US Climate Reference Network

Annual Report for Fiscal Year 2012

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the National Oceanic and Atmospheric Administration
October 2012

Cover Photo:
View of Mt. McKinley from the plane transporting the Alaska site survey team to locations in and near Denali National Park during August 2012 (photo credit: Rocky Bilotta).

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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 and for Their Many Contributions During FY12:

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Preface and Introduction
The year 2012 marks the end of the first decade of observations undertaken by the U.S. Climate Reference Network (USCRN) under the auspices of NOAA's National Climatic Data Center and Atmospheric Turbulence and Diffusion Division. The network consists of 114 sites across the conterminous 48 states, with additional sites in Alaska and Hawaii. Stations are installed in open (where possible), rural locations very likely to have stable land cover/use conditions for several decades to come.

At each site a suite of meteorological parameters are monitored, including triple redundancy for the primary temperature and precipitation variables, and for soil moisture/temperature. Instrumentation is regularly calibrated to National Institute for Standards and Technology (NIST) standards and maintained by a staff of expert engineers. This attention to detail in USCRN is intended to ensure the creation of an unimpeachable record of changes in surface climate over the United States for decades to come. Data are made available without restriction for all public, private, and government use. This section describes the rationale for the USCRN, its implementation, and some of the highlights of the first decade of operations.

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. Scientifically acceptable observations for climate analyses include: (1) operational weather observations when appropriate care in collection and archival methodologies has been exercised to establish sufficiently high accuracy for climate purposes; (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 well-recognized and scientifically acceptable climate proxies which are non-instrumental but nevertheless sufficiently controlled as to ensure numerical high-precision values that are scientifically valid.

The USCRN continues to fulfill this need for obtaining long-term sustainable and robust climate observations that are necessary to document long-term climate change trends for the United States. Beginning in 2009, the USCRN effort in the U.S. began expanding into the State of Alaska, and operating this climate observing network in an Arctic environment presents some unique challenges. There are currently a total of 5 commissioned USCRN stations in Alaska, with an eventual goal of having 29 commissioned stations by 2018. Operating an automated climate quality observing network in a harsh and remote environment that exist at many sites in Alaska presents some unique problems related to station power, access to the station, and continued transmission of data.

One critical use of these observations is as an independent data source to verify the existing U.S. temperature record derived from networks corrected for non-homogenous histories. Future directions for the network are also discussed, including the applicability of USCRN approaches for networks monitoring climate at scales from regional to global. Constructive feedback from end-users will allow for continued improvement of USCRN in the future and ensure that it continues to meet stakeholder requirements for precise climate measurements.

Highlights for FY2012

(1) Commissioning a New USCRN Component System

In 2011, NCDC implemented a sustained soil and relative humidity monitoring program in the USCRN to improve understanding of drought through sub-surface observations of soil moisture and temperature. The addition of relative humidity (RH) measurements complement the existing above surface drought related measurements of ambient temperature, IR (skin) temperature, wind, solar radiation, and precipitation. In 2012, NCDC completed the settling period for the new soil-moisture and soil-temperature probes at all 114 USCRN sites in the conterminous United States. As a result, the USCRN now provides the continuous monitoring of soil conditions across the conterminous United States, and has recently begun expanding the installation of those soil sensors at the current total of 12 stations in Alaska.

(2) Fine-Tuning the USCRN Precipitation Calculation Algorithm

To improve precipitation calculations, NCDC conducted a lengthy analysis of the currently deployed pairwise comparison approach to calculating a single best precipitation value from each USCRN station's triplicate measurements. This analysis revealed some ways to improve the current calculation technique, leading NCDC to develop a new method. This new approach provides a more straightforward accounting based on the 5-minute changes in precipitation depth that improves precipitation totals available to the public for both climate change monitoring and day-to-day applications.

(3) **Refining Quality Control for USCRN Soil-Moisture and Soil-Temperature Measurements**

To assure the quality of USCRN soil-moisture and soil-temperature observations, NCDC now combines basic real-time quality control with more sophisticated post-processing. The post-processing system identifies sensors that are noisier than others at the same depth, or that significantly deviate in response to environmental forcing like rain events, thereby detecting and flagging values that were out of feasible range. However, other longer-term indications of poor sensor performance are now taken into account. The new method allows any faulty behavior in any of the three sensors in each USCRN station to be identified by system experts who can place the instrument on a list that will flag all its values until it can be replaced.

(4) **A new approach to Alaska USCRN Station Design and Power Systems**

In response to the great challenges of the climate of Tetlin National Wildlife Refuge near Tok, one of the coldest places in North America, this station is fundamentally different in two ways. First, to power a station during winter in a very cold and dark climate with insufficient wind resources, a methanol fuel cell was utilized for the first time by the USCRN Program. This system produces power when a catalyst causes methanol and water to react, yielding free electrons. The free electrons are directed into wires and supply a current to the attached systems. Since the system also produces some residual heat, it will help to keep storage batteries warmer and more efficient in the extreme winter cold. During the spring, summer, and fall seasons, the station will be powered predominantly by solar tube panels, which are also a new technology for USCRN and are more effective in diffuse cloudy environments like at Tetlin, receiving light from all angles, even bouncing up off a snow surface.

Second, the station is equipped with dual dataloggers, transmitters, air temperature instrument sets, and wetness sensors. These secondary instruments and all the primary instrument observations are preserved on both dataloggers and sent using dual transmitters. Usually, these single points of failure on USCRN stations are responded to immediately by maintenance engineers, but in a number of the sites selected in Alaska for installation, access will be virtually impossible during the winter months. Therefore, if the primary data logger or transmitter or temperature instrument stack fails, secondary instruments will still be reporting even if the failed primary set cannot be serviced immediately.

(5) USCRN Data Management Plan Posted.

In line with recommendations from NOAA’s Science Advisory Board's Data Archive and Access Requirements Working Group (DAARWG), a data management plan documenting how USCRN transmits, receives, and archives its data was completed and posted on the USCRN web site’s documentation section at http://www.ncdc.noaa.gov/crn/docs.htm.

The remainder of the report will cover the following areas:

- Operational Highlights in Alaska
- Projects to Improve Data Processing, Monitoring, Data Access, and Product Quality
- USCRN Science and Development Programs
- Field and Testbed Activities
- Monitoring Activity Highlights
- Plans for FY 2013

FY 2012 Operational Highlights in Alaska

Site Surveys – Two site survey trips were completed this summer visiting 34 potential site locations and completing 15 detailed site surveys at seven grid locations and Kodiak Island in Alaska (Figure 1).

Site Licenses Signed – Site license agreements were completed for three Alaskan sites in FY 2012.

Stations Installed – One partially installed station was completed (Gustavus) and two new stations (Metlakatla and King Salmon) were installed in Alaska in FY 2012.

Stations Commissioned - One station (Tok) was commissioned in Alaska in FY 2012.

In addition to the two stations installed in FY 2012 at Katmai National Park (King Salmon) and on Annette Island at a National Weather Service office (Metlakatla), seven more sites have been selected for future installations, with three sites already licensed (Selawik NWR, Nowitna NWR, & Glennallen BLM). Licenses are pending from the Eyak Corporation in Cordova, State of Alaska Department of Natural Resources in Deadhorse, and State of Alaska Department of Transportation for sites at Summit (near Denali) and Yakutat. Five more grid target areas were explored in FY 2012, with site surveys completed in far northeast Alaska on Barter Island, on the Alaska North Slope at Ivotuk Airstrip and Toolik Lake Research Station, northeast of Fairbanks near Central and Circle, and in the central Alaska Peninsula near Mother Goose Lake. Site surveys were also completed on Kodiak Island, outside of the current grid but a location of interest to this program. Additional surveys were completed near Fairbanks, AK in collaboration with the National Ecological Observatory Network (NEON) and near Denali, AK in collaboration with Denali National Park. The surveys conducted near Denali may yield a replacement for Summit on the selected sites list, due to difficulties associated with licensing that site.

Surveys have now been completed in 23 grids of the 29 grid network in Alaska (Figure 1). The project expects that the final 6 remaining grids, located in western and southwestern Alaska, will be completed by FY 2015. Issues with site surveying, site licensing, and site engineering and installation have all proven to be more complex in Alaska, and some delays have been encountered, especially when funding levels are not known until very late in the fiscal year, as happened in FY 2012. Lessons learned each year increase the speed of the processing of site approvals and site licenses. This improvement, along with engineering and logistics experiences gained, will allow for station installation to continue on pace in FY 2013, assuming funding arrives in a timely manner.

