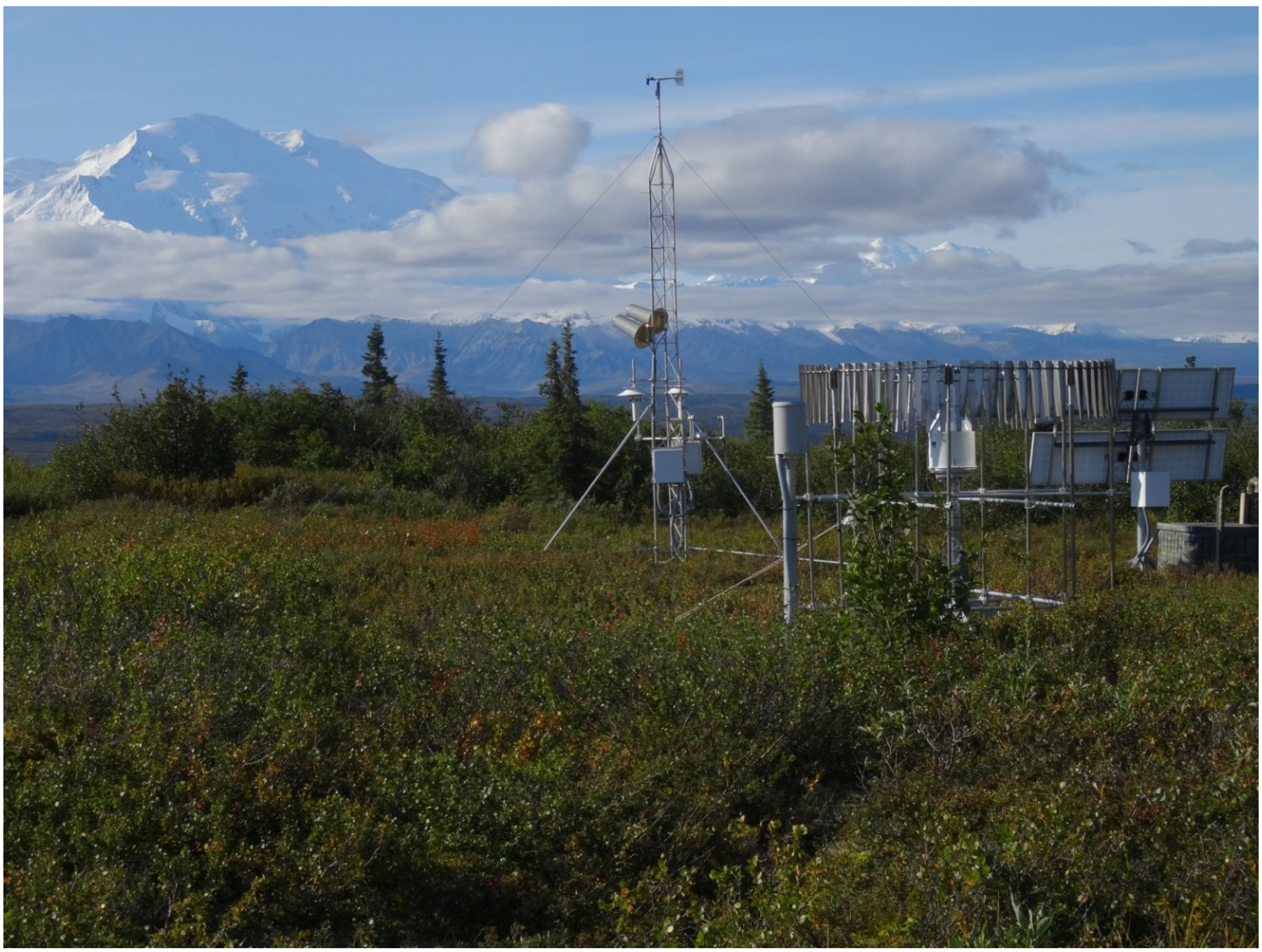
US Climate Reference Network

Annual Report for Fiscal Year 2015



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Cover Photo:
Photo of the new USCRN station in Denali National Park and Preserve with a rare cloud-free view of Mount Denali in the background (Credit – Mark Hall)

