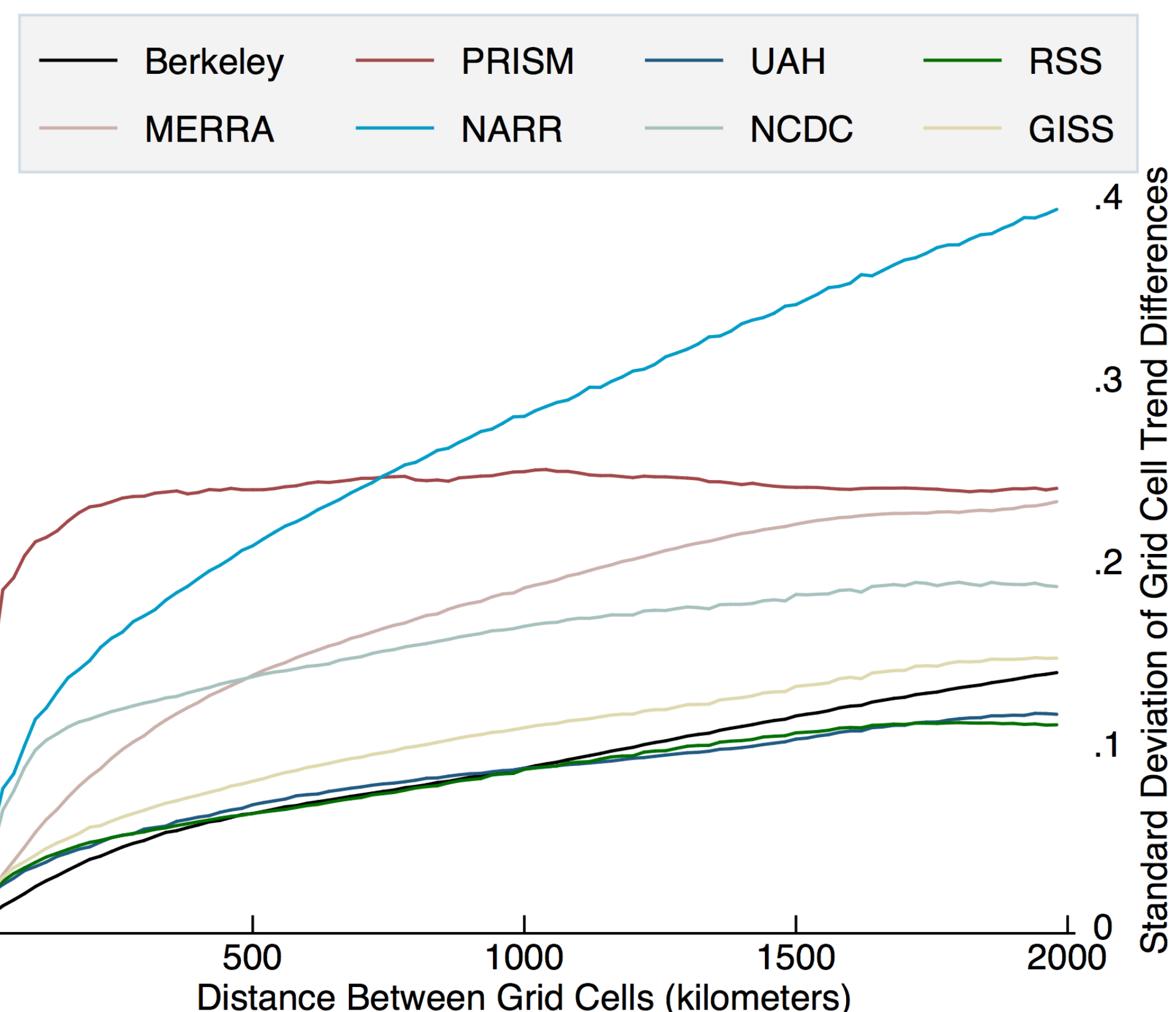
1979 to 2012 CONUS monthly mean temperature trends at quarter-degree resolution (or the highest available) from various surface, reanalysis, and satellite datasets.

