

## U.S. SOIL TEMPERATURE AND ITS VARIATION

### A New Dataset

BY QI HU AND SONG FENG

Soil temperature, at various depths, is important to understanding surface energy processes. It is a key to regional climate variation, as well as to climatic effects on agriculture. Yet, despite the importance of this parameter, long-term, quality soil temperature data for the United States were not available until we recently developed a soil temperature dataset from the historical records of U.S. cooperative stations. The dataset contains 4.66 million observations from 1967 to 2002, with a supplementary set of 1.32 million observations from a different group of U.S. cooperative stations that existed prior to 1967. The structure of the new dataset is outlined in Table 1, and the details of the data parameters and the data are available at the U.S. National Climatic Data Center’s online service ([www.ncdc.noaa.gov/oa/soil/soil.html](http://www.ncdc.noaa.gov/oa/soil/soil.html)).

result primarily from the radiation and sensible and latent heat exchanges at the surface, and heat transfer in the soils of different thermal properties. Because heat conducts very slowly in soils, soil temperature anomalies on daily to weekly time scales in shallow layers near the surface are released to the atmosphere via surface exchange and cannot be distributed to deeper layers. Only persistent long-term (such as interannual and decadal) anomalies in the surface heat budget can propagate to deep soil layers and affect temperature variations in those layers. Meanwhile, the soil temperature anomalies in the deep soil layers also affect surface heat flux and modulate regional climate variations at interannual and decadal scales. In addition to affecting the weather and climate, soil temperature anomalies directly affect the growth and

TABLE 1. Outlined structure of the new soil temperature dataset for each station.

Line 1	Station ID number	Ground cover type	Record length	Latitude	Longitude	Elevation	Climate division	Station name
Line 2	Year	Month	Depth	Observation time	Data and flags from Day 1 to the last day of the month			
Lines 3–N	Repeat for the next month till the last data value							

This new dataset has many potential uses in climate studies. For example, the soil temperature profiles can be used to calculate the rates of exchange of energy in soils and between the land and the atmosphere and, thus, to examine the soil heat effect on regional weather and climate. Variations in soil temperature

yield of agricultural crops. For instance, cool shallow soils in spring delay corn development, whereas warm soils in spring help increase corn yield.

In developing the dataset, we used several media and sources to collect cooperative stations’ soil temperatures at various depths from 1967 to 2002. According to these data sources, 337 stations in the contiguous United States measured soil temperature during this period. Of these 337, only 292 stations continued their measurements for longer than 5 years for at least one depth. Most of these stations measured soil temperature at 10-cm depth, only about 50 stations measured soil temperature at 100-cm depth, and a handful measured soil temperature at 200 cm. A total of seven different surface covers were found in the individual measurement sites: bare ground, fallow,

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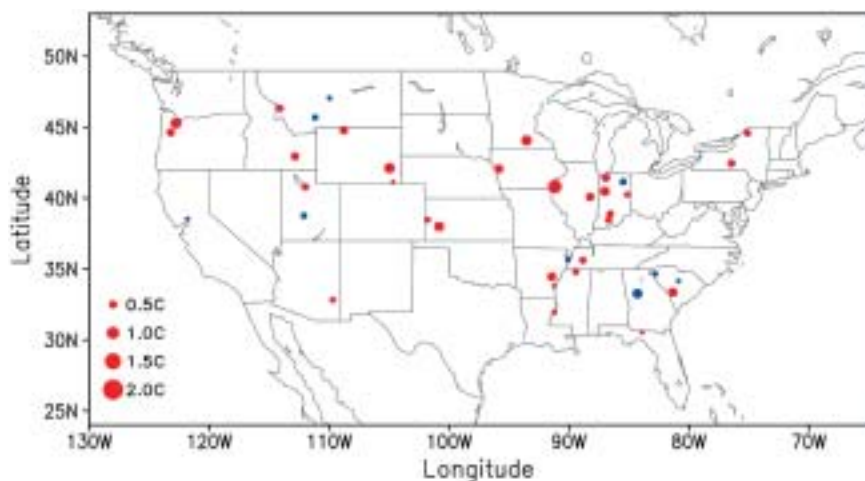


FIG. 1. Trend in soil temperatures at 10-cm depth in  $^{\circ}\text{C} (10 \text{ yr})^{-1}$  (red dots indicate warming and blue dots cooling; magnitude of the trend is shown by the scale in the lower-left corner).

grass, brome grass, sod, straw muck, grass muck, and bare muck. Except for some stations that did not specify their surface cover types, most stations made the measurements under bare ground.

These soil temperature data were examined by a set of quality-control methods. A detailed description of these methods is given in Hu and Feng (2003).

