The United States
Climate Reference Network (USCRN) Annual Report for Fiscal Year 2009:

US Climate Reference Network

Compiled by NOAA/NESDIS
National Climatic Data Center

October 2009

Compiled on behalf of NOAA/NESDIS by:

National Climatic Data Center (NCDC)
151 Patton Avenue
Asheville, NC 28801

Sharon Leduc, Deputy Director, NCDC
e-mail: sharon.leduc@noaa.gov

Howard J. Diamond, USCRN Program Manager
e-mail: howard.diamond@noaa.gov

Michael A. Palecki, USCRN Science Project Manager
e-mail: michael.palecki@noaa.gov

Report will be posted on the USCRN Website at:

http://www.ncdc.noaa.gov/oa/climate/uscrn/

Many Thanks to the USCRN Team Members for Their Invaluable Assistance in Aiding in the Preparation of this Report:

Bruce Baker
Debra Braun
David Easterling
Mark Hall
Jay Lawrimore
Tilden Meyers
RussVose

Rocky Bilotta, Bill Collins, Egg Davis, Scott Embler, Andrea Fey, Diana Kantor, Michael Kruk, and Jon Wilkinson

Assistant Administrator for Satellite & Data Information Services

Mary E. Kicza

Director, National Climatic Data Center

Thomas R. Karl

Preface

Long-term, high-accuracy, stable environmental observations are essential to define the state of the global integrated Earth system, its history, and its future variability and change. Observations for climate include: (1) operational weather observations, when appropriate care has been exercised to establish high accuracy; (2) limited-duration observations collected as part of research investigations to elucidate chemical, dynamical, biological, or radiative processes that contribute to maintaining climate patterns or to their variability; (3) high accuracy, high precision observations to document decadal-to-centennial changes; and (4) observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time to provide information on climate change at millennial and longer time scales.

The USCRN fulfills this need for long-term sustainable and robust climate observations that are necessary to document long-term climate change trends for the Nation. This report is an annual update of the progress made in FY 2009 towards fulfilling those goals. Previous annual reports can be found on the USCRN web site at <http://www.ncdc.noaa.gov/crn>. This report builds on the progress made in 2008 when the final and 114th USCRN station was installed for the continental U.S (CONUS). However, that does not represent the completion of the program; the challenge now is to continue the high level of annual maintenance, equipment refresh, and continued improvements in quality control and quality assurance that will ensure that the USCRN can continue to accurately document climate change on a national scale over the next 50-100 years. This includes critical work begun in 2009 on the installation of soil moisture, soil temperature, and relative humidity sensors at the CONUS stations. Additionally, the program is evolving by beginning a formal expansion into the State of Alaska with the first two installations completed of an eventual implementation of 29 additional stations over the next several years, as well as limited international expansion into particularly climate-sensitive areas in high latitude (e.g., polar) areas, in support of the International Polar Year, and high elevation areas that are under sampled from a global climate perspective.

In summary, we believe this report represents a tremendous set of accomplishments on behalf of the Nation, and details some significant progress towards providing the data and information to aid in characterizing national (and eventually international) trends in climate change.

Thomas R. Karl, Director National Climatic Data Center
October 2009

Table of Contents

Listing of USCRN Data Tables and Figures

1. Introduction

This is the seventh annual report for NOAA's United States Climate Reference Network (USCRN). The primary focus of this report is on the FY 2009 USCRN development and implementation activities. Initial projections of activities planned for FY 2010 are included. FY 2000-FY 2003 USCRN activities were reported in the USCRN FY 2003 Annual Report, and FY 2004, FY 2005, FY 2006, FY 2007, and FY 2008 activities in the USCRN FY 2004, FY 2005, FY 2006, FY 2007, and FY 2008 Annual Reports, respectively.

This report includes reviews of the USCRN, performance measures, and stations installed; research progress and plans; instrument testing and forthcoming new instrumentation deployments; partnership activities at multiple levels; data completeness and data availability via the Internet; and information about NOAA's Global Climate Observing Systems (GCOS) international activities and plans, as well as information about the initial implementations of the USCRN in Alaska and installation of soil moisture (SM)/soil temperature (ST) and relative humidity (RH) sensors throughout the USCRN.

2. Program Base

The required program capability, purpose, and requirement drivers for the USCRN are detailed below:

2.1 Program Capability

The USCRN Program adheres to NOAA's strategy of "Monitor and Observe": "We will invest in high-quality, long-term climate observations and will encourage other national and international investments to provide a comprehensive observing system in support of climate assessments and forecasts." (NOAA Strategic Plan; available at: <http://www.ppi.noaa.gov/PPI_Capabilities/Documents/Strategic_Plans/FY09-14_NOAA_Strategic_Plan.pdf >).

2.2 Program Purpose

The USCRN Program provides the United States with a climate monitoring and climate change network that meets national commitments to monitor and document climate change for the CONUS. The USCRN Program completed the deployment of 114 operational stations in the continental United States as of the end of FY 2008 and as such achieved its target performance measures as documented in Section 3.3. The overall program purpose is to:

Ensure that future changes and variations in primary measurements at specific locations can be monitored without the need for unexplained adjustments and corrections to the data. Primary measurements at each site will include air temperature and precipitation, supplemented with other measurements such as wind speed, solar radiation, and infrared radiation. The network will provide adequate spatial coverage to monitor the annual and decadal-to-centennial temperature and precipitation trends for the CONUS. Fundamental to this goal is the requirement to establish a network that 50 years from now will answer the specific question: “How has the climate of the United States changed over the past 50 years?” The program adheres as closely as possible in both spirit and scientific-technological exactness to the Ten GCOS Climate Monitoring Principles[1]. These have been adopted by the National Research Council (NRC) of the National Academy of Sciences (NAS), as well as the U.S. Climate Change Science Program (CCSP), as defining principles for climate monitoring stations and long-term climate monitoring networks.

2.3 Program Requirement Drivers

2.3.1 Legislative:

- Federal Data Quality Legislation (Act) (Public Law 106-554 Section 515): Section 515 is known as the Data Quality Act—government must assure the quality of the information disseminated.

- Commerce and Trade-15 USC 313: “establish and record the climate conditions of the United States.”

- Global Change Research Act of 1990 requires an early and continuing commitment to “global measurements, establishing worldwide observations, and related data and information systems”

- 44 USC 31 PL 81-754 Federal Records Act of 1950: provides for Agency Records Center and in 1951 the National Weather Records Center established an Agency for U.S. weather and climate records [the National Climatic Data Center (NCDC)] with responsibilities of archiving and servicing.

- 33 USC 883b, Agent Agreement: “… authorize activities of processing and publishing data…”

- 15 USC CH29 PL 95-357 National Climate Program Act: authorizing “…. Global data collection monitoring and analysis…”; “…management and active dissemination of climatological data…”; and “… increase international cooperation … monitoring, analysis and data dissemination”

2.3.2 Executive/International/Programmatic

- Earth Observation Summit [and Group on Earth Observation (GEO) Working Group]: The Summit Declaration reaffirmed the need for timely, quality, long-term global information as a basis for sound decision making and called for filling data gaps. The Summit Declaration also affirmed the need for “producing calibrated data sets in useful formats from multiple sensors and venues”.

[1] See http://www.wmo.int/pages/prog/gcos/documents/GCOS_Climate_Monitoring_Principles.pdf

- CCSP Strategic Plan: The plan has articulated a number of goals, including (1) "complete required atmosphere and ocean observation elements needed for a physical climate observing system"—this includes the USCRN as an underpinning for providing the highest quality benchmark data for enabling the determination of transfer functions with other U.S. meteorological networks, such as the Automated Surface Observing System (ASOS), Surface Radiation (SURFRAD), and Cooperative Observation (COOP); (2) "…easily accessible information about the data holdings, including quality assessments, supporting ancillary data, and guidance and aid for locating and obtaining data"; and (3)"[p]reservation of all data needed for long-term global change research. For each and every global change data parameter, there should be at least one explicitly designated archive."

- GCOS Second Adequacy Report: Concerning data accessibility and quality, "[t]here are many observations of the climate system already being taken today. The report notes many times where there are issues with respect to the limited accessibility to much of the data and problems with its quality. Addressing these issues would have an immediate and positive impact on the ability of the current global observing system for climate to meet the needs of the Parties." More pointedly, the Report states "Notwithstanding the use being made of current information and improvements made in the past few years, the IPCC has recently reported…that additional and sustained climate observations are required to improve the ability to detect, attribute, and understand climate change and to project future climate changes…Without urgent action … the Parties will lack the information necessary to plan for and manage their response to climate change."

- World Climate Data and Monitoring Programme (WCDMP) Guidelines on Climate Observation Networks and Systems (WCDMP No. 52) and Guidelines on Climate Metadata and Homogenization (WCDMP No. 53): These World Meteorological Organization (WMO) documents identify the "best practices" for climatological observations, data collection, metadata, and archival activities. These documents bring all WMO members to similar standards using the Ten Primary Climate Principles referred to in Section 2.2 as a base. These standards are a base for USCRN implementation, and are assiduously applied by the NOAA USCRN Team; thus, USCRN stations and their instrumentation suites are qualified as "Principal Climate Observations Stations" and "Reference Climate Stations."

- NOAA Annual Guidance Memorandum: It is necessary to "Take the Pulse of the Planet" by contributing to the Integrated Global Observing System through development of a "comprehensive, NOAA-wide data collection, quality control, storage, and retrieval program." In support of this goal of an Integrated Global Observing System, several bi-lateral agreements have been agreed upon and are in effect: the U.S/Canada Weather-Climate Memorandum of Understanding; the GCOS initiative to stimulate USCRN-like initiatives in Latin America and other regions; and the Smithsonian Tropical Research Institute (STRI)/NCDC Memorandum of Understanding.

- G8 Endorsement: The 2008 G8 summit held in Japan in May 2008 issued a statement on Environment and Climate Change, endorsing the type of work that the USCRN is working towards accomplishing. The following excerpt from the 2008 G8 Declaration on Environment and Climate Change, paragraph 31, summarizes this endorsement quite well:

> "*We note the opportunity to promote research on complementary technological approaches which may contribute towards maintaining a stable climate. To respond to the growing demand for Earth observation data, we will accelerate efforts within the Global Earth Observation System of Systems (GEOSS), which builds on the work of UN specialized agencies and programs, in priority areas, inter alia, climate change and water resources management, by strengthening observation, prediction and data sharing. We also support capacity building for developing countries in earth observations and promote interoperability and linkage with other partners.*"

2.4. Program Objectives and Characteristics

The USCRN Program objectives are to develop, acquire, install, and operate the premier environmental climate monitoring network in the United States. The USCRN provides stable surface temperature, precipitation, soil temperature and moisture, and relative humidity observations that are accurate and representative of local environmental conditions. Station site location is particularly important because the environmental conditions around each station site must not ever be affected by encroachment of urban expansion or by other conditions that create a changing environment. Accurate climate representativeness and long-term maintenance at each USCRN station location are essential requirements for a climate monitoring network.

As required by the climate science community and codified by the NAS-NRC, WMO, and NOAA's NCDC USCRN Functional Requirements Document, the USCRN, as a primary climate monitoring network, has the following attributes:

a. triple configuration sensors for temperature (see Section 5.1) and precipitation (see Section 5.2);

b. a very high percentage of data ingest over various periods (e.g., minimum of 98% of all possible observations for a given year must be archived at NOAA's national archive, NCDC) to satisfy requirements for climate science;

c. stringent siting standards and an objective, quantitative assessment, which is annually verified and maintained for the long-term for each site as an essential part of the overall metadata pertaining to each site and station;

d. rigorous periodic maintenance and calibration program with thorough documentation, which is systematically collected and archived at least once per year;

e. an organized archive of complete metadata for all USCRN sensors, sites, and data characteristics, which must be long-term and well maintained at the national archive;

f. overlapping observations to develop statistical transfer functions and full metadata for systematic, periodic technology refreshes, which must be maintained for both intra- and inter-network comparisons;

g. strict Configuration Management (CM) for systematically documenting network change(s), maintaining standards, and ensuring that requirements growth does not impinge upon the primary purpose of the network for climate monitoring, which will be accomplished through thorough, updated CM documentation to ensure full implementation of sound scientific data stewardship principles;

h. maintenance of a continuous data analysis and data quality component for continuous monitoring of both network data and metadata;

i. emphasis on the network's primary purpose of satisfying the climate science community's requirements;

j. activities that must be implemented to satisfy all standards, with consistency in change management for a period of a century or more; and

k. capabilities for community, users, and the evolution of requirements; yet remains focused upon and loyal to the constancy and maintenance of the long-term GCOS Climate Monitoring Principles[2].