Single Month Anomalies (February 1983)



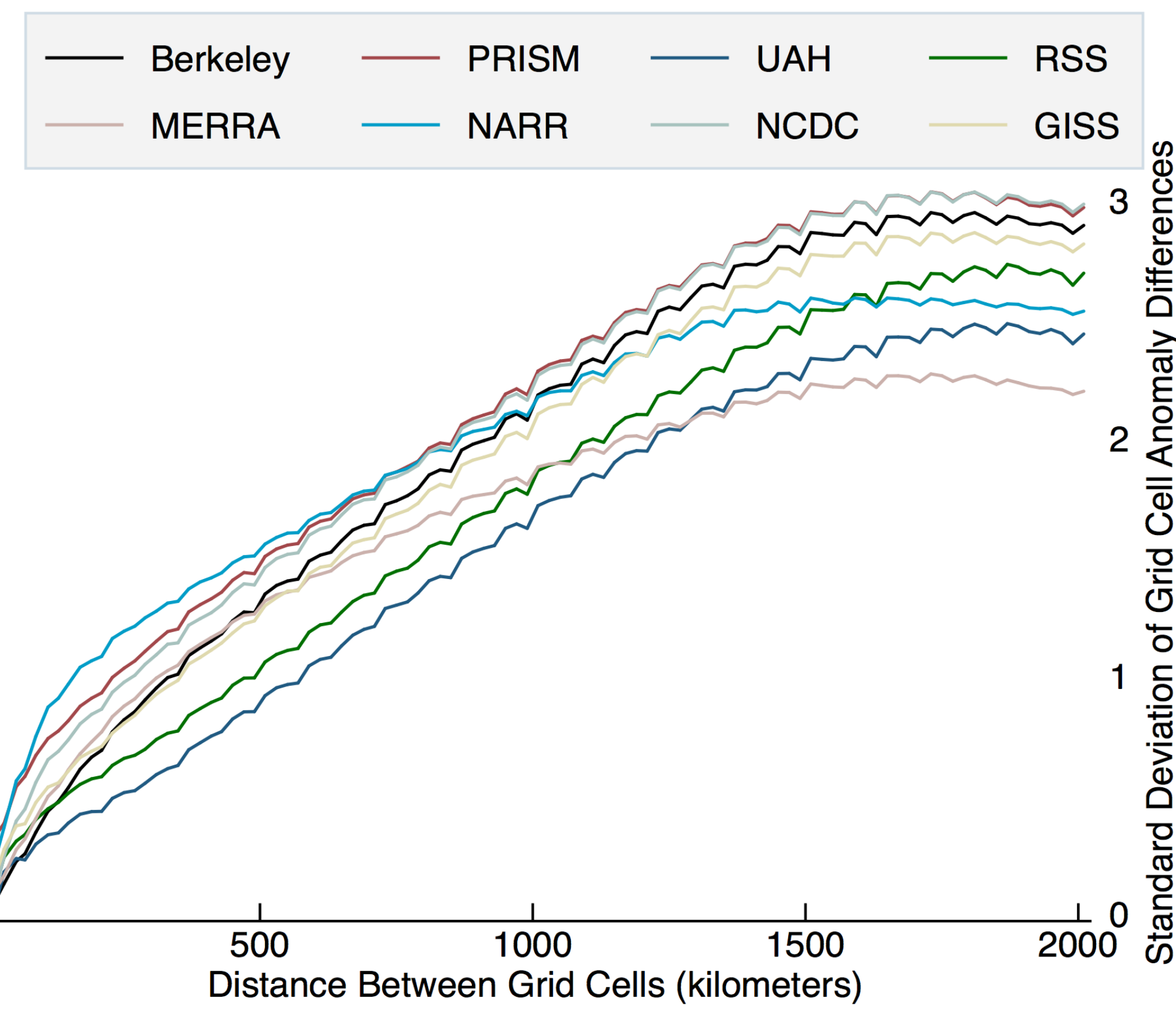
February 1983 monthly mean temperature anomalies (relative to a 1981-2012 baseline) at quarter-degree resolution (or the highest available) from various surface, reanalysis, and satellite datasets.