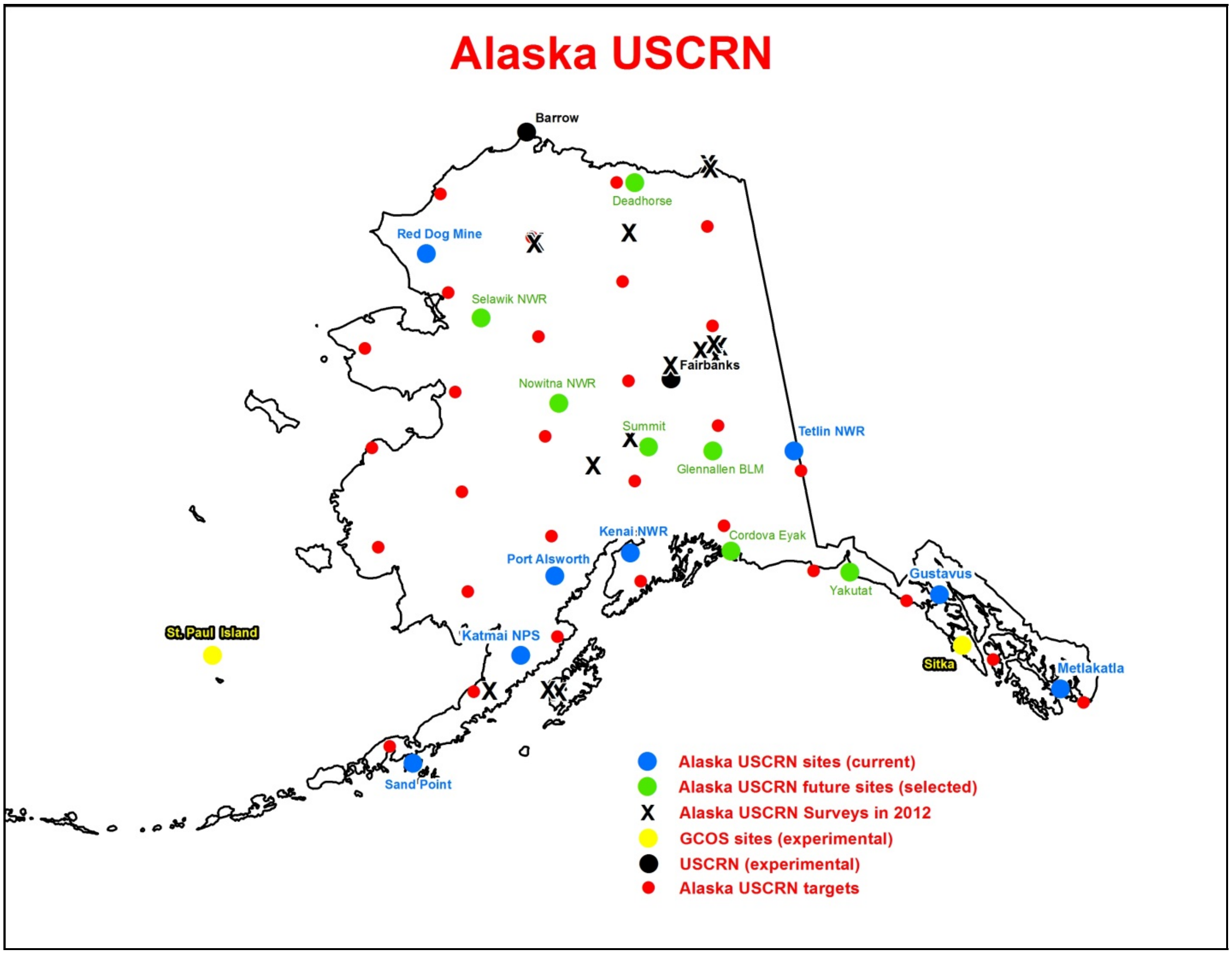


Fig 1. The map of USCRN grids (centered on the red dots), along with existing and planned USCRN sites.

Table 1. USCRN in Alaska Reduction in Climate Uncertainty

FY	Sites Commissioned	Temperature Confidence	Precipitation Confidence
2010	2	59.0%	58.9%
2011	4	62.9%	62.7%
2012	5	64.4%	64.2%

Table 2. USCRN Data Receipt Rates (%)

		Within 30 days	As of Oct 1, 2012
2012	Q1	99.8	99.8
	Q2	99.7	100.0
	Q3	99.8	99.8
	Q4	99.8	100.0
	Total	99.8	99.9

Table 3. FY 2012 USCRN in Alaska Station Status

Station	Licensed	Installed	Commissioned
Sand Point (USGS)	02/12/2009	08/21/2009	09/07/2010
Port Alsworth (Lake Clark NPS)	09/09/2009	09/25/2009	09/07/2010
Red Dog Mine (NANA Regional Corp.)	07/13/2010	08/25/2010	09/12/2011
Kenai (Kenai NWR)	07/13/2010	08/30/2010	09/12/2011
Tok (Tetlin NWR)	07/13/2010	09/26/2011	09/26/2012
Gustavus (near Glacier Bay NP)	06/27/2011	07/20/2012*	FY 2013
Metlakatla (Annette Island WSO)	03/27/2012	07/26/2012	FY 2013
King Salmon (Katmai NP)	06/20/2011	08/17/2012	FY 2013
Selawik (Selawik NWR)	05/29/2012	TBD	TBD
Nowitna (Nowitna NWR)	05/29/2012	TBD	TBD
Glennallen (BLM)	06/11/2012	TBD	TBD
Cordova (Eyak Corp.)	Pending	TBD	TBD
Deadhorse (Dept. of Natural Resources)	Pending	TBD	TBD
Summit (AK DOT)	Pending	TBD	TBD
Yakutat (AK DOT)	Pending	TBD	TBD

*Installation began in 09/2011, completed on 07/20/2012.

Projects to Improve Data Processing, Monitoring, Data Access, and Product Quality

The USCRN developer staff took on many tasks to improve data processing, station monitoring, data access, and product quality in FY 2012. These included creating an efficient system for reprocessing raw data and calculated values, improving the quality control process, and incorporating new 5-minute observations. Also accomplished was an expansion of the USCRN shared code base, a common set of software packages used across all areas of the program. Further enhancements to the Station Monitoring and Reporting Tool (SMART) were made in response to feedback from ATDD engineers and quality control specialists. The transition from the station Anomaly Tracking System (ATS) from NESDIS headquarters to NCDC was completed and several USCRN products began displaying soil moisture and soil temperature values from the USCRN database.

Data Ingest and Processing

Enhanced climate observations: Although temperature, precipitation and relative humidity observations have been previously summarized on 5-minute timescales, it was not until FY 2012 that datalogger and ingest capacity improved to the point that other elements could be collected on this temporal scale. To meet growing user requirements for high resolution observations of other USCRN elements, changes to the ingest, quality control, and database systems were made to accommodate the higher rate of measurement. With these enhancements, 5-minute observations of 5 cm soil moisture/temperature, surface IR temperature, solar radiation, and 1.5m wind speed are now being collected, archived, and made available to users. The climate quality 5-minute soil observations now provided by USCRN will be especially valuable to the satellite community for validation of satellite systems such as NASA's Soil Moisture Active Passive (SMAP) mission, and weather and climate models with land components.

Additional modifications to the ingest software system were made to accommodate the introduction of dual stream transmissions that began with installations at Tok and Gustavus, Alaska. As described in Highlight 4, these systems operate in remote environments that are difficult to reach when equipment outages occur during the winter season. To better ensure uninterrupted observations, the USCRN program established the capacity to operate primary and backup instrumentation and transmitters. As part of this effort to build in an extra layer of redundancy for these remote stations, ingest streams were developed and configured to capture both primary and backup instrument readings in two separate transmissions. The new data display with 5-minute temperature observations collected from the primary and secondary sensors at Tok, Alaska, is shown in Figure 2.

AK Tok 70 SE
FWS, Tetlin National Wildlife Refuge (Seaton Roadhouse site)
Period of record Sep 23 2011 — Sep 15 2012

AK Tok 70 SE - FWS, Tetlin National Wildlife Refuge (Seaton Roadhouse site)

Temperature (°C)

	Sensor #1	Sensor #2	Sensor #3	Secondary Sensor #1	Secondary Sensor #2	Secondary Sensor #3	Calculated
09:05	2.1	2.1	2.1	2.2	2.2	2.2	2.1
09:10	2.4	2.4	2.4	2.5	2.5	2.4	2.4
09:15	2.6	2.6	2.6	2.7	2.7	2.7	2.6
09:20	2.8	2.8	2.7	2.8	2.8	2.8	2.8
09:25	3.1	3.1	3.1	3.1	3.1	3.1	3.1
09:30	3.3	3.3	3.3	3.3	3.3	3.3	3.3
09:35	3.6	3.6	3.6	3.7	3.7	3.6	3.6
09:40	4.0	4.0	4.0	4.0	4.0	4.0	4.0
09:45	4.2	4.2	4.2	4.2	4.2	4.2	4.2
09:50	4.3	4.3	4.3	4.4	4.4	4.4	4.3

Fig. 2. 5-minute temperature observations collected from the primary and secondary sensors at Tok, Alaska on September 14, 2012.

Reprocessing raw and calculated CRN data: Another major success in FY 2012 was the development of software that greatly reduces resources required for reprocessing raw USCRN data. This may involve reprocessing the full USCRN period of record or smaller amounts of data, such as a specific time period and/or station, to flag measurements retroactively after discovering a sensor had been malfunctioning or for correcting values after correcting a software bug. Reprocessing is important for ensuring data consistency as the ingest software is improved and enhanced over time. The process involves re-ingesting the raw datalogger records, those that were received via satellite transmission and those collected on personal digital assistants (PDAs) during station visits, and replacing the values currently stored in the USCRN database with values processed by the most current version of the USCRN ingest software. Reprocessing the period of record was previously a cumbersome and time-consuming process. This software reduces active developer time spent on reprocessing, allowing it to occur on a more frequent and regular schedule.

In addition, on a semi regular basis it is necessary to reprocess calculated USCRN values to address issues such as algorithm improvements, missing values due to transmission interruptions, or software updates. System enhancements were made to drastically reduce the required processing time of this function as well. In so doing it reduced developer effort from several hours to a simple one-click command. The reprocessing software can now be applied to specified date ranges, specified stations and specific elements (e.g., precipitation, temperature, and/or soil moisture). The process also can now be initiated to recalculate all existing calculated values or to only fill in calculated values where they are currently missing. This software has already been used for filling in missing precipitation data resulting from temporary transmission interruptions, and missing soil data from observations prior to incorporation of soil calculations in the ingest software.

Shared Code Base and Database server: Developers made numerous updates to the shared Java code base in FY 2012. More tools are now available for decimal math so software development can move away from performing floating-point calculations in all USCRN software. In addition substantial development endeavors resulted in improved software and database performance. As the size of the USCRN dataset continues to grow, queries become unwieldy requiring enhancements to improve the efficiency of ingest and access tools. Through time the team noted slowed performance on inserting observations into the database each hour. This was addressed by creating new batch inserts within the shared code base, which resulted in a much faster ingest process.

When the USCRN shared database server became heavily loaded by other non-USCRN processes, a large cross-divisional collaborative initiative was undertaken to migrate to newer, faster hardware. This transition resulted in marked improvement which was noted by ATDD engineers accessing system information via the USCRN web reports. As resources permitted, older web reports were redesigned to take advantage of caching capabilities provided by the shared code base, and the website's data source pooling was modernized as older technology became obsolete.

Quality Control Improvements: Enhancements to the USCRN quality control process were made through the addition of a sensor report software package and companion graphing program to aid visual inspection of sensor data as shown in Figure 3. This software uses a variety of statistical checks to identify sensors for placement on a “bad sensor list” and validates sensors previously placed on the bad sensor list. A monthly report of the statistical summaries are automatically generated and emailed to the USCRN science team for expert evaluation using the companion graphing program. Also included is an easy-to-use system for USCRN scientists to update the “bad sensor list” without developer intervention, so that quality flags can be automatically applied to sensor values that are suspect or erroneous. This list is currently used for soil sensors, but can be used for any type of sensor.