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Report will be posted on the USCRN Website at

http://www.ncdc.noaa.gov/crn/annual-reports.html

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 FY15:

Jesse Bell, Rocky Bilotta, Michael Black, Nancy Casey, Bill Collins, Scott Embler, Brent French, Grant Goodge, Mark Hall, John Kochendorfer, Jay Lawrimore, Ronnie Leeper, Tilden Meyers, Michael Potter, Barbara Shifflett, and Tim Wilson

Preface and Introduction

During 2015, the U.S. Climate Reference Network (USCRN) continued to progress under the auspices of NOAA's National Centers for Environmental Information (NCEI) and Atmospheric Turbulence and Diffusion Division (ATDD). The network consists of 114 stations across the conterminous 48 states, 18 stations in Alaska, 2 additional stations in Hawaii, and 2 at international test sites in Canada and Russia. 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 18 operational USCRN stations (16 commissioned) in Alaska, with an eventual goal of having 29 commissioned stations by 2022. 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. These records can now be compared on the web site, and are found to agree well. 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 FY2015

(1) Pushing past the halfway point in Alaska

In FY15, two new stations were installed in Alaska in the Denali National Park and Preserve, and in the Selawik National Wildlife Refuge, thus bringing the network configuration in the state up to 18 out of a planned eventual total of 29 stations by FY 2022.

(2) Modernized Web Site

The USCRN website received a major facelift in FY15. With the growth of mobile platforms, a high priority was placed on the design of a website that was equally useful for traditional desktop access as well as mobile computing environments. This was accomplished by incorporating NCEI's shared web-template and reorganizing content. With these changes tables and pages automatically adjust to the platform from which they originate and content navigation is simplified, greatly improving user access to data and information.

(3) National frost depth maps

As described under Science Activities, a new algorithm for calculating precipitation was put into operation in FY15. This was made possible by the software development efforts of the USCRN programming staff. This involved altering USCRN ingest software with new routines. Automated product and archive applications and monitoring logs were suspended while the reprocessing script ran. The entire period-of-record since the start of 5-minte measurements for all stations was reprocessed using the new algorithm, a process that took approximately one month to complete. Product files were updated and made available to the public. The product files generated using the previous processing algorithm were preserved in the NCEI archive system.

(4) Upgraded USCRN software to use secondary-station measurements

The remote location of some USCRN sites in Alaska combined with the especially severe winter conditions experienced throughout the state makes it difficult or impossible for unscheduled maintenance to be performed during the coldest months of the year at some stations. With this in mind the stations at the nine locations (Deadhorse, Denali, Glennallen, Gustavus, Ivotuk, King Salmon, Ruby, Selawik, and Tok) were designed with redundancy in the equipment most vulnerable to failure. This helps ensure data collection can continue when primary instruments or transmitters fail.

The remainder of the report will cover progress and activities in the following areas:

- Operational Activities in Alaska
- Operational Activities in the Conterminous U.S.
- Projects to Improve Data Processing, Monitoring, Data Access, and Product Quality
- USCRN Science and Development Activities
- Field and Testbed Activities
- Monitoring Activity Highlights
- Plans for FY 2016

FY 2015 Operational Activities in Alaska

Site Surveys: Two site survey trips were completed during the summer of 2015 visiting 21 potential site locations and completing 16 detailed site surveys at five grid locations in Alaska (Figure 1).

Site Licenses Signed: Site license agreements were completed for one additional Alaska site (Denali) in FY 2015, with several others in progress.

Stations Installed: Two new stations (Denali and Selawik) were installed in Alaska in FY 2015.

Stations Commissioned: Three stations (Deadhorse, Ivotuk, and Ruby) were commissioned in Alaska in FY 2015.

In addition to the stations installed in FY 2015 at Denali National Park and Selawik National Wildlife Refuge, one additional site is licensed and pending installation (Cordova). Licenses are pending from the Tongass National Forest at Yakutat, Yukon Delta National Wildlife Refuge at South Volcano Lake, Kodiak National Wildlife Refuge at Red Lake, Koyukuk National Wildlife Refuge Lake near Huslia, Innoko National Wildlife Refuge near Galena, Alaska Department of Natural Resources at Salmon Lake, Alaska Department of Natural Resources at Pumice Creek, Alaska North Slope Borough at Kaktovik, Toolik Field Station, and US Air Force site at Fort Yukon.