When possible, USCRN stations have been co-located with or near existing meteorological observation sites such as those of the NCDC-designated Historical Climatology Network (HCN) at National Weather Service (NWS) COOP sites and affiliated HCN Modernization (HCN-M) sites, the Canadian Reference Climate System (RCS) Network, the Bureau of Land Management-Forest Service Remote Automated Weather Stations (RAWS), the NOAA SURFRAD, the University of New Hampshire's AIRMAP stations, and various state mesonet stations (e.g., Alabama, Kentucky, Oregon, and Washington).

USCRN field stations are designed to operate without planned, daily human obligation, and to continue operations under extreme environmental conditions. NCDC provides data ingest, quality control monitoring, data processing, archiving, and user access capabilities to both the climate research community and the general public. USCRN field system technology has proven to be highly reliable, precise, robust, and maintainable so that it collects, formats, processes, and communicates measurements of environmental parameters to NOAA's national archive at NCDC, the central data management and processing facility. The tables in Section 3 detail the high rate of data availability across the network.

After the initial four years of development and field operations, the first 40 USCRN stations deployed were verified as having sufficient spatial distribution, reliability, and stability to provide the planned science information value. NOAA commissioned the network in January 2004. Since its inception, incremental station improvements have been and will continue to be made under strict CM control. By the end of FY 2008, the network consisted of 114 homogeneous and commissioned stations in 42 States in the CONUS.

2.4.1 Capabilities Required

[2] See http://www.wmo.int/pages/prog/gcos/documents/GCOS_Climate_Monitoring_Principles.pdf

The required capabilities of the USCRN are the following:

a. provision of land-based reference stations and standard land surface observing stations for tiered NOAA ground observing systems such as NOAA's COOP and ASOS networks;

b. coverage of sufficient temporal and spatial resolution to monitor national spatial scales for physical phenomena and to determine with the highest confidence trends of significant socio-economic and scientific importance;

c. measurements of key variables adhering to the NRC and GCOS Climate Monitoring Principles. The two primary variables for USCRN, surface temperature and precipitation, are both measured with triple sensor configurations of the highest quality. The secondary variables of solar radiation, wind velocity, and infrared radiation are measured with high quality single sensors, and are used as primary variable checks;

d. data assimilation, archival, and product generation subsystems for observations; and

e. observing system management and information delivery infrastructure.

3. Program-Level Performance Measures

3.1 FY 2001-2009 Achievements: Milestones and Performance Measures

The performance measures for those previous years are summarized along with those from FY 2009 in Table 1 and Table 2 (in Sections 3.3 and 3.4, respectively).

3.2 FY 2009 Achievements: Milestones and Performance Measures

Following deployment of the final 15 stations in the network in 2008, the focus in 2009 turned toward maintenance of the 114-station network, deployment of soil moisture/soil temperature/relative humidity sensor suites (see section 5.3), and development of new methods for data dissemination as described below.

Since installation of the first USCRN station in 2000, NCDC has provided access to quality controlled CRN data via tables and single-station graphing options on the CRN website. Two new efforts in 2009 led to improvements in the timeliness and ease of access to CRN data. One involved development of new access methods for hourly and daily summaries and a second involved reducing the time between observation and data availability.

(1) The first of these addresses the needs of users in the climate community who require reliable and easy access to historical and current observations on hourly and daily timescales. The traditional means of access via NCDC's website involved crude methods for extracting data from web-based table structures on a station-by-station basis. To address this problem, historical and near-real-time hourly and daily resolution data (e.g., hourly and daily average, minimum, and maximum temperature, hourly and daily total

precipitation, and hourly and daily average solar radiation) are now summarized for the network as a whole and provided via anonymous ftp (<ftp://ftp.ncdc.noaa.gov/pub/data/uscrn/products/hourly02/> and <ftp://ftp.ncdc.noaa.gov/pub/data/uscrn/products/daily01/>). These are updated hourly and several times daily, respectively. These data also are retransmitted from NCDC over NOAAPort for users who have access to this system (WMO header SXXX91 and AWIPS identifier CRNH02 (hourly) and CRND01 (daily)).

(2) As 5-minute and hourly observations are collected at each USCRN station, three one-hour records of observations are transmitted via satellite telemetry to NCDC once per hour. There is a fixed transmission window schedule for the GOES satellite receiver that results in a delay at each station between the end of the latest clock hour being transmitted and the actual time of transmission. While most stations transmit within 20 minutes of the end of the hour, the transmission delay exceeds 40 minutes in some cases. The observations are quickly processed at NCDC to ensure data quality and for computation of official 5-minute and hourly observations from the multi-sensor configuration. However, because of the transmission delay and the packaging of data in clock hour records, 5-minute precipitation totals and temperatures may be more than 1.5 hours old by the time they are accessible via the NCDC website. To reduce the time that elapses between observation and availability for forecasting operations and other real-time needs, an additional set of calculated temperature and precipitation values was designed to be added to each hourly transmission. This involves implementing an algorithm which calculates both precipitation totals and mean temperatures for the twelve 5-minute periods preceding each scheduled transmission time. These “rolling-12” observations are added to each transmission cycle and subsequently collected and made available via NOAA’s Meteorological Assimilation Data Ingest System (MADIS) and NOAA’s Hydrometeorological Automated Data System (HADS). Implementation of this capability is occurring in association with the upgrade of datalogger equipment at each CRN station during regularly scheduled annual maintenance visits. Completion at all stations in the network is expected in FY 2010. Because this procedure deviates from accepted practices for collecting and disseminating climate-quality observations, these observations are preliminary in nature, and no collection, dissemination, or archive of these data is performed at NCDC. Official observations are provided via the USCRN website, the ftp and NOAAPort products described above, and through other traditional data dissemination practices at NCDC.

3.3 FY 2009 Performance Measures: Climate Uncertainty

The deployment and commissioning of the full USCRN network in FY 2008 increased the National Performance Measure (PM) in the CONUS for surface temperature to 98.3%, where it remained in FY 2009. Likewise the National PM for precipitation remained at the level of 95.1%, which was reached at the end of FY 2008. The lower confidence of the precipitation PM compared to the temperature PM is due to the greater temporal and spatial resolution needed to estimate the national precipitation total with confidence.

This is in keeping with the stated Program Goals of national uncertainty reduction for temperature of at least 98.0% and for precipitation a confidence level of at least 95.0%.The increasing growth of the Climate Uncertainty Performance Measure over time in conjunction with the densification of the USCRN network is portrayed in Table 1:

TABLE 1 – USCRN Reduction in Climate Uncertainty

CRN Reduction in Climate Uncertainty
FY 2004-FY 2009

End of Fiscal Year	*Commissioned* USCRN Stations Fielded	Temperature Uncertainty Reduction	Precipitation Uncertainty Reduction
2004	58	96.7%	90.2%
2005	72	96.9%	91.1%
2006	77	97.0%	91.8%
2007	96	97.7%	94.0%
2008	114	98.3%	95.1%
2009	114	98.3%	95.1%

For the first time in USCRN history, there is now enough data from the commissioned network to confirm that the network meets the temperature uncertainty reduction requirement of 98%. Even as the number of stations increased from 2004 through 2008, it was possible to calculate national annual temperature departures since the network was well distributed across the CONUS in each year. These USCRN annual temperatures could then be compared to national temperature departures calculated from the subset of 1221 stations from the NWS Cooperative Observer Program Network selected for climate change studies, the US Historical Climatology Network Version 2 (USHCN V2). The analysis is described in more detail in Sec 5.4. For the five years since commissioning, the USCRN and USHCN V2 national temperature time series share in common more than 99.5% of the variance occurring during this five year period, exceeding the theoretical performance expectations for the USCRN. This result is a tribute to the hard work and persistence of the personnel involved in this program over the years. Because more stations are needed to explain national precipitation departures, it will be a few more years before a similar comparison can be made with USHCN V2 precipitation.

3.4 FY 2009 Performance Measures: Data Ingest

Since the USCRN Program began in FY 2001, the Data Ingest Performance Measure for data completeness (Table 2) continues to be above what the climate science community specified as an acceptable base level for supporting robust climate science studies (that is, to a minimum of 98% data set completeness). This 98% base level was first reached in December 2002. The data ingest has remained near the 99% level since that time. The current network-wide data ingest for the period-of-record is estimated to be above the 99.5% level.

At times, data transmission through the Geostationary Operational Environmental Satellite (GOES) Data Collection System (DCS) and ingest at NCDC can be interrupted due to system outages. Although these outages interfere with near real-time data collection, all data are stored within the station datalogger and eventually downloaded into a Personal Digital Assistant (PDA), often during scheduled Annual Maintenance Visits (AMV). Subsequent to the download, the data are delivered to NCDC and entered into the official archive.

Table 2 – USCRN Data Receipt Rates (%)

Year	Q1 Avg	Q2 Avg	Q3 Avg	Q4 Avg	Annual Avg
2001	**86.8**	**96.5**	**70.5**	**97.4**	**87.7**
2002	**95.4**	**96.1**	**98.4**	**96.7**	**97.0**
2003	**98.5**	**99.4**	**99.8**	**99.5**	**99.4**
2004	**99.9**	**100.0**	**99.8**	**100.0**	**99.9**
2005	**98.9**	**99.9**	**100.0**	**100.0**	**100.0**
2006	**99.9**	**100.0**	**99.9**	**97.4**	**99.3**
2007	**100.0**	**99.8**	**99.7**	**100.0**	**99.9**
2008	**99.6**	**99.8**	**99.8**	**99.9**	**99.8**
2009	**99.9**	**99.8**	**99.9**	**99.2**	**99.8**

4. FY 2009 Installations and Surveys

FY 2009 activities included:

Site Surveys – 7 detailed site surveys at five locations in Alaska during summer 2009.
Sites Approved – None. Alaska USCRN site selection committee will meet early in FY10.
Site Licenses Signed – 2 sites (listed below).
Stations Installed – 2 (listed below in order of installation for FY09).

Sand Point, AK	08/2009
Lake Clark, AK	09/2009

The national grid of 114 USCRN stations has the most stations in Texas (eight) followed by California (seven), and Colorado (six). The high number of stations in Colorado compared to the geographic area of the state is based on the need to sample the heterogeneity of Colorado’s climate due to its rugged terrain. States with no USCRN stations are Connecticut, Vermont, Delaware, New Jersey, Massachusetts, and Maryland. A full listing of USCRN stations can be found on the USCRN web site at <http://www.ncdc.noaa.gov/app/isis/stationlist?networkid=1>.

4.1 USCRN Begins Installation Work in Alaska

Two experimental USCRN stations were installed at sites in Alaska in 2002, and two more USCRN-design stations were installed via the U.S. GCOS Program in 2005 to provide experience with USCRN technology in Arctic environments. NCDC, along with the NWS Alaska Region Headquarters (ARH), held a workshop in Anchorage, AK, in May 2008 that focused on plans to expand the USCRN into all of Alaska. The first targeted funds for USCRN in Alaska were received in FY08 and FY09, thus allowing for the installation of the first two of an additional 29 USCRN stations in FY09 (Figure 1). The intent, based on available resources, is to install and commission these additional USCRN sites in Alaska over the next several years.

NCDC and ARH have established partnerships with federal agencies in the state [e.g., U.S. Geological Survey (USGS), U.S. Park Service, the U.S. Department of Agriculture (USDA)], Environment Canada (with which NCDC has a bilateral climate observing agreement), and the University of Alaska, Fairbanks, to plan for potential USCRN sites in Alaska. Presentations from the workshop can be found online at the following site at: <ftp://dossier.ogp.noaa.gov/USCRN-in-Alaska-Workshop-May2008>.