In addition soil moisture/soil temperature quality control processes and calculations were fully integrated into the USCRN ingest software system. Calculations now include volumetric water content for individual probes, volumetric layer averages, and temperature layer averages for both 5-minute and hourly measurements. A new “frozen soil” flag was added as an additional quality control check for soil moisture values.

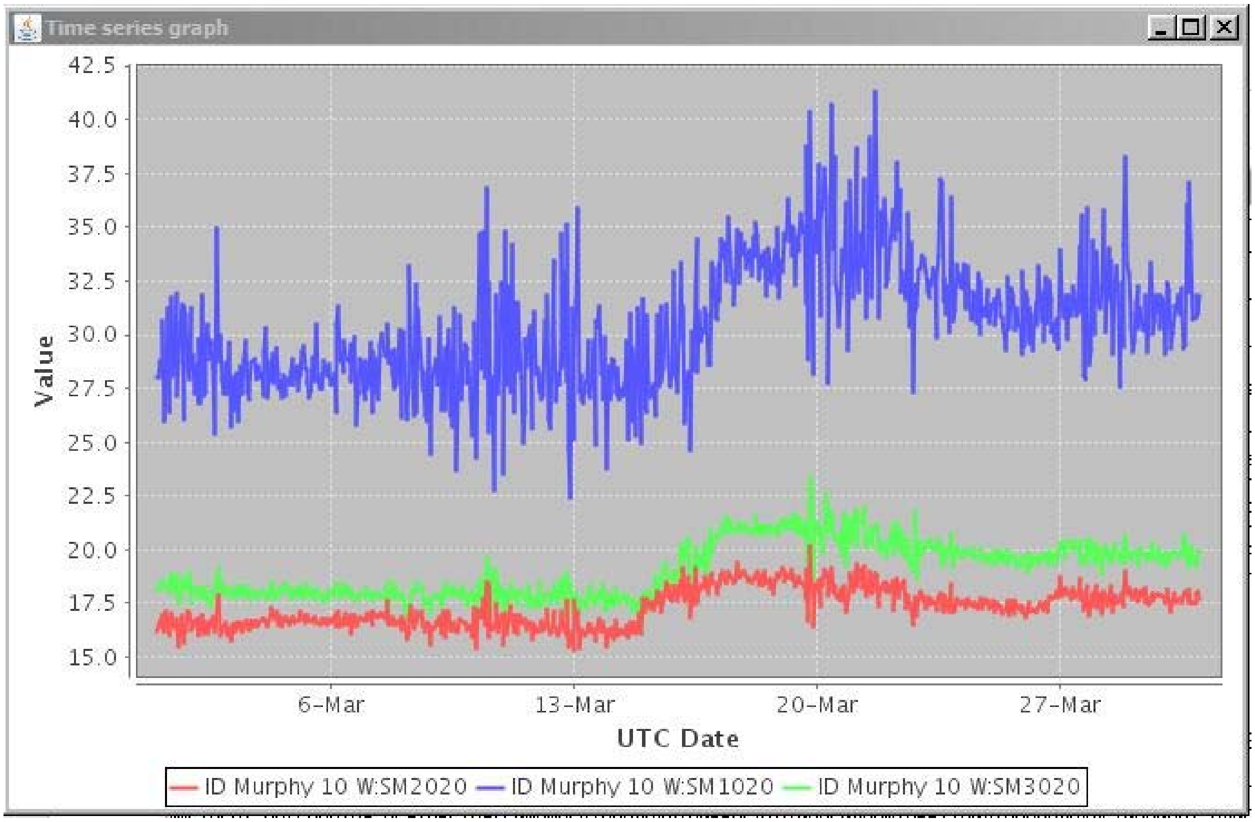


Fig. 3. An easy-to-use graphing tool that can quickly generate plots of sensor values is now available to USCRN scientists and quality control specialists as aids for detecting instrument malfunctions and data quality problems. The three time series of volumetric water content at 20 cm depth can be used to identify a sensor (sensor 1; blue line) that has malfunctioned.

<u>Station Monitoring and Products</u>

FTP Products: In 2009 the USCRN program introduced products containing hourly and daily observations for distribution via ftp and over the Global Telecommunications System (GTS). With the introduction of soil monitoring instrumentation, a soils product was later added. These products have continued to be extremely popular because of easy access via ftp and global transmission over the GTS. Improvements to these products were made in FY 2012 to incorporate soil moisture and soil temperature values directly from the USCRN database. These values were originally limited to the soils product and were calculated by the product's software suite. With these changes the values are calculated, quality controlled, and stored in the database by the USCRN Ingest system, using the newest algorithms available. This change allows the three products to display the same data uniformly and more efficiently compared to the past approach.

SMART: Several improvements were made to USCRN's Station Monitoring and Reporting Tool (SMART) during the past year. SMART took over the functionality that was originally provided by USCRN's legacy Perl ingest system. The new functions include producing flag emails that are sent directly to each engineer and quality control scientist automatically each hour.

Improvements to email reports also included a phase out of plain text and replacement with html and links that take engineers from the email message directly to online sensor pages where technical issues can be more quickly evaluated. Other improvements include the addition of Geonor precipitation gauge reports as a separate product to provide early indications when any precipitation gauge nears capacity. Early indications of gauge totals give ATDD engineers time to contact site hosts who volunteer to empty gauges before they overflow. Timely response is especially important as major extratropical or tropical storms approach. While these two functions were being added, the SMART software system was restructured to improve uptime and performance. As a result SMART system uptime exceeded 99% in FY 2012. Taken together these changes led to better efficiency, more rapid identification of instrument outages, decreased maintenance requirements and lower resource consumption.

Anomaly Tracking System: Changes to the USCRN web-based Anomaly Tracking System (ATS) were also made in FY12. This system is used to record, communicate, and track anomalies that occur at USCRN sites in association with equipment malfunctions or other events that create data integrity concerns. Quality control specialists and engineers enter tickets as system anomalies occur, and the steps taken in response to the problem are logged by ATDD engineers until the problem is fully resolved. This serves as a mechanism for permanently documenting the problem and for ensuring seamless communication from the time problems are identified until resolution. Until 2012 the system was hosted at NESDIS headquarters. As this support to the USCRN program came to an end, NCDC developed the capacity to maintain an Anomaly Tracking System within NCDC's Service Desk application. It fulfills the same role as the previous system, allowing engineers to communicate and resolve problems, but with a greater number of features and more responsive support. In addition the system requires CAC card authentication for ticket entry and meets all NOAA IT security requirements.

USCRN Science and Development Programs

Algorithm Development

Precipitation is a USCRN core observation, yet concerns have been raised regarding the quantity of precipitation calculated across the network. Extensive studies of shielding were conducted in the mid-2000s, with the Small Double Fence Intercomparison Reference (SDFIR) shield combined with a heated throat weighing bucket gauge verified as a good system for catching both liquid and solid hydrometeors. Therefore, attention turned to the algorithm finalized in 2006 to convert inputs from three measurements of bucket depth and a wetness sensor to calculated precipitation totals for 5-minute intervals. Anecdotal evidence indicated that the algorithm was at times too strict in requiring agreements between independent depth measurements and could indeed be partially responsible for real undercatch as precipitation was calculated.

Fortunately, retaining the original depth measurements allows previous years' data to be reprocessed with improved precipitation algorithms as they are developed. Starting in 2011 and proceeding through all of 2012, methods were explored that used the redundant depth data in a different way than the original pairwise comparison method. Instead, all three sets of depths were characterized by the agreement of their changes from one time step to the next, with each change time series weighted according to their agreement. This new approach is called the weighted average quality assurance, or wAvgQA method. The new method has been thoroughly tested for liquid precipitation situations, and that portion of the algorithm is complete. However, testing is ongoing for recovering frozen precipitation liquid water equivalents more accurately, even in challenging situations when the wetness sensor is not working well. It is expected that the complete algorithm will be finalized during FY 2013, and submitted as a change request for adoption by the USCRN Configuration Control Board and also as a manuscript to the AMS Journal of Atmospheric and Oceanic Technology:

> Leeper, R. D., Palecki, M. and Davis, E. U.S. Climate Reference Network implementation of a new precipitation quality assurance method for weighing bucket gauges with three redundant depth measurements.

An example of the improvement gained in implementing the new precipitation algorithm is shown in Fig. 4. On 6 September 2012, a heavy band of precipitation passed over the NC Durham 11 W USCRN station. Sub-hourly calculations of precipitation from wAvgQA (Fig 4., in blue) show the new precipitation algorithm was better able to detect the onset of precipitation for this event compared to the current algorithm (labeled Database, in red). The main reason for the smaller precipitation total calculated by the current algorithm was a period of evaporation before the precipitation causing the reference level for the start of precipitation (a two hour average) to be higher than the actual gauge level when precipitation started. The gauge must start increasing in depth before the difference between the current depth and the reference depth is determined by the algorithm to be precipitation. The new wAvgQA algorithm does not have this weakness, and produced a much more complete precipitation total, as independently verified by the tipping bucket gauge (59.2 mm for the same period). More importantly, the precipitation is more accurately distributed throughout the rain event by the new wAvgQA algorithm, instead of matching the late and abrupt launch of the precipitation event by the current algorithm. With the current algorithm, the beginning 5-minute period reflects the accumulation of precipitation during a number of 5-minute periods until there was enough accumulation to exceed the incorrect reference level.