Surveys have been completed in 26 grids of the 29 grid network in Alaska (Figure 1). The project expects that the final 3 remaining grids, located in western and southwestern Alaska, will be completed by FY 2016. 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 2015. 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 2016, assuming funding arrives in a timely manner.

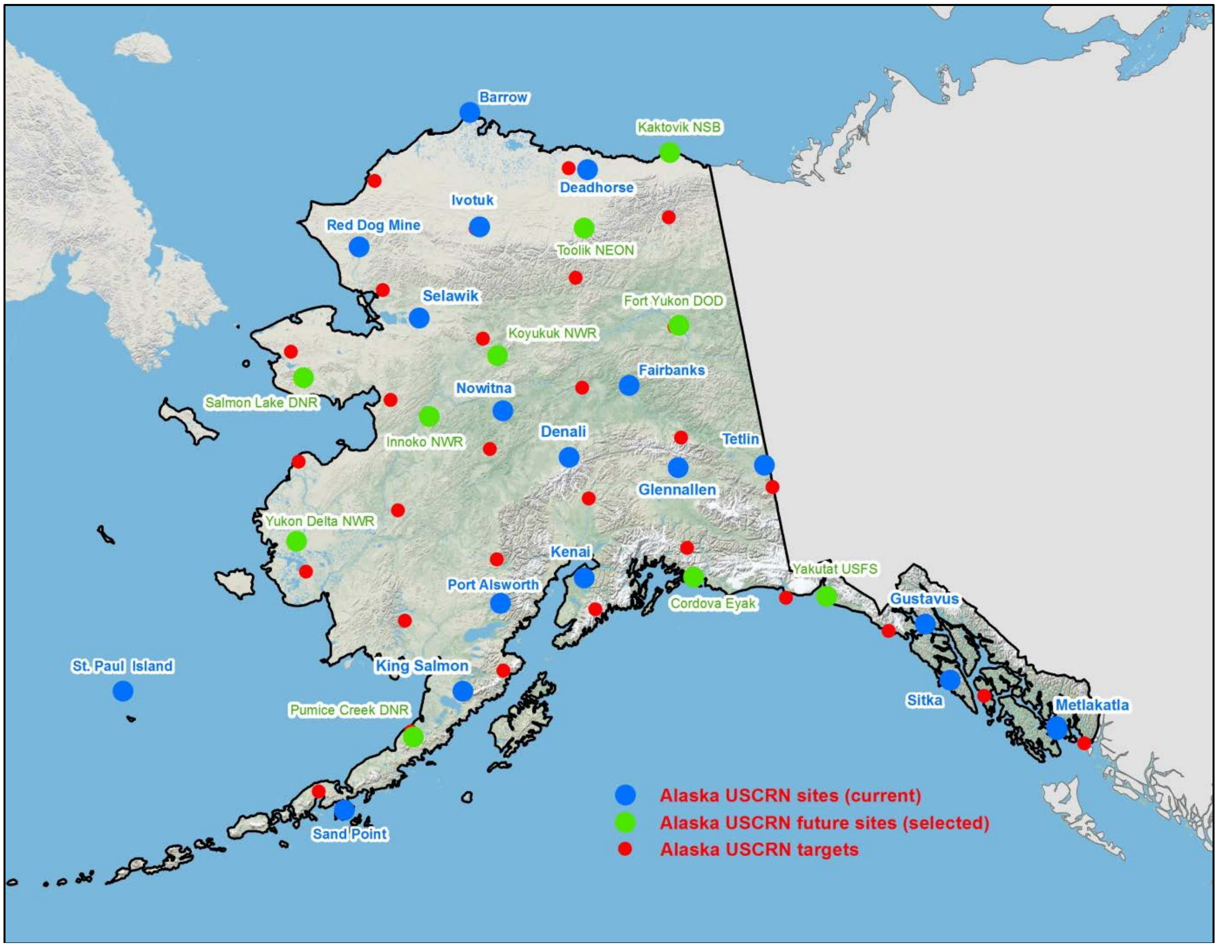


Figure 1. The map of USCRN in Alaska grids (centered on the red dots), along with existing and planned USCRN sites.