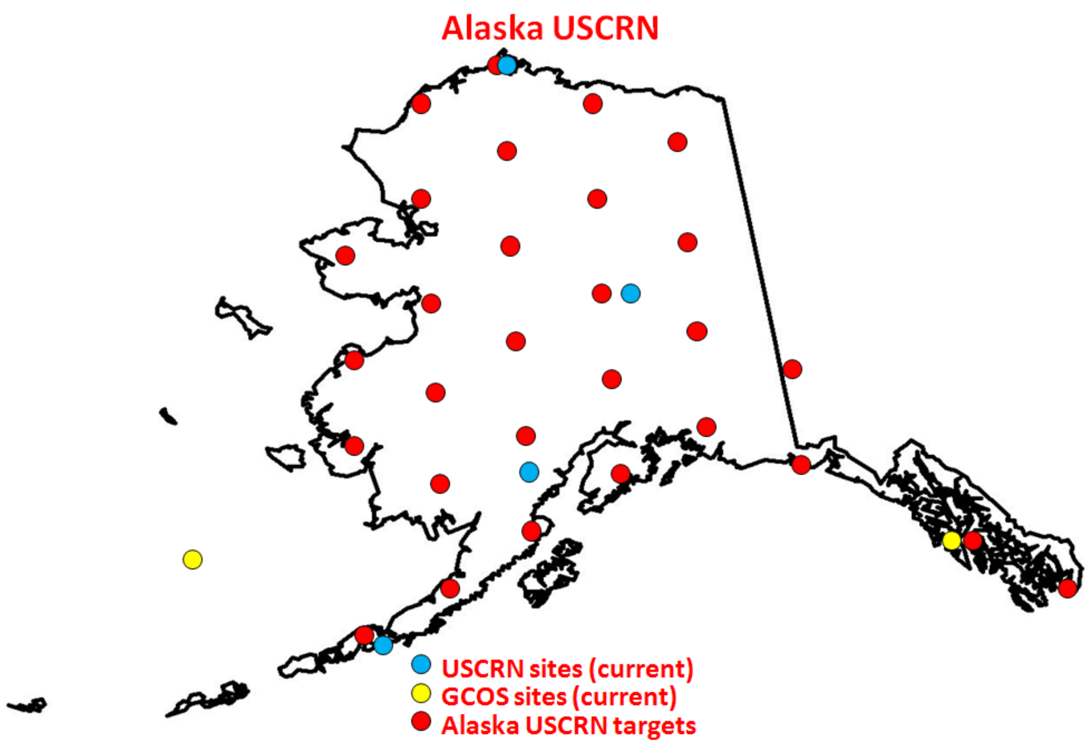


Figure 1. Alaska USCRN Target Grid, including installed USCRN stations and GCOS-sponsored USCRN stations as of the end of FY09.

4.2 Breadth of USCRN Station Partnership Network

The high level of confidence and data ingest for the USCRN could not be accomplished without the support of the various host organizations at each of the sites. The organizational classification of USCRN operational field stations by host agency identity gives an indicator of the breadth of the USCRN partnership of federal and state agencies, universities, foundations, and non-governmental (not-for-profit) organizations that have been involved in hosting station sites for this network.

Beginning in FY08, the USCRN program has partnered very closely with the NWS Historical Climatology Network Modernization (HCN-M) program. Since the primary mission of the USCRN is to determine national climate trends, the complementary HCN-M mission is to deploy a regional scale observing network to better characterize regional trends for temperature and precipitation. With the support of USCRN, NWS is currently conducting an HCN-M pilot project in the four-corner states of the Southwest with long-term plans to field 1000 HCN-M sites across the U.S. to more fully align their climate monitoring capabilities with the GCOS Climate Monitoring Principles. HCN-M configuration work to date has been based on a scaled-down version of the USCRN sensor technology suite; experience with a network of 17 HCN-M prototype sites in Alabama begun in 2006 was a starting point for cooperative work between the two programs. The pilot program involving the installation of 127 HCN-M sites in the Southwest U.S. began in 2008. The first USHCN-M stations were installed in June 2009 and there are now 10 stations installed within the HCN-M network (Figure 2). The continued growth of the HCN-M program will involve considerable collaboration with the USCRN program as it

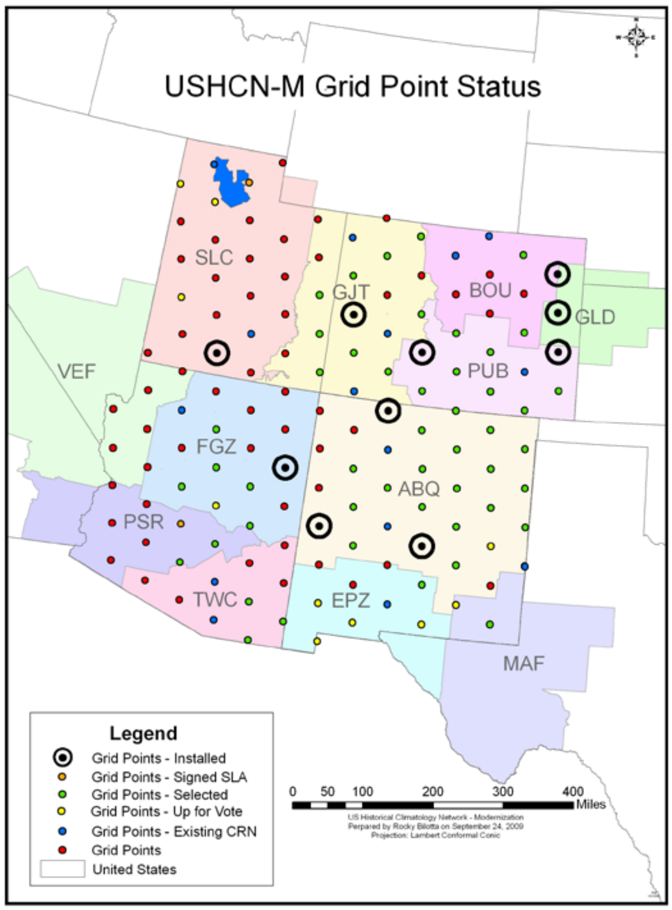


Figure 2. U.S. Historical Climatology Network Modernization Pilot Area and installation status

benefits from lessons learned and successes realized over the past 7 years of experience with implementing and maintaining USCRN.

In addition to providing advice and serving on review panels, the USCRN program at NCDC also provides seats for three personnel working on HCN-M-sponsored projects of mutual interest to USCRN. A station monitoring and warning system is being designed and implemented that will allow for improved rules based notification of system engineers and ingest personnel when either a USCRN or a USHCN-M station is not performing normally. Another major joint project is the revision of the USCRN Web site, with considerable refactoring and modernization of the underlying technology benefitting USCRN, while USHCN-M is provided with unique branding and visibility. Finally and most directly, since the USHCN-M stations are based on USCRN technology, their data are transmitted to NCDC and are archived, processed, and quality controlled using USCRN systems.

5. FY 2009 USCRN Science Program

As the deployment of USCRN in the CONUS was completed in FY 2008, resources were directed to advance the USCRN Science Project in FY 2009. The primary mission of the USCRN Science Project is to provide high quality climate data and information products for understanding climate change on a national scale, enhancing society's ability to plan and respond. By means of scientific strategies of site selection, station engineering and maintenance, and data quality assurance, a set of observations is being collected by USCRN that can serve as a reference for other observation networks, for satellite climate product calibration and validation, and for model initialization and verification. The USCRN Science Project also serves society's needs for weather and water information in near-real time, through ongoing development of climate visualization and drought monitoring capabilities. By producing scientific analyses based on USCRN observations, continually enhancing USCRN products, and actively engaging in outreach on behalf of the USCRN, the USCRN Science Project adds tremendous value to the USCRN Program and helps fulfill the goals of NCDC and NOAA.

5.1 Science and Analysis in Support of Station Engineering and Maintenance

The first step in generating a stream of climate-science-quality data from USCRN is to engage in ongoing assessments of current instruments and station engineering practices, and to look to the future by testing new instruments and practices at test sites and in test beds. The field work related to test site and test bed activities is conducted by NCDC's partner in the USCRN Program, the Atmospheric Turbulence and Diffusion Division (ATDD) of NOAA's Air Resources Laboratory. ATDD also analyzes test bed observations, sharing data and results with NCDC collaboratively.

5.1.1 Marshall Field, Colorado - Test Bed Precipitation Measurements

An intercomparison of precipitation sensors and wind shields was performed to help quantify measurement errors and aid in the design of future precipitation measurement systems. Variability between like measurements was quantified and used to estimate the significance of errors due to shield and sensor type. The largest errors observed were due to inadequate wind shielding during solid-precipitation events, and the magnitude of these errors varied greatly between events. Wind speed and hydrometeor size determine the magnitude of shield-dependent errors, and these errors were modeled using only wind speed and air temperature.

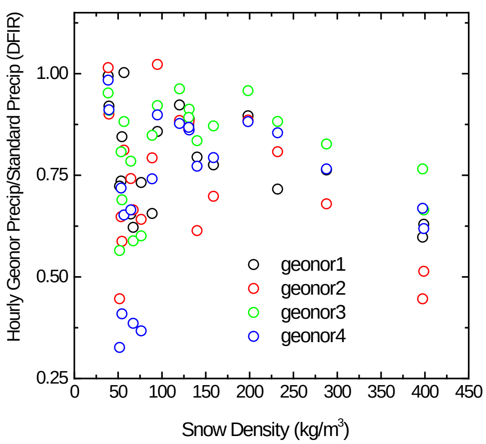
Six Geonor weighing precipitation sensors recorded precipitation continuously; three of the Geonors were mounted within Double-Alter Shields (Figure 3a), one was mounted in a Single-Alter shield, and two were mounted in two separate DFIRs (Figure 3b). Six Hydrological Services heated tipping bucket gauges were also used, two of them mounted in DFIRs and four in Double-Alter Shields. Wind speed and air temperature (T_a) used in this analysis were measured at a height of 1.5 m. Snow depth was measured by the SR50 Ranging Sensor.

Figure 3a. Double-Alter Shield. The Vaisala and Hydrological Services rain gauges as well as one of the automated cameras are in the foreground, right side. Photos taken February, 2009.

Figure 3b. An example hourly photo from the northerly DFIR. The Geonor and Hydrological Services gauges are shown. Photos are taken at 1 hr. intervals at several locations at the site.

All of the events with more than 15 mm of precipitation occurred in the late winter/spring of 2009. Insufficient events occurred during the winter of 2008/2009 to produce any useful sensor/shelter event intercomparisons (only 7 events with more than 5 mm of precipitation occurred), but the importance of shelter type was demonstrated, with the Double and Single-Alter shield resulting in less precipitation caught than the DFIR in cold and windy conditions (Figure 5).

The hourly ratio of measured precipitation to the reference DFIR precipitation was compared to environmental variables. In general, regressions indicated that errors in measured precipitation were correlated with environmental variables, with a trend towards larger errors in colder temperatures and higher winds. The relationship between precipitation measurement errors and snow density (Fig. 4) was poor due to errors in the measurement of snow density.



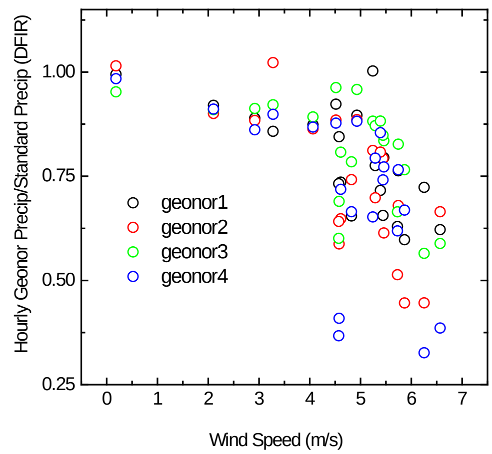


Figure 4. Snow density was estimated from the change in snow depth and the measured liquid equivalent precipitation. Geonor 1-4 are Alter-Shielded.

Figure 5. Ratio of hourly Geonor solid precip to the standard precipitation vs. wind speed.

A student's T-test was used to evaluate the significance of the differences between the different types of measurements, and it showed that the mean of the DFIR shielded measurements were statistically different than the mean of Double-Alter Shielded measurements. A multi-variate regression was also performed to estimate the effects of wind speed and T_a on the Double-Alter Shielded precipitation measurements. It showed that errors in precipitation measurement increased with wind speed and decreased with increasing temperature, and despite the limited number of events available for this analysis, shield-dependent errors were predicted with some success by a simple relationship with T_a and wind speed (R^2 = 0.63, and T-test and ANOVA probabilities that this relationship was insignificant were < .0001.)

5.1.2 Solar Power Site Analysis

USCRN sites that are solar powered have experienced down time during recent winters and were evaluated based on their 2008 and 2009 performance. The conditions under which sites failed or neared failure were analyzed, and solutions were proposed. One of the relatively new components of the work related to this is an analysis of the potential for power production using small wind generators. Based on wind speed data recorded at individual sites during the periods when battery voltage approached critically low levels, it was apparent that many of the problematic sites would benefit from the addition of a wind generator.

At a small number of sites, where wind speeds were insufficient to justify the installation of a wind generator, augmentation of the existing solar array and/or battery bank was recommended. Wind speed was measured at a height of 1.5 m at all sites. These measured data were used to estimate wind speed available for power generation at the planned installation height of 5 m. Roughness length (z_0) was conservatively estimated from available site photos, and the logarithmic wind profile (Thom, 1975)[3] was used to estimate the wind speed at z = 5 m: A 4th order polynomial was fit to wind speed and power data provided by the manufacturer of one of the prospective wind generators (Model AIR X, Southwest Wind Power, Flagstaff, AZ, USA), and potential output from this wind generator was thereby estimated for every hour of data using mean wind speed estimated at z = 5 m.

Low temperatures are known to reduce the capacity of batteries. The degree to which this occurs is described by a 'design factor', which is a function of temperature and describes the amount by which the rated capacity of the battery bank must be multiplied in order to achieve the desired capacity. For the batteries used in the Climate Reference Network, this design factor was 1.60 at 0 to -9° C, and 2.23 at -20 to -11° C The daily average data logger panel temperature was used as the best available proxy for the temperature of the batteries. The results of the joint wind and battery analysis lead to a set of recommendations.