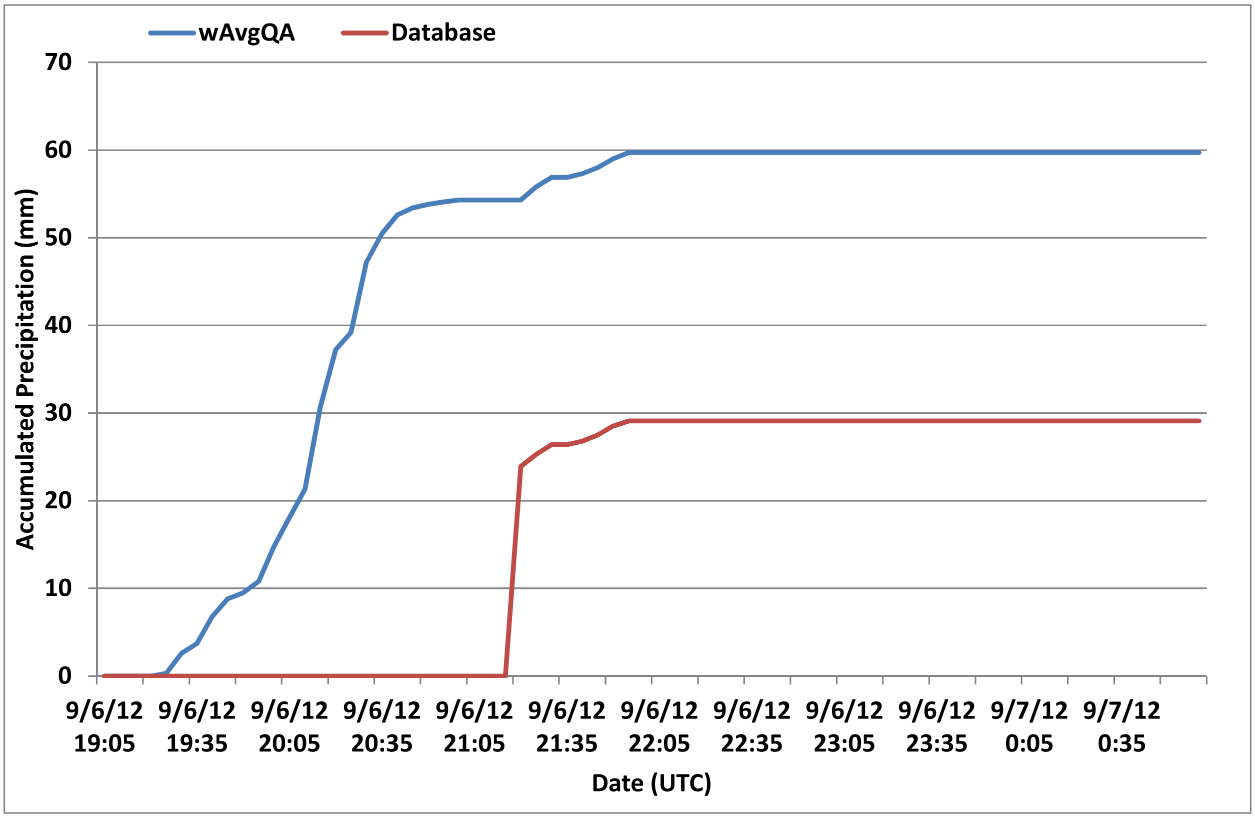


Fig.4. Accumulated precipitation totals during a rain event at the NC Durham 11 W USCRN station on 6 September 2012: the new wAvgQA algorithm for calculating precipitation (blue) compared to the current precipitation algorithm for calculating the precipitation in the Database (red).

Approximately two person-years of effort have been applied to this issue, given the tremendous importance of precipitation to the USCRN mission. It is not guaranteed that this will be the final word on USCRN precipitation, as several weaknesses in the observing system have been identified during this analysis that will need to be addressed, especially the low temperature performance of the wetness sensor, and the lack of good approaches for detecting a malfunctioning wetness sensor. There are also issues with the pre-wetness sensor precipitation data that will not be addressed in this new algorithm, which will be applied only to post-wetness sensor 5-minute precipitation observations. Still, going forward, this new precipitation algorithm will be a substantial improvement for USCRN precipitation calculation.

Research Projects and Papers

Soil Moisture

Bell J.E., M.A. Palecki, W.G. Collins, J.H. Lawrimore, R.D. Leeper, M.E. Hall, J. Kochendorfer, T.P. Meyers, T. Wilson, C.B Baker, H.J. Diamond, 2013: U.S. Climate Reference Network Soil Moisture and Temperature Observations. *J. Hydrometeorol*, doi: 10.1175/JHM-D-12-0146.1.

The stations in the USCRN were designed to be extensible to other missions, and the National Integrated Drought Information System (NIDIS) program determined that the USCRN could be augmented to provide more drought relevant observations. To increase the network's capability of monitoring soil processes and drought, soil observations were added to USCRN instrumentation. In 2011, the USCRN team completed at each USCRN station in the conterminous United States the installation of triplicate configuration soil moisture and soil temperature probes at 5 standards depths (5,10,20,50, and 100 cm) as prescribed by the World Meteorological Organization; in addition, the project included the installation of a relative humidity sensor at each of the station. Work is also underway to eventually install soil sensors at the expanding USCRN stations in Alaska.

This article provides a technical description of the USCRN soil observations in the context of U.S. soil climate measurement efforts, and demonstrates the advantage of the triple-redundancy approach applied by the USCRN to soil moisture and temperature measurements, allowing for improved measurement consistency and continuity. Figure 5 shows how one soil moisture time series divergent from two others is a good indicator of incorrect measurements at the outlier.

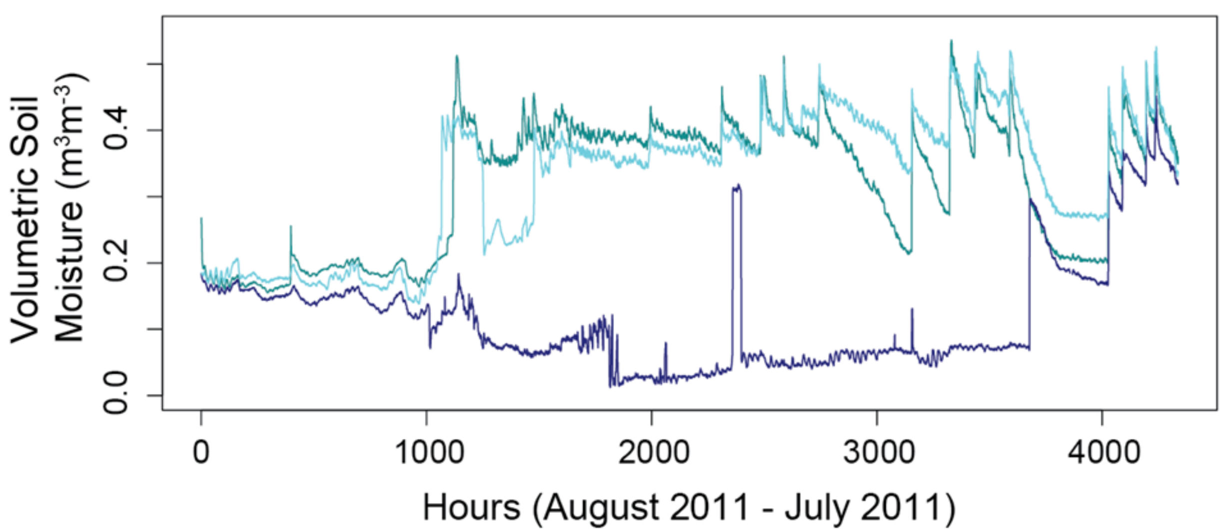


Fig. 5. USCRN triplicate redundancy allow for quick identification of a faulty sensor (dark blue) at the NE Lincoln 8 ENE.

Palecki, M.A., and J.E. Bell, 2013: U.S. Climate Reference Network Soil Moisture Observations with Triple Redundancy: Measurement Variability. *Vadose Zone Journal*. Accepted for publication.

In addition to sensor failure, the triplicate design of USCRN soil probes have allowed for an initial characterization of variability of soil moisture measurements. Nationwide analysis of soil moisture during early-to-mid growing season in 2011 and 2012 was performed to examine the differences in response to the widespread drought of 2012. The redundancy of the network helps retain the continuity of the record over time, and also provides key insights into the variations of measurements at a single location that are related to a combination of installation effects and the impacts of soil differences at the local level. This article highlights the usefulness of deploying triplicate configurations of soil probes for detecting faulty sensors and for better understanding the nature of soil moisture measurement variability.

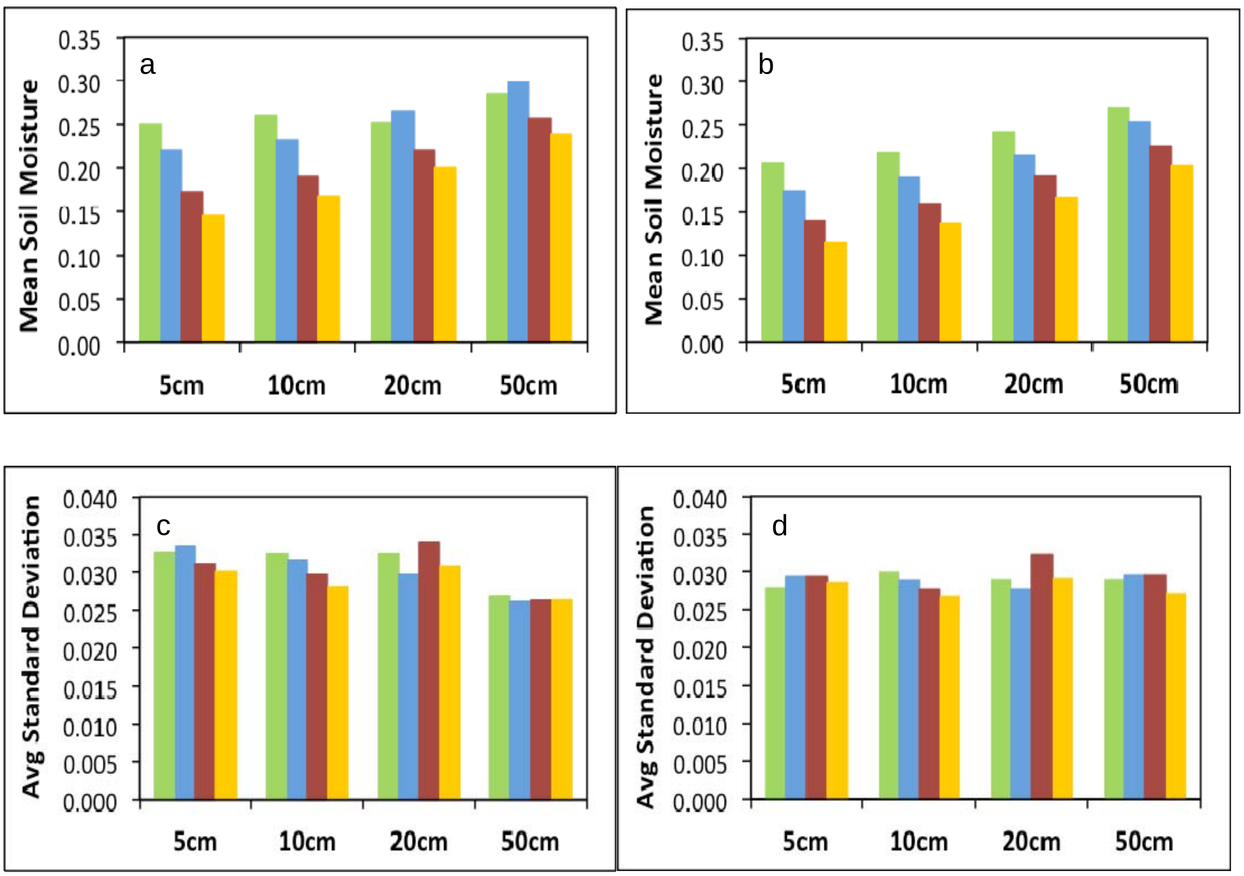


Fig 6. USCRN network-wide mean monthly soil moisture (m^3m^{-3}) for: (a) 2011 and (b) 2012. USCRN network-wide monthly average of the hourly standard deviation of three independent measurements of soil moisture (m^3m^{-3}) for: (c) 2011 and (d) 2012. The bars in each group from left to right represent April (green), May (blue), June (red), and July (orange).