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%
2013	12	72.6%	72.4%
2014	13	73.4%	73.1%
2015	16	76.7%	76.0%

Table 2. USCRN in Alaska Data Receipt Rates (%) for FY 2015 by Quarter[1]

	Within 30 days	As of 9/30/15
Q1	98.4	99.1
Q2	95.6	96.2
Q3	94.8	95.5
Q4	99.9	99.9
Total	**97.2**	**97.7**

Table 3. FY 2015 USCRN in Alaska Station Status

Station	Licensed	Installed	Commissioned
Barrow (NOAA Earth Systems Res. Lab.)	4/27/2001	08/2002	07/2013
Fairbanks (NOAA/NESDIS(FCDAS))	7/23/2002	08/2002	07/2013
St. Paul (NOAA NWS)	6/10/2005	08/2005	07/2013
Sitka (USGS)	6/15/2005	08/2005	07/2013
Sand Point (USGS)	02/12/2009	08/2009	09/2010
Port Alsworth (Lake Clark NPS)	09/09/2009	09/2009	09/2010
Red Dog Mine (NANA Regional Corp.)	07/13/2010	08/2010	09/2011
Kenai (Kenai NWR)	07/13/2010	08/2010	09/2011
Tok (Tetlin NWR)	07/13/2010	09/2011	09/2012
Gustavus (near Glacier Bay NP)	06/27/2011	09/2011	07/2013
King Salmon (Katmai NP)	06/20/2011	08/2012	07/2013
Metlakatla (Annette Island WSO)	03/27/2012	07/2012	07/2013
Glennallen (BLM)	06/11/2012	08/2013	07/2014
Deadhorse (Dept. of Natural Resources)	05/07/2014	06/2014	09/2015
Ivotuk (Arctic Slope Regional Corp.)	05/07/2014	06/2014	09/2015
Ruby (Nowitna NWR)	05/29/2012	08/2014	09/2015
Selawik (Selawik NWR)	05/29/2012	08/2015	TBD
Denali (Denali NP)	01/07/2015	08/2015	TBD
Cordova (Eyak Corporation)	01/23/2013	TBD	TBD
Yakutat (Tongass USFS)	Pending	TBD	TBD
Bethel (Yukon Delta NWR)	Pending	TBD	TBD
Fort Yukon (US Air Force)	Pending	TBD	TBD
Kodiak (Kodiak NWR)	Pending	TBD	TBD
Hulsia (Koyukuk NWR)	Pending	TBD	TBD
Galena (Innoko NWR)	Pending	TBD	TBD
Nome (Salmon Lake AKDNR)	Pending	TBD	TBD
Port Heiden (Pumice Creek AKDNR)	Pending	TBD	TBD
Kaktovik (North Slope Borough)	Pending	TBD	TBD

FY 2015 Operational Activities in the Conterminous U.S.

The USCRN Program continues to successfully meet the requirements of data delivery in the conterminous U.S. (Table 4). During FY15, no new installations were made in the conterminous U.S. The process continued to complete a site license with the Ohio Agricultural Research and Development Center near Wooster, OH, in anticipation of the federal government selling the land where OH Coshocton 8 NNE is located. In addition, the two stations at

[1] **The overall data receipt rate for the entire USCRN (including the stations in Alaska) was 99.8% (see Table 4) which is above the performance measurement standard of 98% across the entire network.**

Goodwell, OK, continue to be run in parallel in order to determine transfer functions from the old station (2E) now located in a less-than-ideal situation (near a gray water center pivot irrigation experiment) versus the new station (2SE) that will replace the original. Figure 2 demonstrates that the overall difference in air temperature between the two sites is quite small by month, and the adjusted time series of monthly maximum and minimum air temperatures from the old site are both correlated to the new site with an R^2 = 0.9997, an intercept near zero, and a slope near one. The annual precipitation difference based on the average monthly differences is only 3.0 mm, which is insignificant compared to month-to-month variations. Therefore, no transfer function will be required to combine the precipitation climatology into one record, although there will be differences in day-to-day and month-to-month comparisons because the stations are more than a mile apart.