Site by Site Solar Power Summaries

- **Aberdeen, SD**: A wind generator will help this site significantly.
- **Lander, WY**: Additional batteries are all that is recommended for the time being, although the potential for wind energy production is very good.
- **Montrose, CO**: Increasing the size of the battery bank is recommended. Installation of a wind generator is justified based on locally measured winds and the fact that the surface is very rough, and significantly stronger winds than were locally measured are expected a height of 5 m.
- **Northgate, ND**: Some combination of a wind generator, additional batteries, and possibly additional solar panels are needed at this site.
- **Sandstone, MN**: The size or efficiency of the solar array must be improved. Doubling size of the solar array is recommended. In addition, the size of the battery bank may need to be increased.
- **Spokane, WA**: More solar panels or a wind generator should be added, and the size of the battery bank should be increased.
- **Sundance, WY**: A wind generator and additional batteries are recommended.

Increased battery bank capacity will allow all systems to operate through periods subject to reduced battery capacity due to low temperatures or when solar power is lacking. Less generated energy will be lost by having more batteries, and indeed batteries will charge more efficiently when their voltage is low. Although it may require more time for the battery voltage to increase when there are more batteries to charge, this is not a disadvantage. However, more batteries will in some cases cause more energy to be used, as during periods of low energy production the Geonor heaters and aspiration fans will remain active for longer as the batteries will presumably remain above 12 V for longer. This indicates that when battery capacity is increased, energy production may also have

[3] Thom, A.S., 1975. Momentum, mass and heat exchange of plant communities. Vegetation and the Atmosphere, Vol. 1. Academic Press.

to increase even when it does not appear necessary from the available data. More significantly however, the quality of the data will likely improve, as the fans required for temperature aspiration and the Geonor heaters will remain active longer. Monitoring hourly power production and power use at one or more test sites would be useful. Data from such test sites could be downloaded during annual visits and used for future analysis of the power requirements of all sites. Such data could be used to remove uncertainties in the estimated current that is generated and required by USCRN stations in response to changing environmental conditions.

5.1.3 Soil Moisture and Soil Temperature Sensor Testing and Deployment

A workshop was convened in Oak Ridge, TN from March 3-5, 2009, in order to provide a forum for discussing issues related to the installation of soil moisture, soil temperature and relative humidity instruments for the USCRN stations in FY 2009-2011. The goal of the workshop was to gain knowledge and information from existing networks, determine an optimal configuration (depths, replication, placement), discuss products and user data needs for operations and research, understand ancillary data and metadata options (e.g., soil classification, infiltration rates, etc.), refine QA/QC procedures, review sampling protocols, explore the idea of a soil moisture/temperature testbed, and address the issue of station representativeness for the remote sensing and modeling communities. The workshop report is posted U.S. Drought Portal site at: <http://www.drought.gov/imageserver/NIDIS/workshops/crn/USCRN_SMST_workshop_summary.pdf>. Following the workshop, it was decided that the installation of soil moisture and temperature sensors at CRN sites would have single sensors at three closely separated holes at 5, 10, 20, 50, and 100 cm depths. This would allow a better sampling of the soil conditions at each site, at the expense of less direct comparison of sensors at the same depth. Data are now being transmitted from more than 35 sites.

Soil moisture and temperature sensors were first installed by ATDD for preliminary examination at a single site in Oak Ridge, TN. The initial installation had sensors at each of four holes at depths down to 100 cm. At 5 and 10 cm depths there were three sensors for each hole and intensive examination considered only these depths. Various means were used to examine the data in a preliminary fashion, included plots, statistics and distributions of inter-senor differences (mean and standard deviations), statistics and distributions of one-hour changes, correlation between changes at various sensors (one-hour and three-hour changes), and results were stratified by the early dry period and late wet period.

In addition, a direct comparison of individual sensors under control and under realistic environmental conditions was performed. The measurements from a large number of sensors were compared with each other in dry sand, wet sand, and water. Then these sensors were installed in separate holes, three at each of 5, 10, 20, 50, and 100 cm depths. Extensive examination was made of the measurements from the resulting data. As is reasonable, it was found that co-located temperature sensors in soil do not agree with each other as well as in free air. The progress of installing these sensors at CONUS

USCRN sites (35 expected by the end of FY 2009[4]) is depicted below (Figure 6). The deployment process was stopped for 4-6 weeks during the late summer due to a manufacturing issue at the supplier, preventing more from being installed in FY 2009.

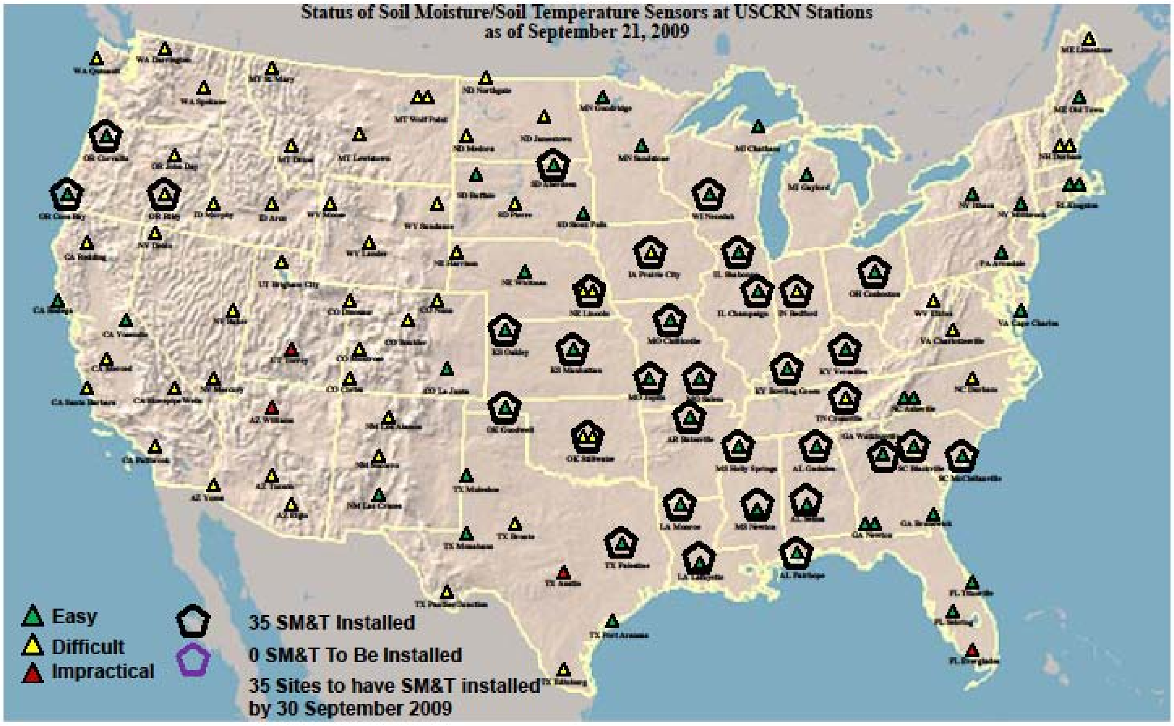


Figure 6. Map of USCRN sites with soil moisture and soil temperature probes installed at the end of September, 2009. The color coded triangles indicate the level of difficulty anticipated during installation.

5.1.4 Station Monitoring and Warning System Development

With the USCRN and USHCN-M, accuracy and reliability are critical attributes which must be maintained in order for collected climate data to be scientifically credible. To ensure the highest degree of credibility, all climate stations in these two networks must be constantly monitored for potential problems. As problems are identified, they must then be prioritized, diagnosed, and scheduled for maintenance. Traditionally, the operation of each station has been closely watched by trained engineers and scientists to look for signs of hardware or software failures. This manual observation approach worked well when the number of climate stations was small and

[4] The goal for FY09 was 40 stations installed with soil and RH sensors, however due to a shortage of sensors from the manufacturer, we were only able to install the sensors at 35 stations.

there were enough people available to review climate station data frequently. But with the expected increase in the number of USHCN-M climate monitoring stations in the next few years, manual observation will become increasingly difficult and expensive. If the ability to monitor the networks is compromised, then it is possible that undetected failures at a station will prevent one or more of a climate monitoring network's performance measures from being achieved.

The Monitoring and Warning System (MaWS) is a software tool that is intended to assist with analyzing and maintaining station health for the USCRN and USHCN-M networks (Figure 7). MaWS will automate much of what human operators have already been doing as well as introduce more complex analyses of climate station data. MaWS's main tasks are to search for abnormalities in climate station data, inform maintenance personnel regarding the existence of a potential problem, and also provide a preliminary diagnosis. Once people are made aware of a problem it can be repaired quickly before significant data lose occurs. Problems can be detected and diagnosed around the clock, in a consistent and reliable way.

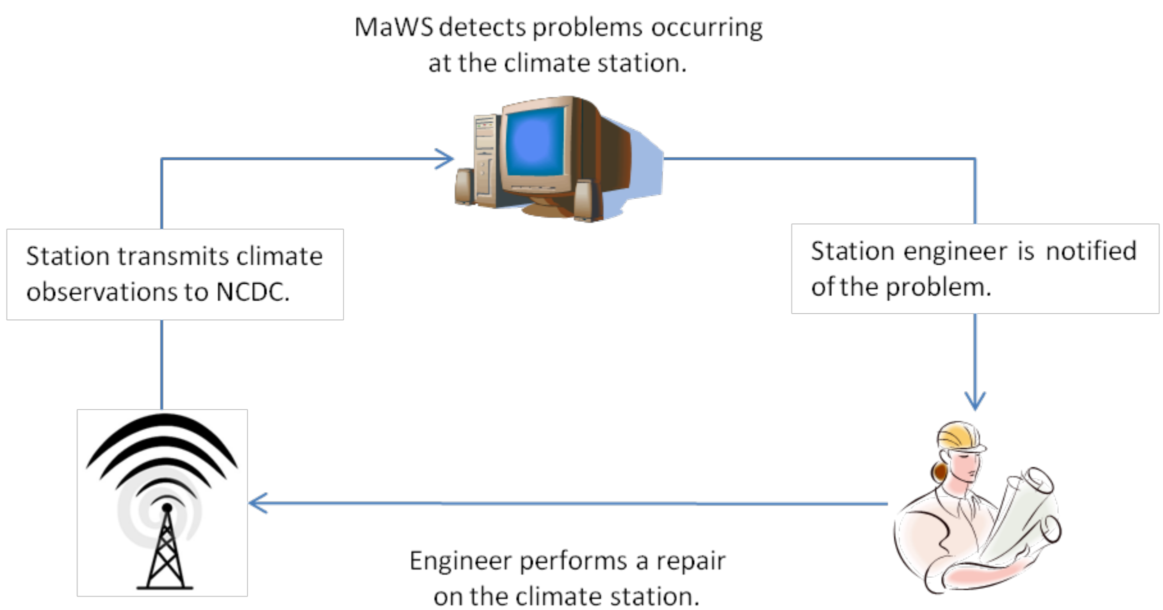


Figure 7. Schematic diagram illustrating the work flow of the new Monitoring and Warning System (MaWS) for USCRN and USHCN-M.

5.2 Science and Analysis in Support of Data Quality

The USCRN Program is heavily engaged in developing an initial set of quality control measures for the new soil moisture and soil temperature measurements now being received. There is also a substantial effort being made to evaluate the current quality control system being applied to existing data streams, both to improve real time quality control and reexamine historical records. In the latter case, the USCRN data are being ingested into an external quality control system associated with the Global Historical Climatology Network Daily (GHCN-D) data set, as well as undergoing analysis within the context of the USCRN Program.

5.2.1 Soil Moisture and Soil Temperature Quality Control

The development of quality control procedures for USCRN soil moisture and temperature observations is following two pathways, one leading to a limited but robust set of QC algorithms for deployment in the near term, and the other a more complex QC approach to serve as a long term solution. Observed behaviors of the soil moisture data in particular indicate a variety of issues that must be discerned. Examination of the various sets of soil moisture and temperature data by USCRN program QA/QC consultant was facilitated by his development of a general code for calculation of various statistics and the quality control of the data. This code continues to be revised and expanded as required. The code includes the following steps: read soil moisture and temperature data from USCRN files (also air temp and precipitation), compute moisture from dielectric values, compute distributions of soil moisture and temperature one-hour changes, look for values out of range, check for bad zero values of temperature, look for excessive changes in temperature and moisture, test for frozen soil, test for constant (and therefore, bad) values of temperature and dielectric, compute inter-sensor correlations as diagnostics, compute a single, representative value from 3 sensors at same depth. At each step, a quality assessment is made and metadata are saved. All results are written to files for further examination.