Temperature and Precipitation

Palecki, M.A. U.S. Climate Reference Network temperature record: an initial examination. Preprint for AMS 24th Conference on Climate Variability and Change (4 p.). [Basis for journal article in near future].

One of the most important applications of USCRN temperature data to date has been its use in examining the reliability of the U.S. temperature record. Using a segment from 2004 to 2008 of USCRN station temperatures from which an estimated normal had been removed, a national temperature departure from normal was calculated. These departures from normal were then compared to national departures for the standard United States temperature data set, the U.S. Historical Climatology Network (USHCN) Version 2. USHCN Version 2 consists of more than 1200 historical climate stations with varying levels of consistency that have been quality controlled and homogenized for the express purpose of looking at climate trends . The comparison showed a nearly one-to-one correspondence between the USCRN and USHCN annual temperature departures from 2004 to 2008. This confirms that the statistical methods used to correct and homogenize the USHCN did a great job in the modern era, lending credibility to the performance of these methods during the pre-USCRN period, too.

A first difference approach allows a similar comparison to be done with a short base period, such as 2006-2010, applied to both sets of stations and averaged over the conterminous U.S. There is no interdependence of results, as there is when USHCN Version 2 data are used to estimate USCRN normal. Over the period from 2005-2011, a very high degree of correlation exists between first differences of USCRN and USHCN Version 2 conterminous averages of maximum and minimum temperatures, both for the annual temperatures as expected, but also for monthly temperatures. Figs. 7a and b show the latest annual updates for this relationship, with an R^2 = 0.99 for minimum temperatures and R^2 =0.98 for maximum temperatures. Even when reducing the comparison to a single month, the relationship strength still exceeds an R^2 =0.99, and also clearly demonstrated that July 2012 was the warmest month on record for both USCRN and USHCN Version 2 (Fig. 8).

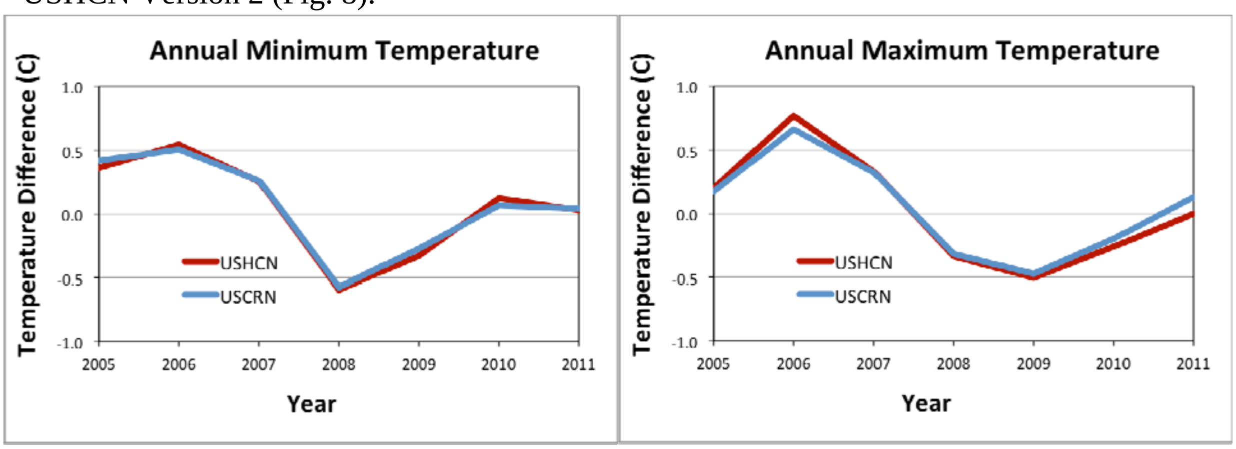


Fig. 7. Comparison of conterminous U.S. annual temperature differences from the base period 2006-2010 for USCRN and USHCN v2: a) minimum temperature, b) maximum temperature.

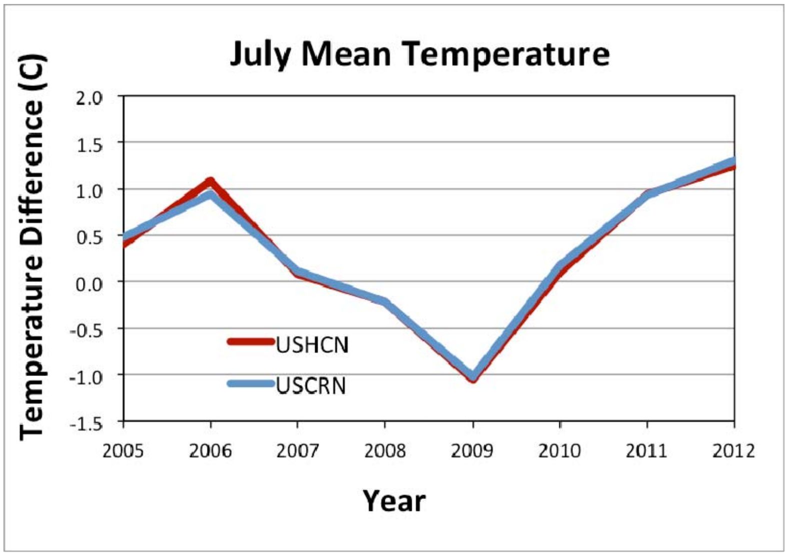


Fig. 8. Comparison of conterminous U.S. July mean temperature differences from the base period 2006-2010 for USCRN and USHCN v2. July 2012 was the all-time warmest month for the conterminous U.S. for both networks.

Leeper, R.D., and M.A. Palecki. Impact of network design on daily temperature and precipitation and their application: USCRN and COOP. 20th Conference on Applied Climatology [Basis for journal article in near future].

As the USCRN begins to take on more climate related activates, such as active participation in the monthly and annual climate monitoring of the U.S., differences between U.S. Cooperative Observer Program (COOP) and USCRN network design and the role of network architecture on observational differences will become increasingly relevant. Therefore, it is important to study the differences between USCRN and COOP temperature and precipitation observations, and discern the reasons for these differences. To limit the role of local biases (land use/land cover and nearby landscape) on reported network differences, selected station pairs collocated within 500 meters were used in this study. In addition, the impact of network design on commonly used indices such as growing season, heating and cooling degrees days, palmer drought index, and fire danger index will also be explored. Network design leads to some systematic biases between collocated station pairs and underscores the importance of sensor redundancy and instrumentation shielding to observation quality.

For example, it is difficult if not impossible to directly compare daily COOP station averages and totals to USCRN observations at many locations, even if one uses the stated observation time as the day boundary for USCRN. Scatter plots of COOP and USCRN daily and event precipitation totals for the recent record at ID Murphy 10 W show marked differences (Figs. 9a and b). At first glance, COOP and USCRN daily precipitation observations were not well correlated. However, by accumulating consecutive days of precipitation with dry days on either side (event-based totals) and then comparing these totals to USCRN totals over the same period, it becomes clear that station observations are well correlated when time of observation errors are removed. Only then can precipitation amounts be compared, and indeed the USCRN sites do catch more precipitation for most events.

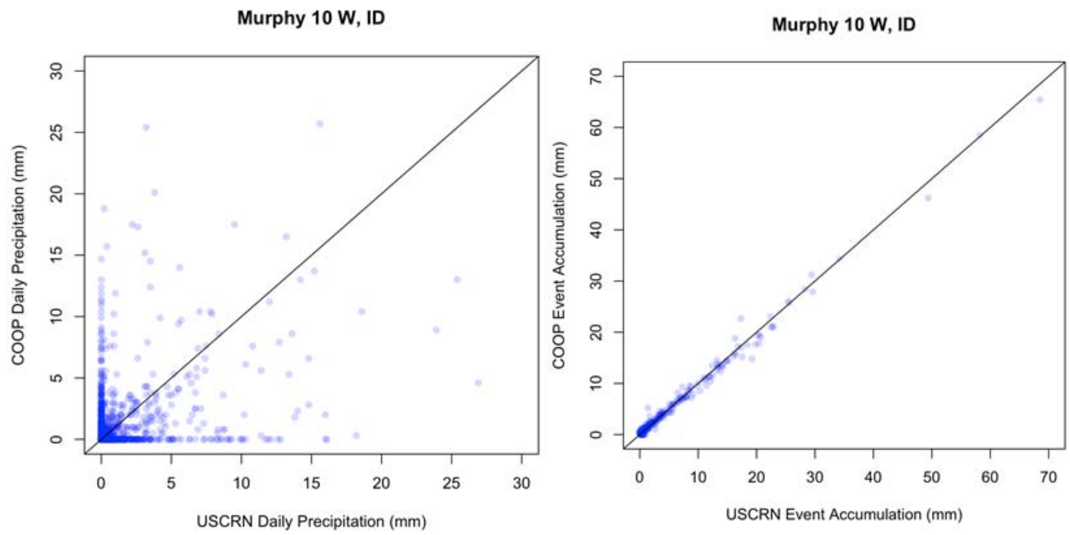


Fig. 9. Scatter plots of COOP and USCRN daily (a) and event wise (b) precipitation totals for the period of record since 5-min precipitation has been observed (May 2006) at ID Murphy 10 W.