Table 4. Overall USCRN Data Receipt Rates (%) for FY 2015 by Quarter

	Within 30 days	As of 9/30/15
Q1	99.7	100.0
Q2	99.5	99.7
Q3	99.7	99.7
Q4	100.0	100.0
Total	**99.7**	**99.8**

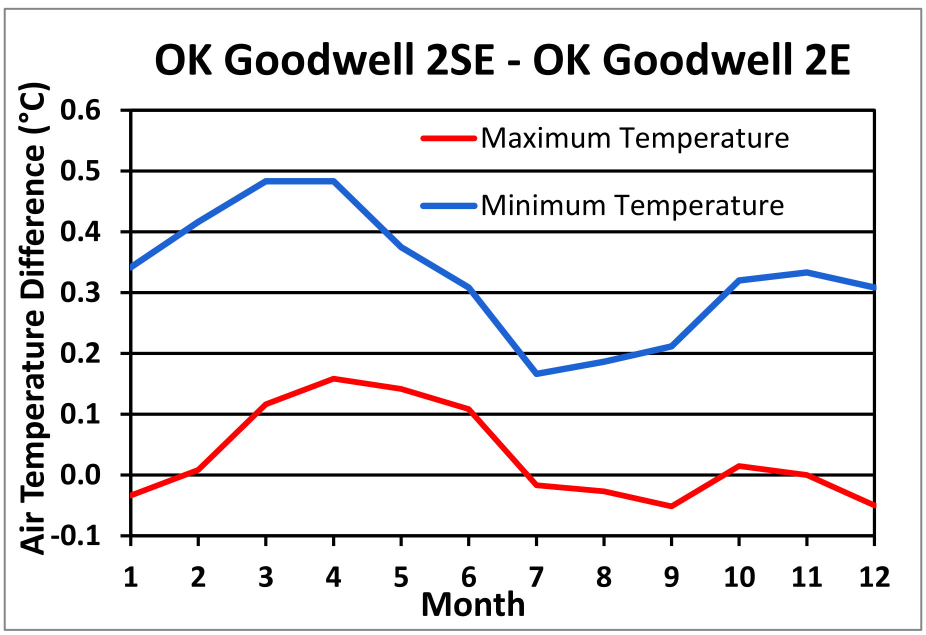


Figure 2. The mean monthly differences in air temperature between two USCRN stations near Goodwell, OK.

Improvements to Data Processing, Monitoring, Access, and Product Quality

Operation and maintenance of USCRN data ingest, quality assurance, monitoring, access, and product systems continued in FY15. The program's two computer analysts did an outstanding job keeping systems up and running. They provided systems monitoring on a continual basis and quickly responded to outages that periodically occurred due to factors associated with aging infrastructure and changing IT policies and procedures. While doing this they also were able to make improvements to enhance performance of the USCRN database and access systems. This was especially important given institutional technological constraints associated with servers and database systems that rely on Oracle.

Revamped website

The USCRN website received a major facelift in FY15. With the growth of mobile platforms, a high priority was placed on the design of a website that was equally useful for traditional desktop access as well as mobile computing environments. This was accomplished by incorporating NCEI's shared web-template and reorganizing content. With these changes tables and pages automatically adjust to the platform from which they originate and content navigation is simplified, greatly improving user access to data and information. In addition, the NCEI shared web template provides a uniform look-and-feel between USCRN and other webpages in the NCEI domain. Many content updates were made to USCRN documentation to incorporate recent changes, including improved pages describing measurements and instruments. Other changes to the USCRN site layout were made to improve navigation and make learning easier for new users. These included changes to the organization of categories and links on the home page and improved grouping of similar sets of data and information (Figure 3).