A meeting at Oak Ridge, TN on August 19, 2009, among the NCDC and ATDD personnel working on these issues and the consultant was very productive. A method was described for using soil bulk density measurements to better define the upper limit of soil moisture used in range checks. The acceptable range of step changes in both soil moisture and soil temperature will be developed based on the observed record (Figure 8). Lessons learned from the consultant's off-line analysis system will be incorporated in operational QC where feasible.

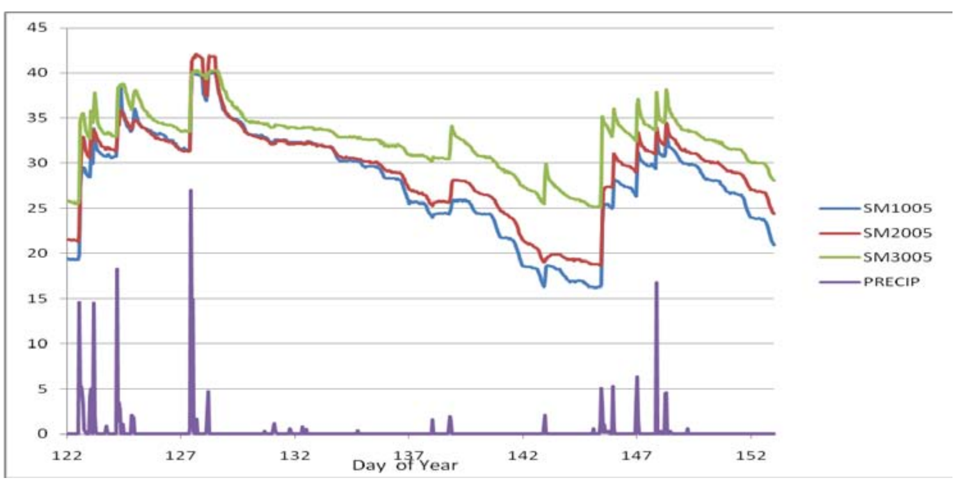


Figure 8. Three independent measurements of soil moisture at the 5 cm depth at Gadsden, AL, from Day 122 (2 May 2009) to Day 152 (1 June 2009): moisture (dielectric), precipitation (mm).

5.2.2 Historical Quality Control

The automated quality control and assurance algorithms for the USCRN, while highly capable, do not identify all potential failure modes. Some types of electronic, instrument, or transmission failures yield data that are not necessarily correct, although within an allowed range. As problems are detected, there is a need to indicate exceptions to QA/QC processing and to provide feedback for improving QA/QC algorithms. Procedures are being designed for registering observations on an exception list, for the use of the list, and for modifying the composition of the list. Exceptions may be considered when automated NCDC QA/QC processes do not flag observations identified by NCDC or external data users as potentially invalid due to a concurrent system failure.

As an example, one mode of failure that has been identified recently yields a precipitation amount even in dry conditions when the wetness sensor malfunctions. In the course of a normal morning transmission from the station antenna to the satellite, radio frequency interference causes the wetness sensor to go to zero (brick red line in Figure 9), indicating wetness whether or not it is raining. If the rain gauge depth measurements rise for reasons other than precipitation (i.e., condensation, uneven solar heating, etc.), the ingest system will calculate a precipitation amount. This type of failure is declared by a peer review process to be an "exception", an improved algorithm is implemented to detect these events, and the bad precipitation record is flagged as defective.

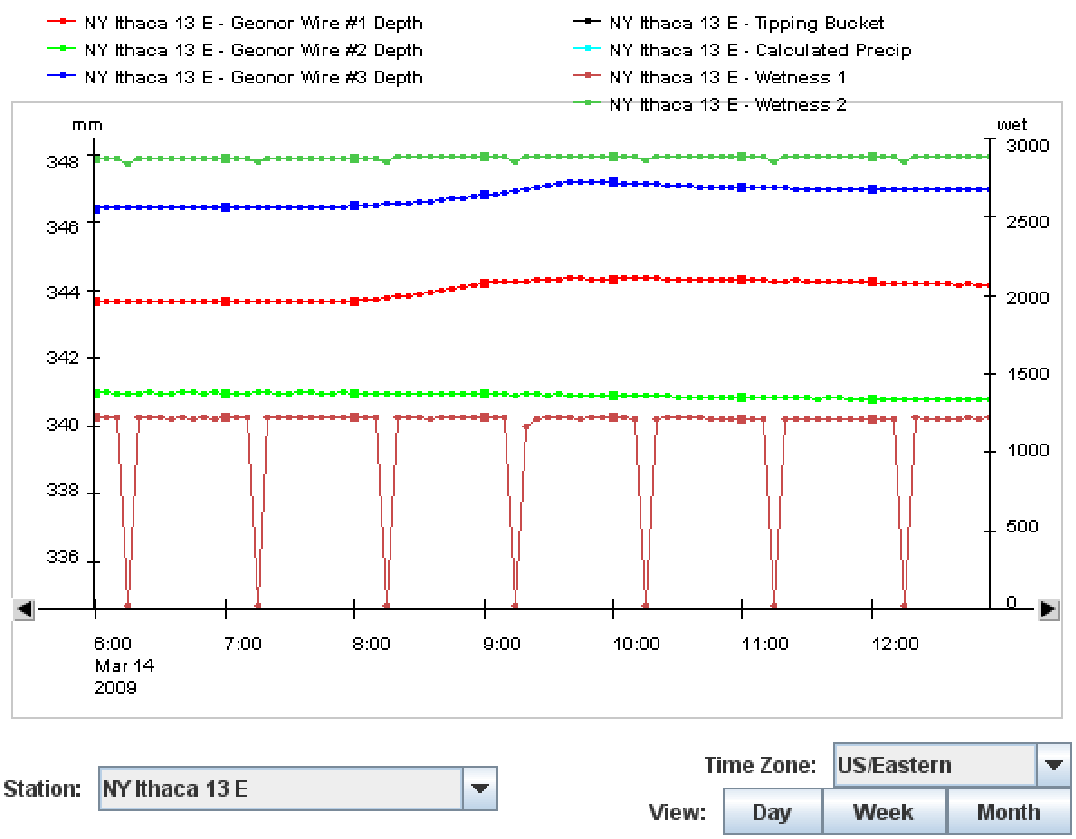


Figure 9. Wetness sensor failure during satellite transmission at 15 minutes after every hour.

5.2.3 External Quality Control by GHCN-D Algorithms

The quality control system and algorithms for the Global Historical Climatology Network Daily (GHCN-D) data set have been peer reviewed in the published literature[5], and provide a strong test to the quality of USCRN observations. In addition, by subjecting the USCRN daily observations to this added layer of quality control, the USCRN data are contributed to the GHCN-D data set, where all NCDC daily data resources will eventually reside. Only about 40 USCRN daily climate records (maximum temperature, minimum temperature, or precipitation) were flagged by the GHCN-D quality control system, out of some 600,000 possibilities. This provides great reassurance that there are very few large outliers in the USCRN data set that have not been caught by ingest quality control

5.3 Science and Analysis in Support of Product Development

A complete revision of the USCRN Web site has commenced in FY 2009, along with the start of an effort to design new data visualization products for climate sciences analyses and for stakeholder viewing. The work will continue through FY 2010.

5.3.1 USCRN Web Site Development

The process of rewriting the USCRN website began in July 2009. Our web development team is listening to the needs of the community and working to provide a more intuitive user interface, more comprehensive documentation, better organization, accurate program information, and web services for ease of data access. The team is also incorporating new technologies for the additional USHCN-M program stations by providing a separate suite of information and reporting capabilities. USHCN-M project information will also be integrated into existing documents where appropriate.

By releasing more frequent, incremental updates to the USCRN/USHCN-M website, visitors will see more up-to-date program information and data online. The team has already updated the look-and-feel, updated content, and made navigational changes. Enhancements will be deployed throughout FY 2010 at the USCRN web site at <http://www.ncdc.noaa.gov/crn/>. Some links may change as revisions continue, so users are asked to use the improved navigation to find items of interest.

5.3.2 Data Visualization Development

In keeping with USCRN's efforts to develop quality control algorithms for soil moisture/soil temperature measurements and to leverage CRN data for science purposes, a series of visualizations are being developed. Some of these visualizations will eventually be incorporated in the Web site revision, while others have been prepared for off-line scientific analyses.

---

[5] Durre, I., Menne, M.J., and Vose, R.S., 2008: Strategies for evaluating quality assurance procedures, *J. Appl. Meteor. Clim.*, 47, 1785-1791.

The visualization effort is based on the use of the Adobe Flex[6] development environment in combination with the Flare application programming interface (API) to create an infrastructure which will enable USCRN visualizations to be created on demand in an efficient and consistent manner. This infrastructure handles user interface, data connections, and basic display management. Beyond simple line graphics of any station and variable that can be drawn in real time, many specialized visualizations are being developed. For instance, the visualization in Figure 10 shows the range of single layer soil moisture measurements expressed by changing the line thickness tracing the mean value for the three samples. Range or more complex statistics can be visualized by using color, line width, or transparency superimposed on the base mean.

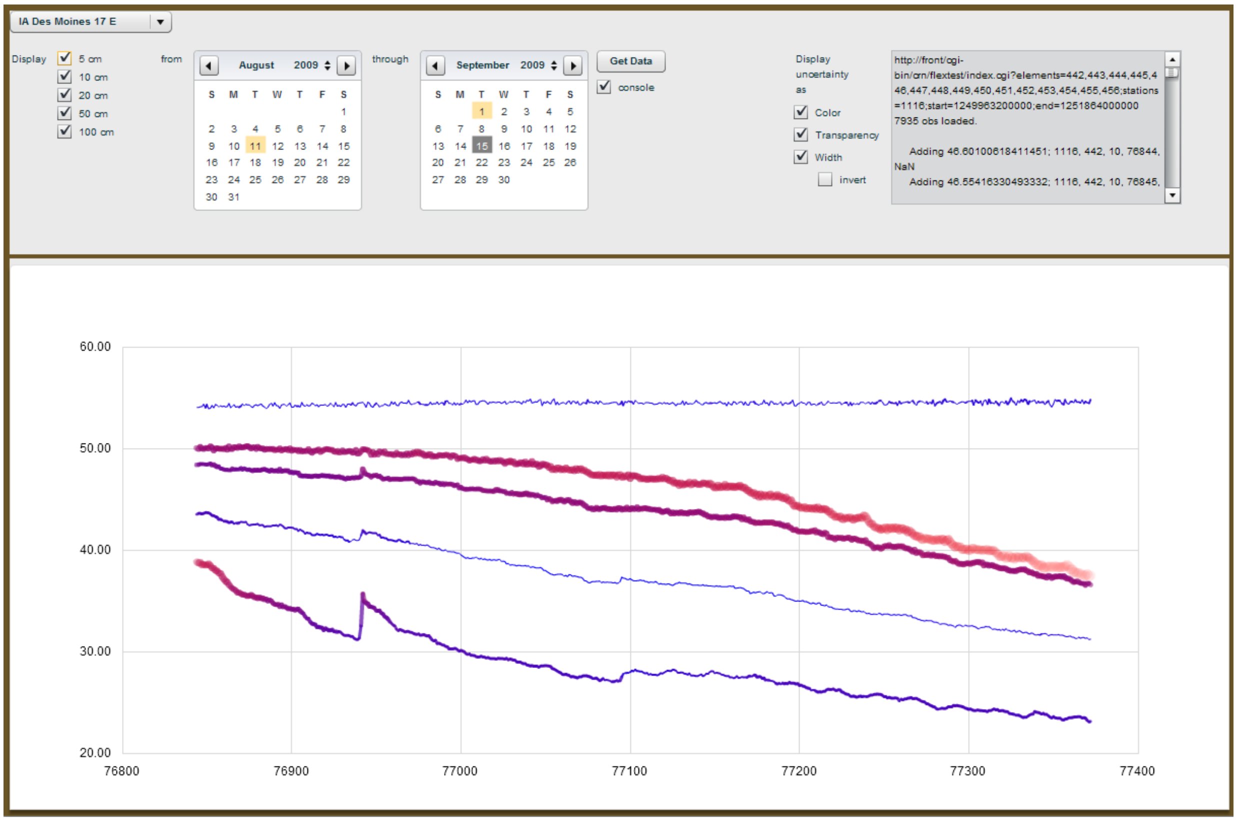


Figure 10. Using line thickness to visualize the range of individual soil moisture measurements that make up the mean layer values for the three-hole sample at the USCRN station at Des Moines, IA.