Bilotta, R.G., E. Shepherd, A. Arguez, and J.E. Bell. Changes in air-freezing index and frost depth between two climate thirty-year periods. Currently under revision.

The air-freezing index (AFI) represents the cumulative amount of heat removed from the near-surface zone during the cold season. The way in which it is calculated represents the portion of the cold wave penetrating the ground and establishing the depth of frost. The distribution of AFI values over time is commonly used in construction industries to provide a climatological estimate of the depth of frost likely to occur in worst case, 100-yr return intervals. This establishes the depth to which road bases or building foundation must penetrate in order to avoid frost heaving.

In examining the changes in the conterminous U.S. values for the Air Freezing Index (AFI) and its 100-yr return interval from 1951-1980 to the current normal period 1981-2010, the AFI was also calculated for the 114 USCRN sites in the nation for 2005-2010. The national values for each winter were a simple average of the AFI for each station across the U.S. (Fig. 10), and show a strong relationship to AFI derived from several thousand normals stations, R^2 =0.92.
The project is currently being revised to improve the fit of the curves representing 100-yr and other return intervals. Eventually, year-to-year estimate of frost depth based on AFI will be compared directly to the frost measured by USCRN soil probes.

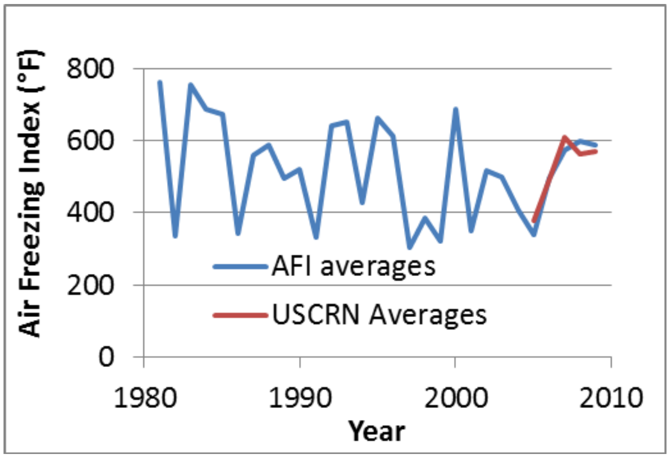


Fig. 10. Accumulated Air Freezing Index calculated for each winter from 1981-2010 for 2,385 climate normal stations (blue) and from 2005-2010 for 144 USCRN stations (red).

Field and Testbed Activities

Marshall Field, Colorado

The Marshall solid precipitation testbed was operational throughout the winter of 2011/2012, with numerous weighing gauges in several different types of shields running continuously throughout the winter. While the winter was drier than normal, several significant (> 2 mm) snowfall events occurred, and the pattern of catch efficiency generally correlated well with previous years. Routine monitoring of the site required to confirm that all of the sensors were working as expected was performed throughout the winter, with small issues being addressed mainly by National Center for Atmospheric Research (NCAR) staff as they arose. The 2011/2012 winter was designated the official "pre-SPICE" study period, with special focus given to selection of the reference precipitation measurements to be used in the World Meteorological Organization Solid Precipitation Intercomparison Experiment (WMO-SPICE). Because of this, analysis in preparation for the WMO pre-SPICE workshop held in Boulder, CO June 11-15, 2012, focused on potential reference gauge/shield combinations and on the algorithm used to estimate the reference precipitation rate.

One new type of instrument deployed to measure snowfall was the Campbell Scientific SR-50 acoustic sensor. This instrument measures the distance between the snow surface on a measuring board and the acoustic sounder, and subtracting the zero snow distance and accounting for several issues, the snow depth can be determined. Using a time series of snow depth change over time and adjustments for temperature, liquid water equivalence, compaction, and other processes, the snowfall over time can be estimated. Figure 11 displays an example of the relationship of manual measurements to automated snowfall measurements at a collaborative site at Fort Collins, CO. High degrees of accuracy can be achieved, which provides the proof-of-concept for adding snow sensors to USCRN sites at some point when new resources are identified and available.

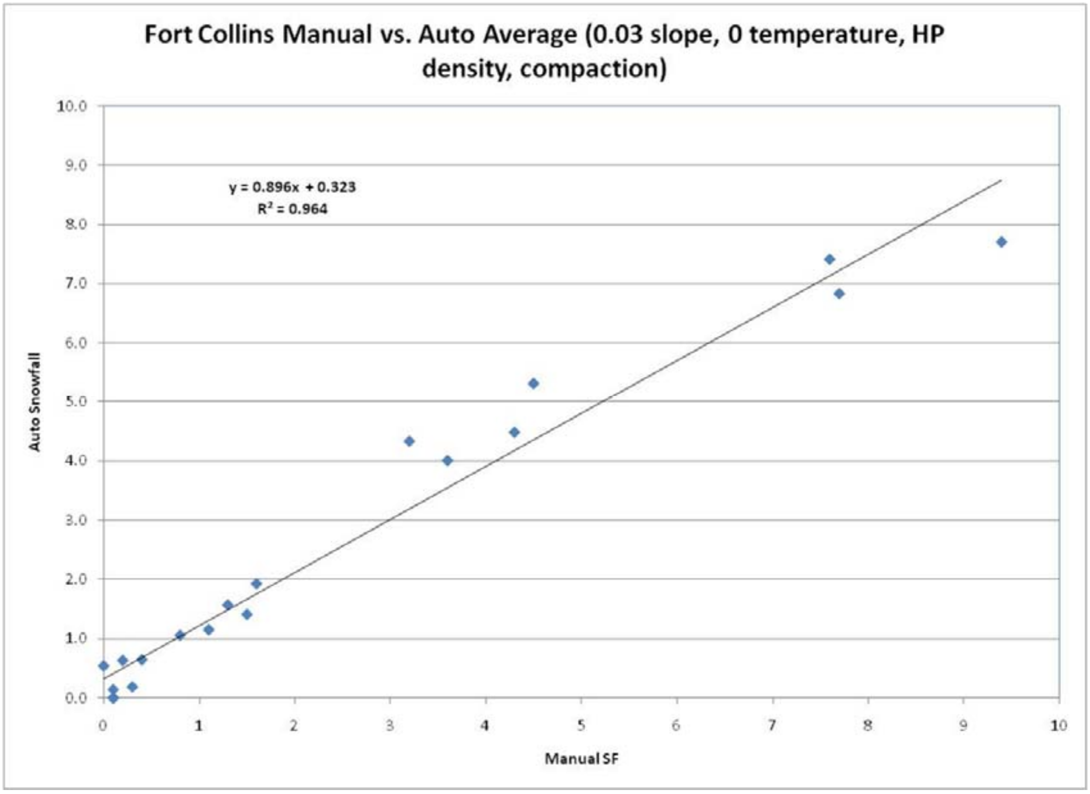


Fig. 11. Measurements of snowfall taken manually and using the Campbell Scientific SR-50 acoustic sensors. The strong correlation between the two types of measurements provides confidence that with further development automated technologies can be used in the future to reliably measure snowfall.

Oak Ridge, TN

Instruments tests were ongoing at the Oak Ridge facilities during FY 2012. One of the more important new technologies examined was the Acclima soil moisture and temperature probe. It has been determined that the Stephens Water Hydra II Probe used currently by USCRN Program has some difficulties in measuring soil moisture accurately in soils that are very saline or cation enriched clays. The Stevens' probe operates at 50 MHz, while the Acclima Digital Time Domain Transmissometry probe operates at 70 MHz and tends not to be as sensitive to clays and salts. Initial side-by-side comparisons (Figure 12) show that results in normal loamy soils are very similar for both probe types, although the Acclima dries more quickly. Unfortunately, the Acclima requires more disruption of the soil strata to put in place below the surface, so it is being considered as a replacement now only in places where the Steven's probe does not work.

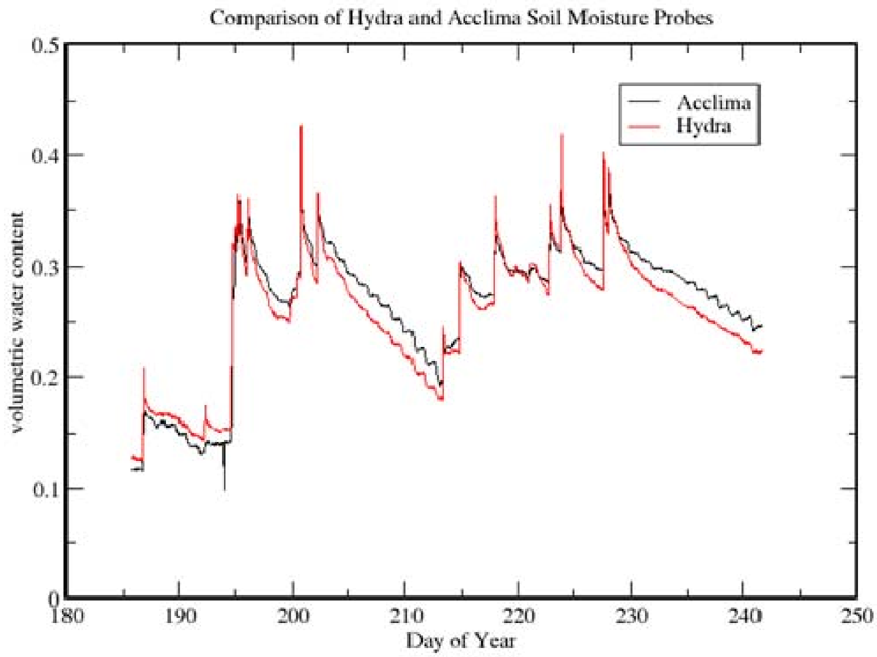


Fig. 12. A comparison of volumetric water content (m^3m^{-3}) for adjacent locations at Oak Ridge instrumented with Stevens and Acclima soil moisture probes.