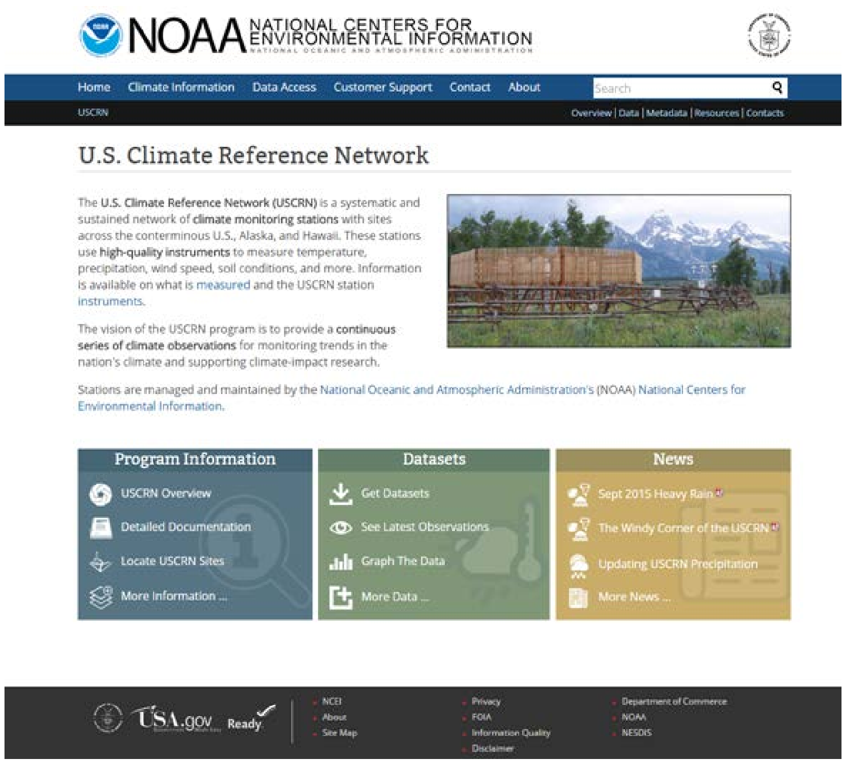


Figure 3. USCRN home page, available at https://www.ncdc.noaa.gov/crn/

Centralized logging of USCRN applications
There are a large number of processes associated with USCRN acquisition, ingest, data management, station monitoring, quality control, and access systems. The large number of processes, servers, and the requirement for 24/7 operations dictates a reliance on automated systems and error reporting to identify problems so that they can be promptly addressed to facilitate a return to normal operations in the shortest amount of time possible. To aid in catching and fixing operational problems, USCRN applications were modified so that they could deliver logs and error reporting to a central location. With this accomplishment programmers are now able to see at a glance when errors or performance problems arise on any of USCRN's processes and servers. This centralization provides a considerable savings in time that would otherwise be spent logging into different machines and manually searching through log files, while also helping ensure rapid identification and resolution of operational problems.

Implemented a new Official Algorithm for Precipitation 2.0
As described under Science Activities, a new algorithm for calculating precipitation was put into operation in FY15. This was made possible by the software development efforts of the USCRN programming staff. This involved altering USCRN ingest software with new routines. Automated product and archive applications and monitoring logs were suspended while the reprocessing script ran. The entire period-of-record since the start of 5-minte measurements for all stations was reprocessed using the new algorithm, a process that took approximately one month to complete. Product files were updated and made available to the public. The product files generated using the previous processing algorithm were preserved in the NCEI archive system.

Upgraded USCRN software to use secondary-station measurements:
The remote location of some USCRN sites in Alaska combined with the especially severe winter conditions experienced throughout the state makes it difficult or impossible for unscheduled maintenance to be performed during the coldest months of the year at some stations. With this in mind the stations at the nine locations (Deadhorse, Denali, Glennallen, Gustavus, Ivotuk, King Salmon, Ruby, Selawik, and Tok) were designed with redundancy in the equipment most vulnerable to failure. This helps ensure data collection can continue when primary instruments or transmitters fail.

These stations are equipped with a primary and a secondary datalogger that are connected to two separate temperature shields that each contain two aspirating fans. The shields house three temperature sensors, which is in keeping with the USCRN standard of triplicate measurement of primary elements. There are also primary and secondary wetness sensors, IR surface temperature sensors, and transmitters.