A major advantage to creating a data visualization infrastructure is the ease with which interactive visualizations can be created as needed. For example, when evaluating the step change component of soil moisture quality control system, it is useful to dynamically adjust step change thresholds and see which measurements fail to pass quality control by colorizing the data segments that fail the selected test threshold (Figure 11). The same infrastructure can be used for non-time series visualizations, such as data distributions by variable or station (not shown). Other useful features not discernable in a snapshot include mouse-over-triggered data, dynamic

[6] Mention of any particular brands of software does not constitute an endorsement by USCRN.

panning and zooming, and other features. These approaches show great promise, and the data handling approach used may be made compatible with existing visualization tools on the USCRN sensor pages.

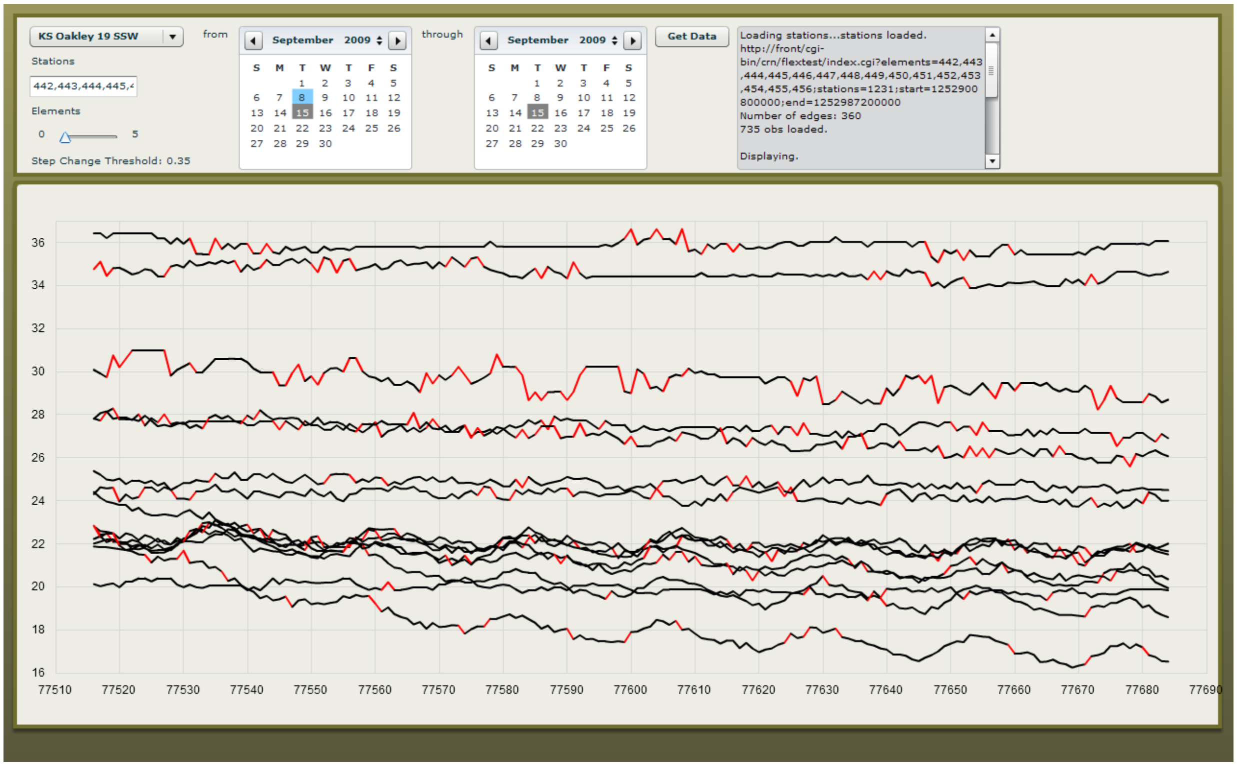


Figure 11. Applying a simple step change detection to all 15 soil moisture probe time series from the USCRN station at Oakley, Kansas. Red segments indicate step changes of larger magnitude than the threshold set by the user.

Work is ongoing on other methods of data visualization, including geographic map displays, and a type of diagram called a heat map. Heat maps are two dimensional representations of data that seem particularly well suited for displaying vertical slices of data over time, such as soil moisture evolution by layer and day of year as shown in Figure 12. The top portion of the figure displays soil moisture in volumetric water content using conventional line representation, while the bottom heat map uses color intensity to indicate the soil moisture (brown area) and soil temperature (green-red area) in the five layers of soil at Oakley, Kansas. The conventional representation is jumbled and hard to read, while the heat map shows clearly the impacts of rain events on soil moisture levels, and the daily temperature cycle penetrating soil layers. Visualizations like this one will be quite useful for displaying complex data to stakeholders and the public.

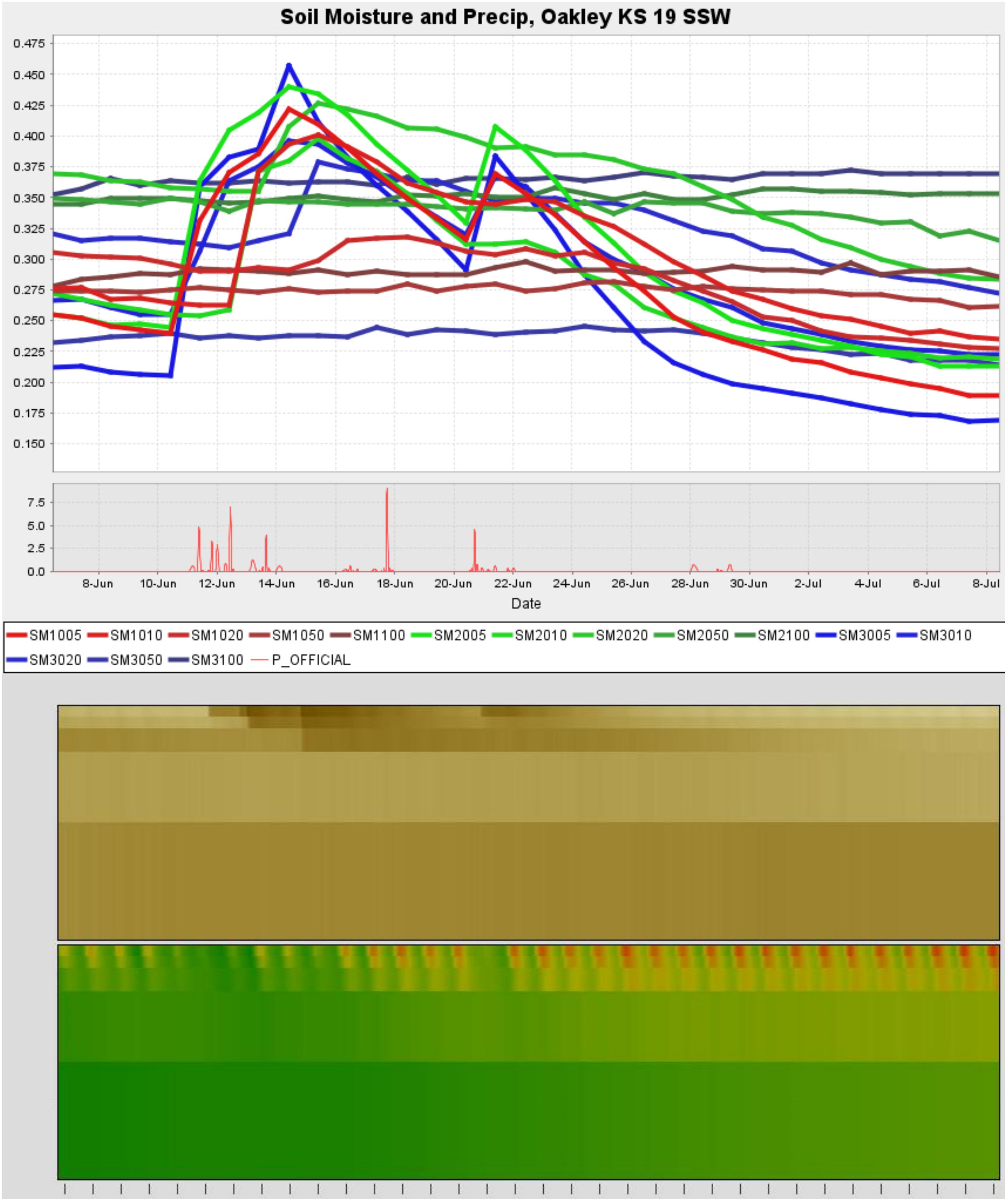


Figure 12. Visualization of soil moisture and soil temperature at Oakley, Kansas, using a heat map approach (lower panels) versus a time series approach (upper panel). The more moist the soil, the darker the brown color, while temperature ranges from green (cool) to red (warm).

5.4 Climate Science

After five years of data collection since commissioning, there is now a large enough set of USCRN observations to perform useful and insightful climate analyses. Foremost among these analyses is the calculation of national temperature, and the use of this new and independent measurement of temperature departures in the CONUS to confirm that existing time series based on the subset of the COOP network in the USHCN V2 is accurate despite having to undergo corrections for station and observation changes. Another active science area involves preparation for the use of USCRN observations in satellite calibration and validation studies. Many other science applications will also be pursued in coming years, some by USCRN personnel, but many by new external data users.

5.4.1 USCRN Climate Change Studies

Since USCRN stations were initially commissioned beginning in 2004, the network has grown from 40 stations distributed across the U.S. to the final plan number, with 100 stations observing a full year of data in 2008. While neither 40 nor 100 stations are a large number, statistical analyses of existing stations indicate that the continental U.S. annual air temperature average is well represented in either case, as long as the stations are well distributed at each stage of network deployment[7] Therefore, five useful years of annual continental U.S. air temperatures are available from the USCRN to compare to USHCN V2.

USCRN and USHCN V2 air temperature measurements cannot be directly compared in raw form, as air temperature is measured by an instrument aspirated by a fan in the case of USCRN, and by natural ventilation in USCRN V2. However, a highly significant regression relationship can be constructed between the two data types, and then used to generate a synthetic time series for the 1971-2000 normals period at the location of the USCRN sites. This time series can then be used to generate 30-year estimated air temperature normals for the USCRN stations[8]. Subtracting the estimated normals from the monthly USCRN air temperatures generates a time series of monthly air temperature departures from normal that are compatible with the predecessor observation technology used in constructing the USHCN V2, but with year-to-year changes that are independently measured.

The USCRN annual continental U.S. air temperature departures for 2004-2008 are extremely well aligned with those derived from the national USHCN V2 (Figure 13). For these five years, the USCRN explains 99.7% of the maximum temperature and 99.5% of the minimum temperature variance in the USHCN V2 annual air temperature departures, with a mean bias of -0.03°C for both maximum and minimum temperature. This finding provides independent verification that the homogenization adjustments made to the USHCN V2 data do not lead in the last five years of the record to a different result than one would derive from science-quality measurements taken at pristine locations.

---

[7] Vose, R.S., and M.J. Menne, 2004: A method to determine station density requirements for climate observing networks. *J. Climate*, **17**, 2961-2971.

[8] Sun, B., and T.C. Peterson, 2005: Estimating temperature normals for USCRN stations. *Int. J. Climatol.*, **25**, 1809-1817.

A variety of other science projects utilizing the USCRN data are underway, both internally at NCDC and ATDD, and also at stakeholder locations. USCRN Program personnel are strongly involved with users interested in using USCRN measurements in satellite calibration/validation studies. With the advent of soil moisture measurements, work on drought monitoring products has commenced. FY 2010 science work will take off from a strong starting point.

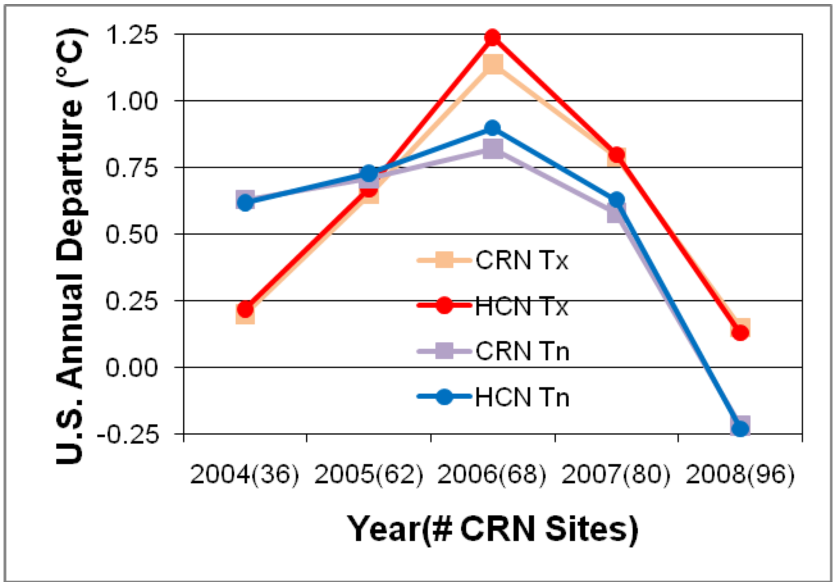


Figure 13. Comparison of the USHCN V2 and USCRN 2004-2008 continental U.S. annual air temperature departures from the 1971-2000 normal (°C). The number of USCRN stations available in each year is given in parentheses next to the year.