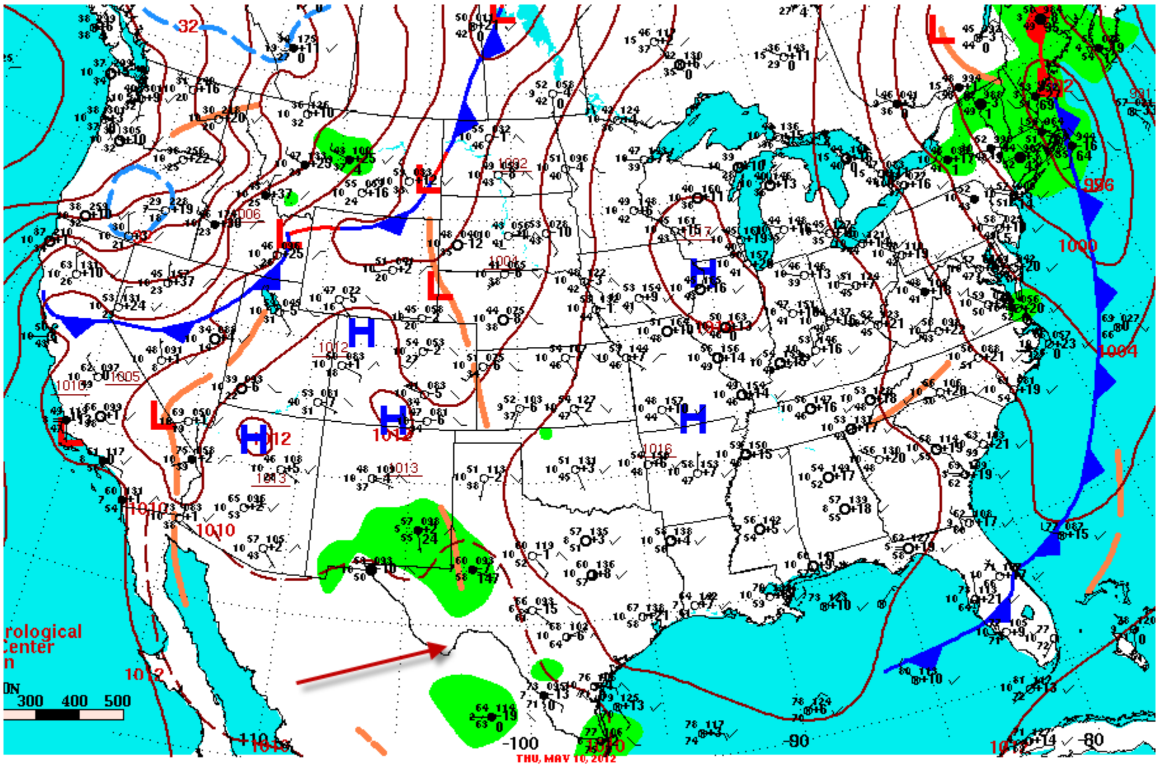
Monitoring Activity Highlights

New USCRN Record

On May 10, 2012 the USCRN site at Panther Junction 2 N, TX (Big Bend N.P.) experienced a record 5 minute precipitation amount of 0.83" (21.0 mm). It was not only a new record for the station, but also a new record for the USCRN network. The previous network record 5 minute event had been 0.73" at Titusville, FL (7/7/2006) and Lander, WY (7/25/2007). For perspective the rainfall rate of 0.83" (21.0mm) in 5 minutes is equivalent to 9.96" (253.0 mm in one hour).

Several aspects of this event make it even more unusual. The precipitation occurred at 0230 hours LST, and thus no solar input to aid in the instability of the atmosphere. It occurred well ahead of the summer "monsoon" season which usually develops from early July through mid-September. The surface ambient temperature at the onset was 59ºF (15ºC) and ended at 52ºF (11ºC). Surface relative humidity values were 90 to 92% which would indicate dew points of

50ºF (10ºC) to 56ºF (13ºC). Finally, there was very little in the way of surface weather features, just a weak trough (Figure 13). The precipitation was triggered mainly by a very small upper level low in northern Mexico (Figure 14).



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

Fig. 13. Surface Weather Map for May 10, 2012

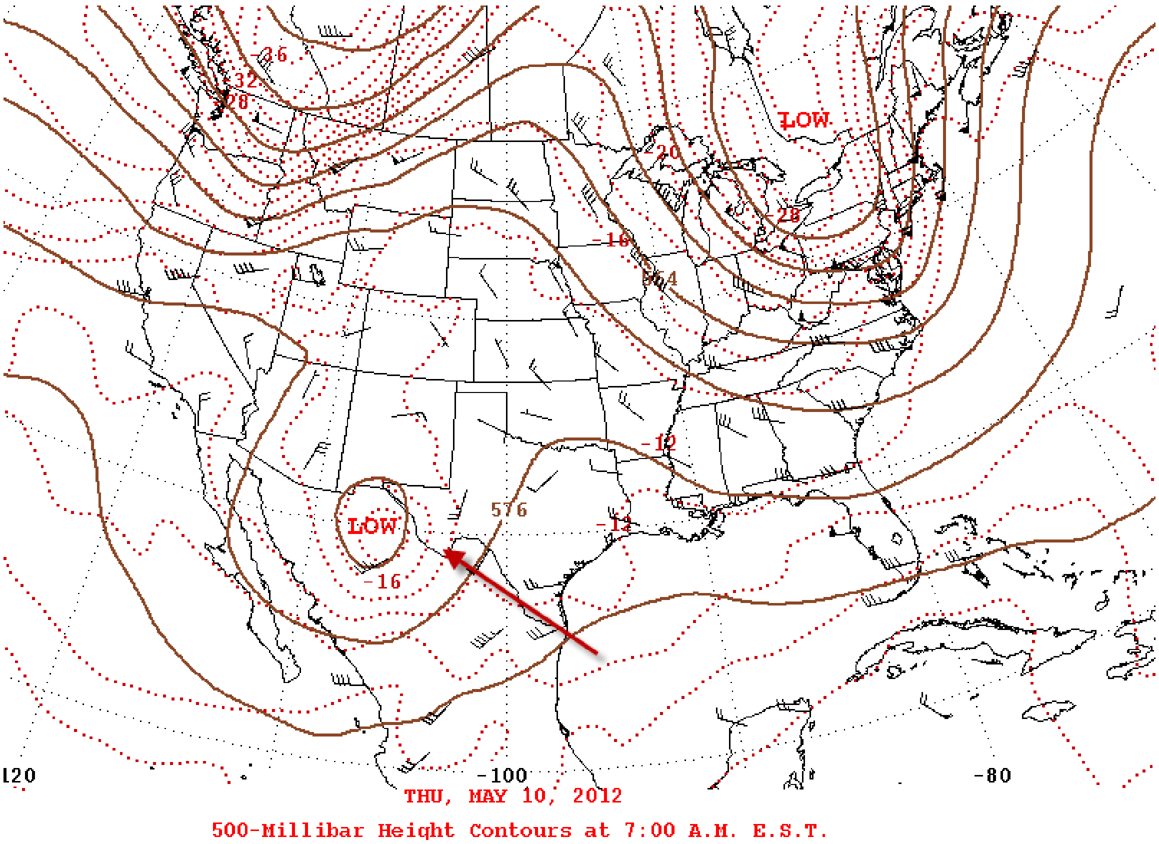


Fig 14. Upper Air Map at 500 mb on May 10, 2012

Noteworthy Events

As derived from twice daily upper air soundings it has been known for many years that dry air often resides in the mid-levels of the tropical atmosphere. However with the addition (in the Spring 2011) of a relative humidity sensor to the suite of instruments on the USCRN site at 11,179 feet, 3407 m, approximately at the 700hPa level) on the slopes of Mauna Loa, HI, it is now possible to monitor the humidity element on a continuous basis. The 5-minute ambient temperature and humidity records from the site have shown how large changes of >70% can occur in minutes (Fig. 15). These large and rapid changes are occurring without any correspondingly large changes in the ambient temperature. Thus the rapid humidity fluctuations indicate that the station has experienced an air mass change between the moist tropical boundary layer below and the much drier mid-level atmosphere above (Fig 13). Also shown below are the 00 UTC and 12 UTC soundings from the Hilo, HI, upper air site about 30 miles east which confirm the RH readings from the USCRN site.

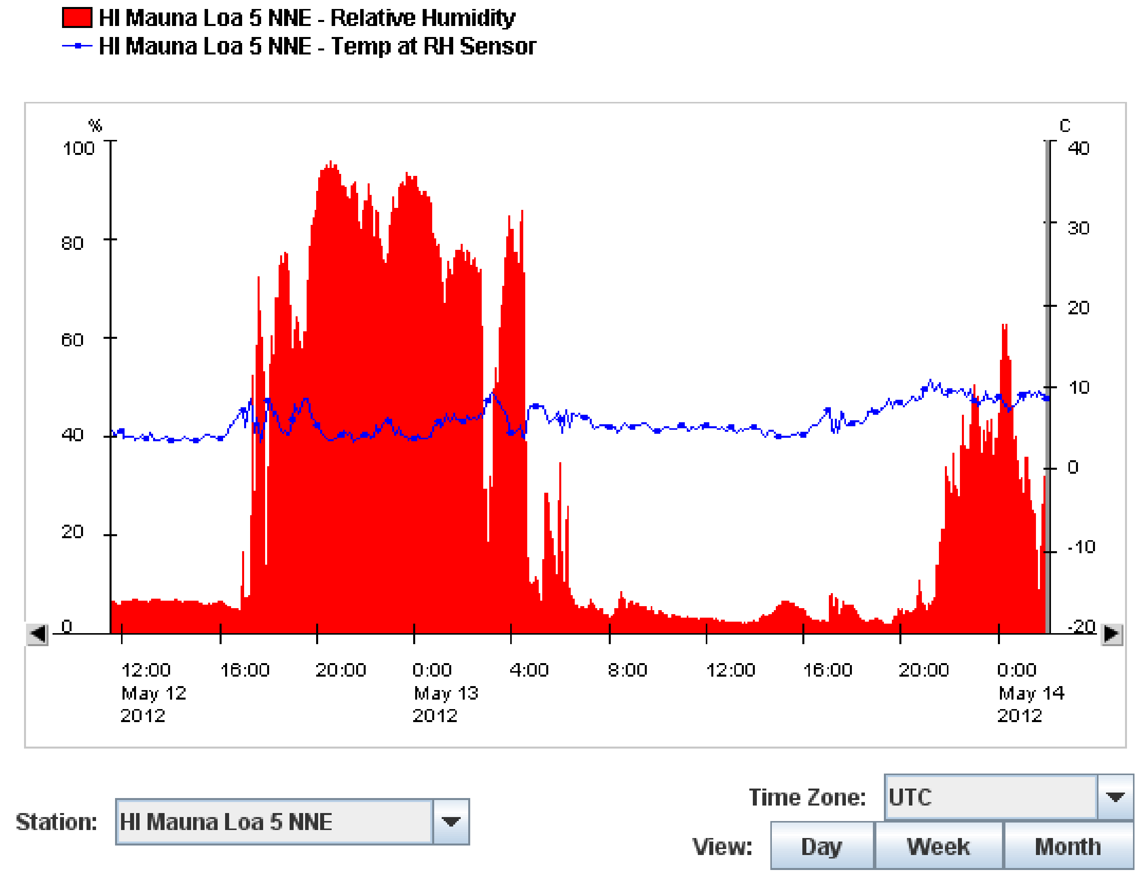


Fig. 15. Performance of temperature and RH sensors at Mauna Loa on May 13, 2012.