Variance of Trends over Distance



Variation (as measured by the standard deviation) of **trend** differences (left) and **anomaly** differences (right) as a function of distance for each dataset. Created by taking all possible permutations of CONUS grid cell pairs whose midpoints are within 2000 km of each other and calculating the difference in trends. Aggregate statistics are calculated at intervals of 20 km.

Variance of Anomalies over Distance



Results

To evaluate the spatial characteristics of the climatology and trends produced by the new Berkeley Earth dataset, we obtained comparable quarter-degree data from PRISM and NCDC (based on USHCN), reanalysis data from NARR and MERRA, and two-degree data from GISS and MSU lower troposphere satellite products (UAH and RSS). We examined both the spatial characteristics of 1979-2012 trends (the period of overlap of all datasets) and the anomalies from of an arbitrarily chosen individual month (February 1983) relative to the 1981-2010 baseline period.

While the absolute temperature fields produced by the new Berkeley Earth dataset show considerable spatial variability, the climate fields (both trends and anomalies) are notably smoother than most other surface temperature dataset. Berkeley trend and anomaly fields are most similar in spatial structure (at least over short distances) to those of the MERRA reanalysis product. Overall CONUS annual anomalies are quite similar to those of NCDC and GISS, the two data products normally used to measure overall CONUS climate changes. They show notably more historical warming than the PRISM dataset, consistent with the known impact of homogenization on CONUS temperature records [Williams et al 2012]. Despite its use of homogenized data, the NCDC dataset still shows localized variations in long-term trends that may be related to incomplete homogenization rather than real physical effects.

Over longer distances, the Berkeley dataset shows less trend variability than PRISM, NCDC, and both reanalysis products (NARR and MERRA). It is much more similar to GISS and the satellite products (UAH and RSS), which are somewhat smoothed by their lower spatial resolution. There is considerably less divergence in the spatial characteristics of single-month anomalies, which is unsurprising as inhomogenities will be larger relative to trends than anomalies. Spatial variability of anomalies in the Berkeley dataset is quite similar to that found in PRISM, NCDC, and GISS over long distances, though Berkeley shows significantly less spatial variability over short distances. Reanalysis products and satellites show notably less variation of anomalies over longer distances.

Discussion

There is no easy way to determine the true spatial characteristics of climate trends and anomalies, as there are no dense station networks of sufficient length lacking significant inhomogenities and satellite records do not currently provide high-resolution outputs. In practice, we are stuck with records with known large biases due to station moves, instrument changes, and other non-climatic factors. However, by comparing spatial characteristics of different datasets with weather-model driven reanalysis products as well as outputs from GCMs we can get a better sense of what spatial characteristics we would expect of a "true" climate field.

The new Berkeley dataset produces relatively smooth curves that appear to effectively represent true climatic conditions with localized biases removed. However, we have not yet been able to rule out the possibility that the approach may be over-smoothing and suppressing real trends when down weighting divergent trends during the kriging process. Additional work is needed to confirm whether the fields produced are overly smooth or not both by using tests with synthetic data and by comparing the results to the spatial characteristics of high-resolution GCM fields.

References

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Hausfather et al, 2013: Quantifying the Effect of Urbanization on U.S. Historical Climatology Network Temperature Records. J. Geophys. Res., 118.
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Williams et al, 2012: Benchmarking the performance of pairwise homogenization of surface temperatures in the United States. J. Geophys. Res., 117