5.4.2 USCRN Participation in Satellite Calibration/Validation Efforts

The USCRN Program has been very active in working to provide information and data for satellite calibration/validation (cal/val) efforts, and planning to participate in several projects of this nature in FY10. Jeff Privette of NCDC's Remote Sensing Services Division is collaborating with the USCRN to study the representativeness of the downward infrared derived skin or surface temperature collected at USCRN sites to determine its utility for calibrating and validating surface temperatures measured by polar orbiting satellites. Jeff has also funded research by Boston University to use high resolution satellite imagery to estimate the homogeneity of land use around selected USCRN sites, which will have a more general application to all potential satellite cal/val users.

The onset of the collection of soil moisture and temperature data has engendered great interest in using the 5 cm level observations for satellite cal/val projects. The NASA Soil Moisture Active and Passive satellite program to fly in 2014 has already enlisted USCRN assistance, with Tim Wilson of ATDD attending the first cal/val workshop for SMAP, and Tim and Mike Palecki of NCDC attending the first SMAP applications workshop. The USCRN has been invited by Michael Cosh (US Department of Agriculture) and Thomas Jackson (National Aeronautics and Space Administration) to be participants in the first soil moisture test bed for SMAP, to be located in Oklahoma near the two USCRN stations in Stillwater. The utility of USCRN observations for enhancing satellite based Climate Data Records is high, and this type of activity is expected to expand in future years.

5.4.3 USCRN Science Outreach

Without personnel specifically oriented to outreach or education, the communication to potential user communities is largely accomplished through Web activities and attending science meetings. While most Web activities in FY 2009 have been devoted to rebuilding the underlying infrastructure of the Web site, improvement of content will be a key focus of FY 2010, including more data visualization capabilities and more reports on USCRN-based science. We will encourage the climate community to visit the Web site and use our data products through listserv messages and meeting attendance. At certain milestones, public outreach through NOAA press releases or news items may be suitable.

Engagement with our site hosts is also critical to our efforts, both to inform them about ongoing USCRN activities and to encourage continued diligence on their part regarding site stability and station health. Two newsletters for site hosts were released during FY 2009, but plans for more were curtailed by other priorities. It is the intent of the program to produce more newsletters in FY 2010, and also to design a process for a more personal form of communication annually that is customized to the individual station and includes a page of data summaries for the previous year.

5.5 Research Papers and Meeting Presentations in FY 2009

Soil Moisture and Soil Temperature Observations and Applications:
A Joint U.S. Climate Reference Network (USCRN) –
National Integrated Drought Information System (NIDIS) Workshop
Organizers Bruce Baker and Tilden Meyers, Oak Ridge, TN, March 2009.
Report posted on the National Integrated Drought Portal website at
<http://www.drought.gov/imageserver/NIDIS/workshops/crn/USCRN_SMST_workshop_summary.pdf>

USCRN personnel and partners made four workshop presentations:
Baker, C.B.: Soil moisture, soil temperature, and relative humidity measurements for USCRN.
Collins, W.: Preliminary results from ATDD's soil moisture/temperature testbed.
Meyers, T.: Temperature characterization of the Hydra II
Palecki, M.A.: The U.S. Climate Reference Network: current status.

Arguez, A., and J.H. Lawrimore, 2009: Perspectives on temperature trends and variability from the first U.S. Climate Reference Network stations. 21st Conference on Climate Variability and Change, American Meteorological Society, Phoenix, AZ, Jan 2009.

Diamond, H. J., 2009. The U.S. Global Climate Observing System (GCOS) Program: An update on continuing efforts to implement reference climate observation sites. 25th Conference on International Interactive Information and Processing Systems (IIPS) for Meteorology,

Oceanography, and Hydrology, American Meteorological Society, Phoenix, AZ, Jan 2009.

Groisman, P., and M. Palecki, 2009. Lessons learned from the operation of the United States Climate Reference Network at high elevations and/or severe environments. Mountains: energy, water, and food for life. The SHARE project: understanding the impacts of climate change, Milan, Italy, May 2009.

Groisman, P., and M. Palecki, 2009. Lessons learned from the operation of the United States Climate Reference Network at high elevations and/or severe environments (poster). Sixth International Scientific Conference on the Global Energy and Water Cycle, Melbourne, Australia, August 2009.

Menne, M.J., C.N. Williams, Jr., and M.A. Palecki. On the reliability of the U.S. surface temperature record. Journal of Geophysical Research (Atmospheres) (submitted).

Palecki, M.A., C.B. Baker, and H. Diamond, 2009: The U.S. Climate Reference Network in Alaska: experimental observations and deployment, 10th Conference on Polar Meteorology and Oceanography, American Meteorological Society, Madison, WI, May 2009.

Palecki, M.A., and M. Brewer, 2009: The U.S. Climate Reference Network: detecting climate change and monitoring drought. Annual Meeting, Association of American Geographers, Las Vegas, NV, March 2009.

Palecki, M.A., and M. Brewer, 2009: U.S. Climate Reference Network: Current Status and Future Directions (poster). Soil Moisture Active Passive Mission Applications Workshop, Washington, D.C., September 2009.

Palecki, M.A., and M.J. Menne, 2009: On the reliability of the surface temperature record Part 1. American Association of State Climatologists, Grand Rapids, MI, July 2009.

6. FY 2009 International Cooperation

6.1 The Canadian Climate Partnership and Technology Exchanges

The first nation to duplicate USCRN technology and practices was Canada. In August 2008, a Canadian RCS station was deployed at the USGS EROS Data Center in Sioux Falls, SD, which serves as one of the USCRN formal testing sites. It is anticipated that network transfer functions will be examined between the two networks starting in FY 2010. Such transfer function determinations between these two national nets would increase the geographic spatial area of homogeneous long-term climate observations over North America by more than100%. U.S./Canada discussions have included:

a. The role played by triple temperature and precipitation sensor configurations;

b. Processing multiple observations into single temperature and precipitation values using standardized algorithms;

c. Field lessons learned, such as experience in measuring solid precipitation;

d. Detecting, reporting, and tracking anomalous events for station maintenance;

e. Installation, maintenance, and inspection protocols;

f. Using the Internet to disseminate data and documentation; and

g. Quality control procedures.

Currently, the Canadian RCS has deployed the triple configuration at 303 sites and is in the beginning stages of implementing the USCRN precipitation algorithm.

A representative of Agriculture and Agri-Food Canada expressed interest in co-located soil moisture measurements in anticipation of the deployment of a soil moisture measurement network in Southern Canada. This possibility will be pursued during FY 2010.

6.2 The Global Climate Observing System (GCOS) Program and the USCRN

In addition to United States–Canada activities, USCRN stations have been selected for deployment in various environments on other continents where assistance in modernization is desired. Towards this end, two USCRN-technology stations outside the CONUS were configured to be GCOS-USCRN test stations (high-elevation and high precipitation environment stations). These two stations were deployed to two extreme Hawaiian environments as prototypes for possible future deployments in the Andes and in high-precipitation environments. Planning has continued on fielding a USCRN station configuration at the Russian Arctic climate station in Tiksi as part of the overall U.S./Russia climate bilateral agreement; currently, installation in Tiksi is still planned for the September 2009 timeframe.

In 2008, NCDC entered into a formal Memorandum of Understanding (MOU) with the Smithsonian Tropical Research Institute which, based on available funding, would allow the two agencies to collaborate in installing and maintaining up to 20 sites at STRI tropical research areas around the globe (see figure below) over the next 10 years. At a minimum, the USCRN program is investigating some preliminary site survey work for a possible initial installation of a USCRN station at the STRI site at the Luquillo Experimental Forest station in Puerto Rico.

7. USCRN Station Data

Historical meteorological and climatological observations are often compromised by non-standard equipment, incomplete records, poor sensor exposure or poor siting, observer discontinuities, and other related issues. The impact of these issues concerning historical data provenance, continuity, and general quality becomes more serious over time. Tremendous strides have been made in improving the utility of these historical data through the development of sophisticated statistical approaches for the homogenization of time series. However, a far better pathway for detecting future climate change is the establishment of an observation network that avoids these pitfalls through its design and maintenance.

These issues have been addressed in the design and fielding of the USCRN; and the foundation has been established towards generating high-confidence climate attributions from this network. With completion of the deployment phase and the collection of more than 8 years of data at some stations, we are reaching the point of being able to derive meaningful climate insights from this network. While a ten-year period-of-record is recommended for conservative applications of USCRN to the study of climate change at the national level, efforts made in FY 2009 to begin to link these new and relatively brief records to longstanding homogenized climate records for purposes of climate monitoring were successful, as discussed in Sec 5.4. USCRN stations are already serving as robust and stable platforms for monitoring extreme events. The inclusion of battery backup and in some cases solar panels has enabled USCRN stations to continue operating during severe weather conditions

7.1 Operations During Extreme Conditions

As an example of the robust nature of USCRN station engineering, one needs look no further than two ice storms that occurred in the United States during FY 2009. Around December 11-12, 2008, up to two inches of ice were deposited in New England, causing more than 1.4 million people to lose power, closing 300 state and local roads, and requiring a state of emergency to be declared over much of the region. Central Massachusetts and southern New Hampshire were especially hard hit. Despite these events, though, the two Durham, NH, USCRN stations experienced no data losses, and recorded precipitation through the subfreezing portions of the event (Figure 14). Since Durham hosts a pair of USCRN stations, it was interesting to note the high correlation of measurements taken during the event.

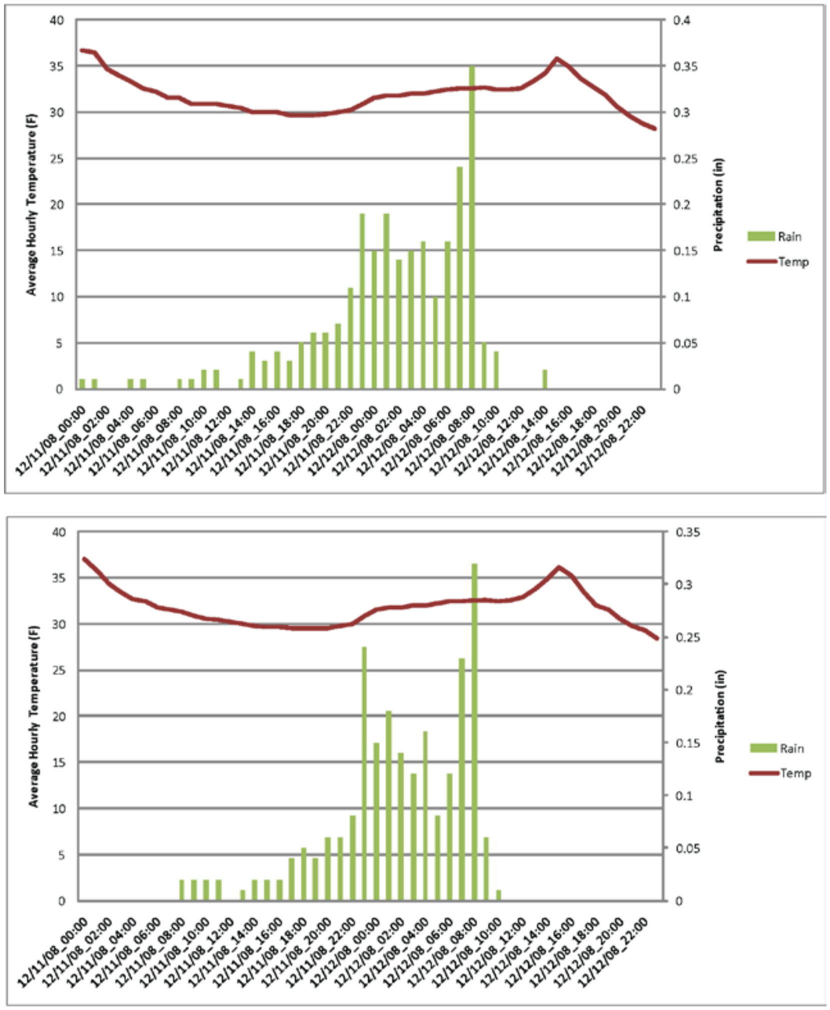


Figure 14. Hourly air temperature and precipitation at Durham, NH, during the major ice storm in the Northeast, Dec 11-12, 2008.

A highly unusual level of warmth scorched the Northwest during late July 2009. While the numbers are not particularly large from the perspective of the overall USCRN network, it was still a very unusual event to find temperatures soaring above 100°F in places where the high temperature is usually in the 80s. The Coos Bay, OR, site was the only network location completely under a maritime influence, and its maximum temperatures did not reach in the mid-70s, even as all around reached record warmth (Figure 15).