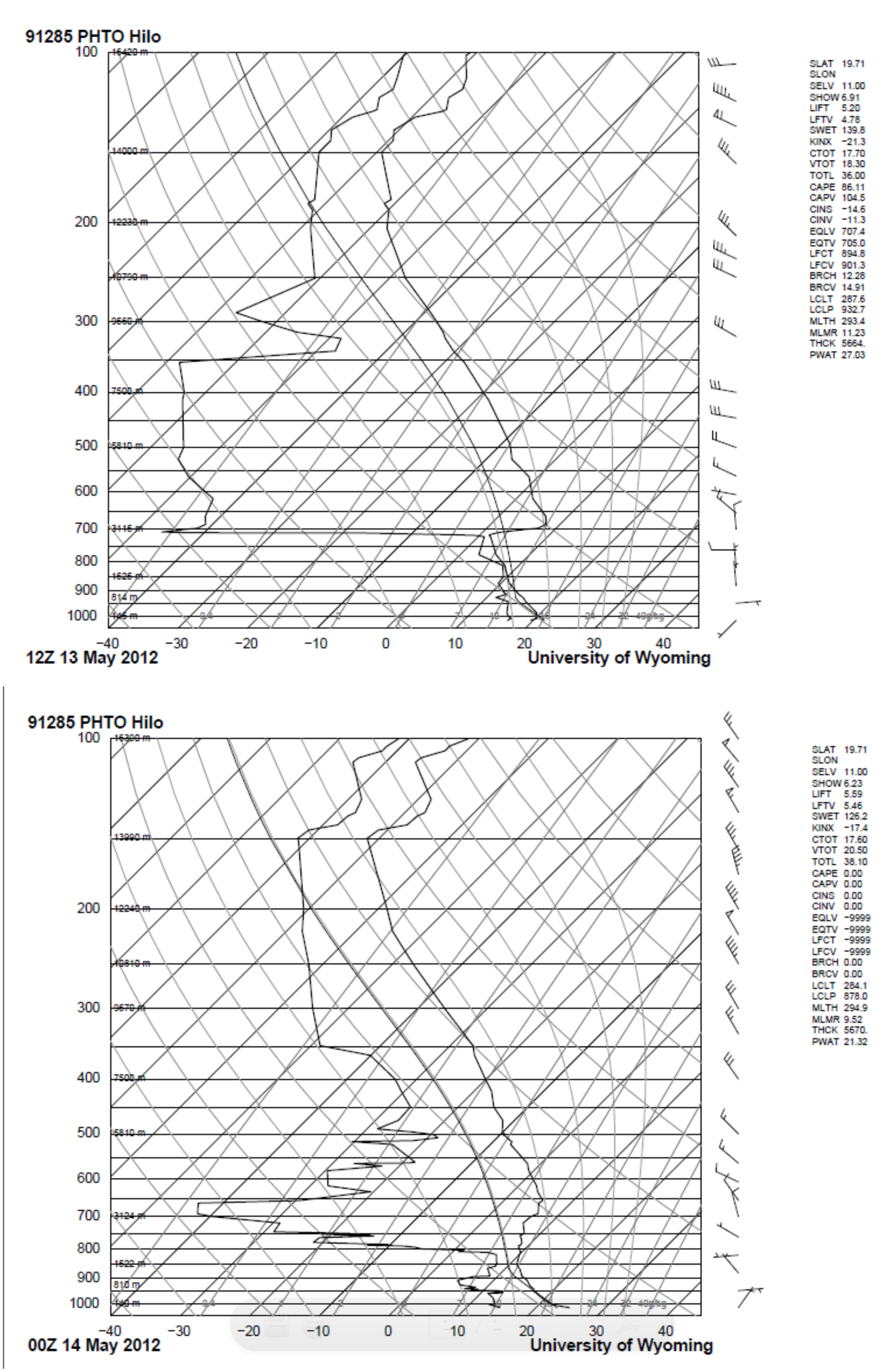


Fig. 16. Mauna Loa USCRN temperature and relative humidity graph for May 13, 2012.

Given the many discussions about warmer atmospheric temperatures over the last year, the Fig 17 indicates that there were no stations during February 2012 in the USCRN, RCRN, and Alabama Networks that had an extreme monthly maximum temperature below freezing. This is more amazing considering the fact that three of the stations (Boulder 14W, CO, Beaver, UT, and Socorro 17 WSW, NM,) are at elevations near or above 10,000 ft (3000 m). The networks lowest extreme monthly maximum temperature was 1.8°C (35°F) at Beaver, UT.

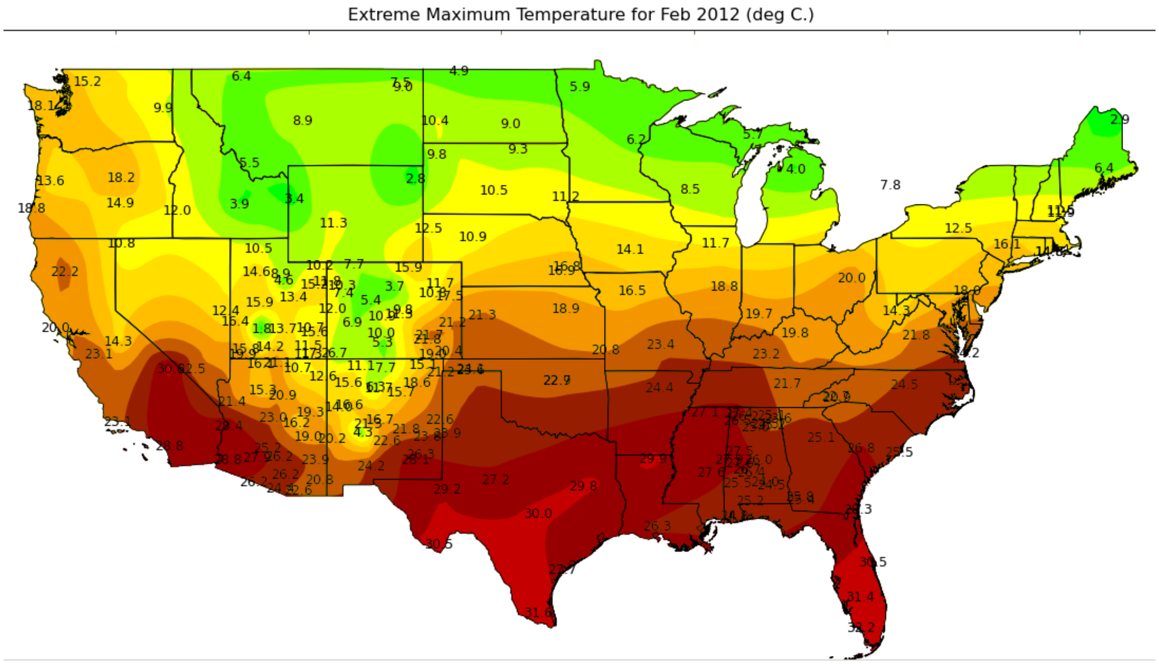


Fig 17. National USCRN Extreme Maximum Temperature Map for February 2012.

Plans for FY 2013

A number of long term science projects described above will reach completion in FY 2013:

1. Precipitation algorithm improvement
2. Comparisons of close-by USCRN and COOP station temperature and precipitation
3. USCRN temperature record examination and applications
4. Air Freezing Index modernization and comparison to soil freezing depth

Several new science projects will be built upon the progress made over the past year:

1. Generation of new pseudonormals for monthly station precipitation, and using these to generate national precipitation departures from normal
2. Soil temperature relationships to the phenology of the growing season will be studied using satellite normalized difference vegetation index values for locations near USCRN stations

3. Soil moisture gravimetric samples will be gathered at many USCRN stations to calibrate automated measurements, and the representativeness of USCRN soil moisture for a wider surrounding area will be examined near the Millbrook, NY, USCRN station.
4. USCRN soil moisture data will be used to examine the evolution of the 2011-2012 drought in the central U.S.

Data and software infrastructure are continuing to evolve and improve according to long term plans:

1. The current version of the USCRN database will be fully archived using netCDF 4
2. A new database will be generated by ingesting all data since 2004 using the improved ingest software system and uniform rounding methods
3. The new and local anomaly tracking system will take over for the old system managed in Washington D.C.
4. Procedures for handling data exceptions will be in place and functional
5. Improvements to the shared code base and Web site are ongoing

Hardware testing and deployments will continue:

1. A site survey trip to Alaska will take place during Summer 2013
2. Two stations will be deployed in Alaska
3. USCRN will continue to work with WMO Spice with regards to improving winter precipitation measurement
4. Testing of new and/or alternative observation equipment will take place

USCRN will play a larger role in monitoring U.S. climate change in the second decade of its existence. During FY 2013, USCRN national temperature data will begin appearing on the Climate of the U.S. web report that is updated monthly. In addition, a paper describing the USCRN at the end of its first decade was accepted for publication by the Bulletin of the American Meteorological Society:

Diamond, H.J., T.R. Karl, M.A. Palecki, C.B. Baker, J.E. Bell, R.D. Leeper, D.R. Easterling, J.H. Lawrimore, T.P. Meyers, M.R. Helfert, G. Goodge, and P.W. Thorne, 2013: U.S. Climate Reference Network after one decade of operations: status and assessment. *Bull. Amer. Meteor. Soc*., **94**, 4; doi: 10.1175/BAMS-D-12-00170.

Despite continuing budgetary pressures, the USCRN Program will continue to do its best to meet its mission of continuing to create the highest quality record of U.S. national climate change over the next 50 years.