The soil temperature stations have different “times of observations”: some measured daily maximum and minimum, some took observations at morning and afternoon hours, and still others took an observation at a single hour every day either in the morning or the afternoon. Hence, it is essential to “synchronize” the data so that they can be used to describe the climatology. In Hu and Feng (2003), a method was proposed and applied to develop a “daily mean soil temperature” at each depth from the soil temperature dataset.

The daily mean soil temperatures were further used to describe the contiguous U.S. soil temperature climatology for 1967–2002. The climatology shows that the annual soil temperature at 10-cm depth, where most stations have soil temperature measurements, decreases gradually from 297 K in the coastal areas along the Gulf of Mexico to below 281 K at the U.S.–Canada border. In terms of seasonal varia-

tion, the largest seasonal change occurs from spring to summer, when the 293 K contour line “jumped” over more than 20 degrees of latitude from the southern United States to the U.S.–Canada border. In contrast, the soil temperature change in the transition from summer to fall and from fall to winter is mild. At these times, the soil heat storage still dominates the soil temperature variations. In the vertical direction, the annual soil temperature at 20-cm depth is the coolest among the temperatures from near the surface to 200 cm below.

Although data length for most stations is only 36 years (1967–2002), analysis of the soil temperature variation still provides insight into the soil temperature change. The analysis of 38 stations that have more than 30 yr of data shows that the average soil temperature at 10-cm depth has been warming at a rate of  $0.31^{\circ}\text{C} (10 \text{ yr})^{-1}$ . Among those stations with increasing soil temperatures, the ones in the northern half of the United States have the largest rates (Fig. 1). On the other hand, among the few stations with a cooling trend, the ones with largest cooling rates are in the Southeast, and the decrease in soil temperatures at those stations was consistent with a decrease in the air temperatures at the stations. At 100-cm depth, the few stations in the north-central United States showed a statistically significant warming trend at an average rate of  $0.30^{\circ}\text{C} (10 \text{ yr})^{-1}$ .

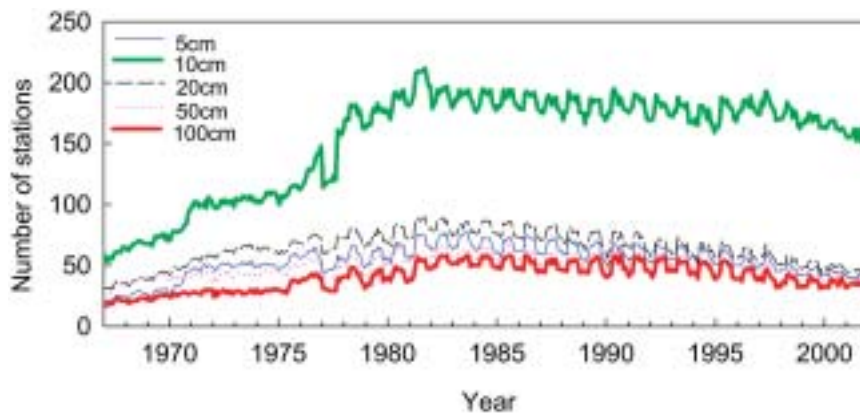


FIG. 2. Change in number of U.S. cooperative stations that measured soil temperatures.

The steady decrease of the number of U.S. cooperative soil temperature stations after the 1980s (Fig. 2) is troubling, particularly in light of the importance of soil temperature change in recent decades and its relationship to changes in regional air temperature and precipitation. To describe and thereby understand soil temperature variation and its role in climate and environmental change, a minimal—yet adequate—spatial coverage of soil temperature will be essential. Indeed, some local and regional soil temperature stations were installed and started taking observations since the early 1980s. For instance, the number of stations in the Great Plains region has grown by more than 103 since 1980. Many of those stations, however, measure only upper-layer soil temperatures because of their primary mission of servicing the regional agricultural communities. A serious issue with the regional observation networks is their instability. Because they have often been operated under contract with various agricultural and industrial collaborators, individual stations in a network

could and have been removed after a short-term (a few years) mission or program ended and the contract terminated. This instability has undermined the strategic role of those networks in making up the spot-tier network of the U.S. cooperative soil temperature observations.

A potentially promising soil temperature network is the USDA NRCS Soil Climate Analysis Network (SCAN). It has grown from 21 stations at its start in 1991 to the current 84 stations in 38 U.S. states and territories. The soil temperature data from SCAN stations will go through quality assurance and will be evaluated for their role in complementing the soil temperature observations from the U.S. cooperative stations.

#### FOR FURTHER READING:

Hu, Q., and S. Feng, 2003: A daily soil temperature dataset and soil temperature climatology of the contiguous United States. *J. Appl. Meteor.*, **42**, 1139–1156.