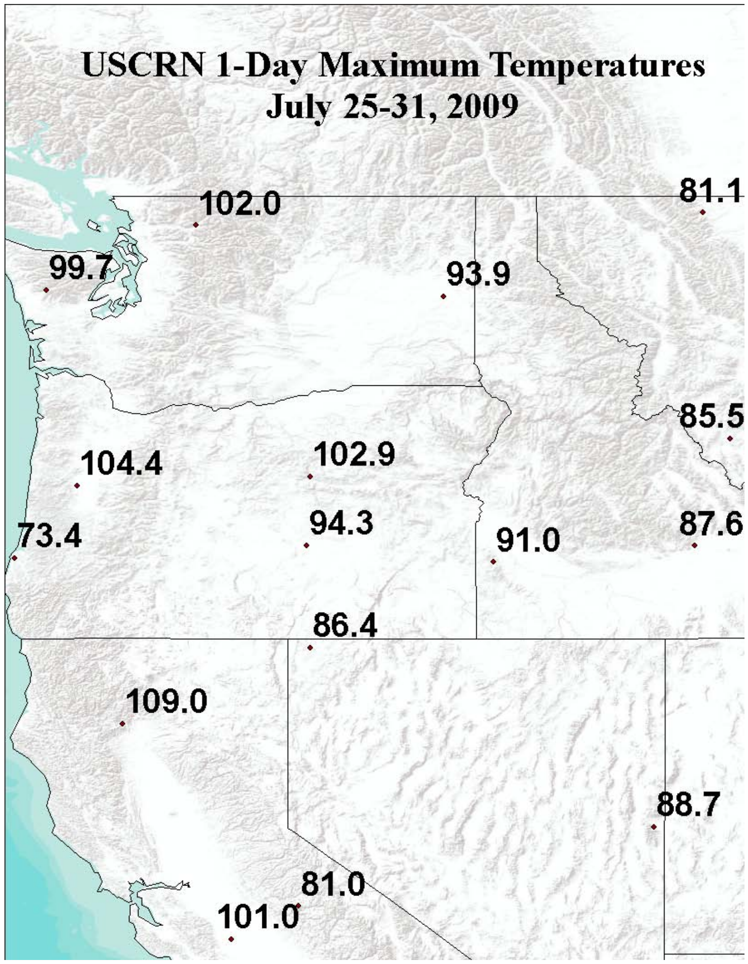


Figure 15. Single day maximum temperatures at USCRN stations during the late July 2009 heat wave in the Pacific Northwest (°F).

7.2 Defining the Ranges of Parameter Records: The Present USCRN Network Records and Ranges

Despite the short period-of-record of the USCRN network, records of various parameters from this network are of interest because of their high confidence levels, the known calibrations of the sensors, and the precision measurement ranges of the various sensors.

The network has already recorded some significant events and it will record more and more varied events in the future, so this early collection of records should be considered only the first part of a dynamic tale.

Variables indicated as records in Table 3 and Table 5 are records measured by stations of the USCRN network only.

TABLE 3
USCRN TEMPERATURE RECORDS (°F)

Highest Air Temperature = 126°F
Stovepipe Wells, CA; July 5, 2007

Lowest Air Temperature = --57°F
Barrow, AK; February 3, 2006

Highest Ground Surface Temperature = 162°F
Stovepipe Wells, CA; June 24, 2006

Lowest Ground Surface Temperature = -58°F
Barrow, AK; February 3, 2006

TABLE 4
USCRN MAXIMUM & MINIMUM TEMPERATURE DURATION STREAKS (DAYS)

Maximum Temperature Durations: Stovepipe Wells, Death Valley, CA

120°F:	**8 Days**	**July 13 – 20, 2005**
110°F:	**32 Days**	**June 13 – July 14, 2007**
100°F:	**98 Days**	**June 9 – September 14, 2007**
95°F:	**126 Days**	**May 30 – October 2, 2008**
90°F:	**132 Days**	**May 12 – September 20, 2005**

Minimum Temperature Durations, Barrow, AK

-50°F:	**2 Days**	**February 3 – 4, 2006**
-30°F:	**11 Days**	**January 8 – 18, 2008**
0°F:	**67 Days**	**January 8 – March 15, 2005**
<32°F:	**234 Days**	**October 12, 2006 – June 2, 2007**

TABLE 5
USCRN PRECIPITATION RECORDS (INCHES)
(November 2000 – September 2009)

Greatest 5-minute:	**0.73”**	**Titusville, FL**	**Jul 7, 2006**
	0.73”	**Lander, WY**	**Jul 25, 2007**
Greatest 15-minute:	**1.89”**	**Titusville, FL**	**Jul 7, 2006**
Greatest 30-minute:	**3.08”**	**Titusville, FL**	**Jul 7, 2006**
Greatest 60-minute:	**3.77”**	**Titusville, FL**	**Jul 7, 2006**
Greatest 24-hour:	**19.64”**	**Hilo, HI**	**Feb 1-2, 2008**
Greatest 1-Day:	**17.83”**	**Hilo, HI**	**Feb 2, 2008**
Greatest 5-Day:	**42.23”**	**Hilo, HI**	**Feb 1 – 5, 2008**
Greatest 7-Day:	**46.86”**	**Hilo, HI**	**Jan 30 – Feb 5, 2008**
Greatest 30-Day:	**63.46”**	**Hilo, HI**	**Jan 16 – Feb 14, 2008**
Greatest 365-Day:	**184.90”**	**Quinault, WA**	**Oct 1, 2006 – Sep 30, 2007**

Note: The Quinault 2007 water year record is 52.21” greater than the 37-year mean water year total of 132.69” from the Ranger Station site one mile to the SSW. The greatest water year record total for the Quinault area is 186.22” set during the 1972 water year (Oct 1, 1971 – September 30, 1972).

8. USCRN Documentation Access: Selected Internet Addresses by Topic

The USCRN Team is aware of and sensitive to the multi-functional, multi-level composition of the climate science community that accesses and uses the USCRN Web pages. As a result, the USCRN Web pages will be revised in 2009-2010 in an effort to conform to as many of the suggestions and needs of the user community as possible. This is an iterative process, that is, the USCRN Team is learning continuously and attempting to satisfy the climate science community needs as they are made known, and as resources allow. This gradual improvement process should match needs with data and with resources. It is most practical to acknowledge that this process will continue as it is not yet at a fully satisfactory level for all possible users.

New applications and products will be forthcoming in the years to come. Because of these changes, there will be some changes in Web addresses for familiar products and Web pages. Therefore, it is suggested that users go to the main level and utilize the new navigation bars to find what is needed.

USCRN Home: <http://www.ncdc.noaa.gov/oa/climate/uscrn/>

USCRN Program Documents (in 5 primary document classes):
<http://www.ncdc.noaa.gov/crn/programoverview.html>

USCRN Performance Measures, derivation, and progress are explained in the USCRN Annual Reports Series, particularly starting in FY 2003/2004:
<http://www.ncdc.noaa.gov/crn/programdocs.html>

USCRN Program Development Plan, Functional Requirements, and Configuration Management Documents are at:
<http://www.ncdc.noaa.gov/crn/programdocs.html>

USCRN annual reports can be found at:
<http://www.ncdc.noaa.gov/crn/programdocs.html>

USCRN Site Information Handbook and Station Commissioning Plan are at:
<http://www.ncdc.noaa.gov/crn/programdocs.html>

USCRN Field Maintenance Plan (also in the Configuration Management Series):
<http://www.ncdc.noaa.gov/crn/programdocs.html>

CRN detailed documentation on metadata, data processing, instrument monitoring, data documentation, and station installation/maintenance can also be found at:
<http://www.ncdc.noaa.gov/crn/docs.html>

The USCRN site data website is under constant revision with new additions as new sites are added and as new metadata is received and posted. The USCRN active maintenance page, which is referenced at this site, has restricted access as some information in that area involves active maintenance, housekeeping, and monitoring. Information on the other areas is, however, available here:
<http://www.ncdc.noaa.gov/crn/sites.html>

Detailed data and documentation about USCRN site hardware, sensors, and calibration hardware can be found at:
<http://www.ncdc.noaa.gov/crn/instrdoc>

The USCRN science pages were not vigorously developed during the Deployment Phase of the USCRN. As the period-of-record of stations is now approaching scientifically useful lengths, this page is of a priority for community inputs and exchanges as well as for internal exchanges and postings. The information is available at:
<http://www.ncdc.noaa.gov/crn/instrdoc>

The most direct way to access the data from the USCRN stations is to go directly to:
<http://www.ncdc.noaa.gov/crn/hourly>

USCRN data and their metadata are also available from a number of sources:
All elements and metadata:
NCDC Customer Services (NCDC.Orders@noaa.gov)
USCRN Monitoring website (<http://www.ncdc.noaa.gov/oa/climate/uscrn/>)
Hourly temperature, precipitation, solar radiation, surface temperature:
USCRN ftp site (historical and near-real time)
<ftp://ftp.ncdc.noaa.gov/pub/data/uscrn/products/hourly01>

9. FY 2000-2009 Summary

The USCRN has been completed in the CONUS for one year, but is still a very young network. Resources are now being devoted to improve quality control, data systems, and the Web site, making the observations more available and useful to stakeholders. Three major start-up activities commenced simultaneously during FY 2009. The USCRN Science project will lead the continuing development of data and analysis products and visualizations. The USCRN in Alaska will complete the vision of deploying a network of climate-science-quality stations in Alaska at the same resolution as they exist in the CONUS. The NIDIS sponsored expansion of the USCRN to include soil moisture and soil temperature probes and relative humidity measurements will lead to increased visibility of the network as a source for information with which to monitor drought. The trajectory of the USCRN Program is still in the ascendancy.

10. FY 2010 Planned Activities and Goals

Research and engineering development activities envisioned for FY 2010 focus and resources include:

- Maintaining the long term integrity of the USCRN stations in the field through improvements to site stability oversight, regularized outreach to site hosts, and completion of a monitoring and warning system for station health.
- Maintaining the long term integrity of the USCRN observations by enhancing data quality control and rewriting data processing software systems with an internally consistent and modular architecture.
- Completing the development of a new Web site, updating and expanding old content and providing easy access to data products and visualizations.
- Producing new climate information products, climate analyses, and scientific content for USCRN stakeholders, especially emphasizing the needs of drought monitoring.
- Promoting the use of USCRN data through publications, presentations at conferences, and Internet-based outreach.
- Continuing to promote the USCRN model for climate reference station design through bilateral and international contacts.
- Building on the success of the Russian Arctic USCRN installation in Tiksi, some consideration will be given to a second Russian station in Yakutsk which is a unique cold weather station from an extremes standpoint. Installation of stations in Russia can be problematic, but the possibility has been factored into FY 2010 planning.
- Taking the opportunity to possibly install a USCRN station at the observatory in Blue Hill, MA; this site has a long and storied climate record, and would mesh well with the goals of the USCRN program.

Acronyms and Abbreviations

AMV	Annual Maintenance Visit
ASOS	Automated Surface Observing System
ATDD	Atmospheric Turbulence and Diffusion Division
°C	Degree Celsius
CCSP	Climate Change Science Program
CIMO	Commission for Instruments and Methods of Observation
CM	Configuration Management
CONUS	Continental United States
COOP	Cooperative Observation
CPC	Climate Prediction Center
DA	Double Alter
DCS	Data Collection System
DFIR	Double Fence Intercomparison Reference
EROS	Earth Resources Observation Systems
°F	Degree Fahrenheit
GCOS	Global Climate Observing System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GHCN-D	Global Historical Climatology Network Daily
GOES	Geostationary Operational Environmental Satellite
HCN-M	Historical Climatology Network Modernization
IPCC	Intergovernmental Panel on Climate Change
LCD	Local Climatological Data
LDAS	Land Data Assimilation System
MaWS	Monitoring and Warning System
MOU	Memorandum of Understanding
MTBF	Mean Time Between Failures
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRCS	National Resources Conservation Service
NWS	National Weather Service
PDA	Personal Digital Assistant
PM	Performance Measure
RAWS	Remote Automated Weather Station
RCS	Canadian Reference Climate System
RH	Relative Humidity
RI	Rainfall Intensity
SCAN	USDA/NRCS Soil Climate Analysis Network
SDFIR	Small Double Fence Intercomparison Reference
SNOTEL	USDA/NRCS Snowpack Telemetry System
SM	Soil Moisture

ST	Soil Temperature
STRI	Smithsonian Tropical Research Institute
SURFRAD	NOAA Surface Radiation Budget Network
TB	Tipping Bucket
USCRN	United States Climate Reference Network
USDA	U.S. Department of Agriculture
USDP	U.S. Drought Portal
USGS	U.S. Geological Survey
WCDMP	World Climate Data and Monitoring Program
WMO	World Meteorological Organization