Since the first of these stations was installed in 2011, data from the primary and secondary set of instruments have been collected and archived. But until this year software did not allow automated replacement of data from the secondary stream in the event of a failure in the primary. And it was not possible for data from the secondary stream to be viewed from the USCRN website without special knowledge of the specific transmitter number.

Software improvements to USCRN ingest, the website, and data products now provide seamless substitution of data from secondary stations in the event that a primary station's observations are unavailable. While at first glance this replacement appears to be transparent to the user, information is available from the USCRN website indicating when observations from the secondary instrument are being used.

Modernized software for NCEI's Integrated Surface Data

In addition to providing data access through the USCRN website and data products, USCRN data are provided to customers as part of NCEI's Integrated Surface Dataset (ISD). The ISD dataset is housed in an Oracle database and access is provided through the Climate Data Online web tool (https://www.ncdc.noaa.gov/cdo-web/search) that is maintained by NCEI's Data Access Branch. In the early years of the USCRN program, software was written to provide an interface and transfer mechanism between the USCRN database and ISD. This software was designed to run on an IBM server which over the past several years became out of date. The software also performed many functions that were no longer necessary and failed to properly reprocess records when USCRN data from station dataloggers were collected and delivered to NCEI by ATDD engineers at each annual maintenance visits (via PDAs). In addition, the IBM server is nearing its end-of-life. To ensure that ISD-formatted files can continue to be produced, and to keep those files in sync with the USCRN database, the software was modified to operate on any machine and process all changes to USCRN's database.

Performed major upgrade to CRN's database schema

A continued increase in the processing load on NCEI's server and database infrastructure across all areas of the Center resulted in degraded performance of the USCRN database in early FY15. This caused a slowdown in data access internally as well as for customers accessing data and reports via the USCRN website. To address this problem, a redesign of the USCRN database was undertaken during the second half of the year. This involved creating new partitions and organizing tables to optimize query performance. Additionally, several extra columns were added to the primary tables that enable programmers and researchers to more easily filter, group, and sort large time-series. These upgrades reduced the response time by half which improved on-the-fly analysis as well as day-to-day operations.

Identified Operational Quality Control Issues

Attention to data quality issues during day-to-day operations resulted in the identification of several issues beyond those detected through standard automated checks.

- Identified erroneous relative humidity values in the subhourly and hourly FTP products for at least 5 stations.
- Identified Geonor wire depth values between -15 and -5 that were flagged prior to a change in the QC threshold range check that took place in April 2013.
- Applied flags to bad sensor data for two air temperature sensors which were reporting a temperature of 0.0 °C at Panther Junction, TX due to a faulty datalogger.
- Worked with ATDD to identify and correctly re-ingest a non-standard set of PDA data downloaded from the datalogger during an annual maintenance visit for the station at Jamestown, ND.
- Identified issues with unflagged hourly wind speeds reading 0.0 for prolonged periods (particularly in Alaska in 2012) due to freezing conditions.

Supported quality control of soil moisture/temperature data

At most USCRN locations, measurements of soil temperature and soil moisture are made at five depths from 5 to 100 cm in three triangular directions surrounding the USCRN tower for a total of 2,976 individual belowground observations. The substantial number of sensors combined with the environment in which the sensors operate requires continuing and sustained attention to identify potential instrument problems. To aid in quality control efforts, computer analysts developed vital software to plot soil measurements on-the-fly, plot sensors individually, and produce 3-panel graphs showing statistics on soil sensor values (dielectric constants, precipitation, and volumetric soil moisture). These plots are consolidated in individual multi-page PDFs and analyses of the data are also provided in corresponding spreadsheets. These are shared with researchers and ATDD for the evaluation of sensor performance, providing for a more thorough and efficient quality control process for soil moisture and temperature measurements.

The example in Figure 4 shows how the statistics and accompanying plots can alert ATDD engineers to the impact of missing values on the soil moisture volumetric average. Missing values for all three sensors are evident in the dielectric measurements from 12 October through 24 October. In addition, there is anomalous behavior in sensor 3 near the end of the month. This alerts the soil quality control team to manually apply flags to the sensor during this period.

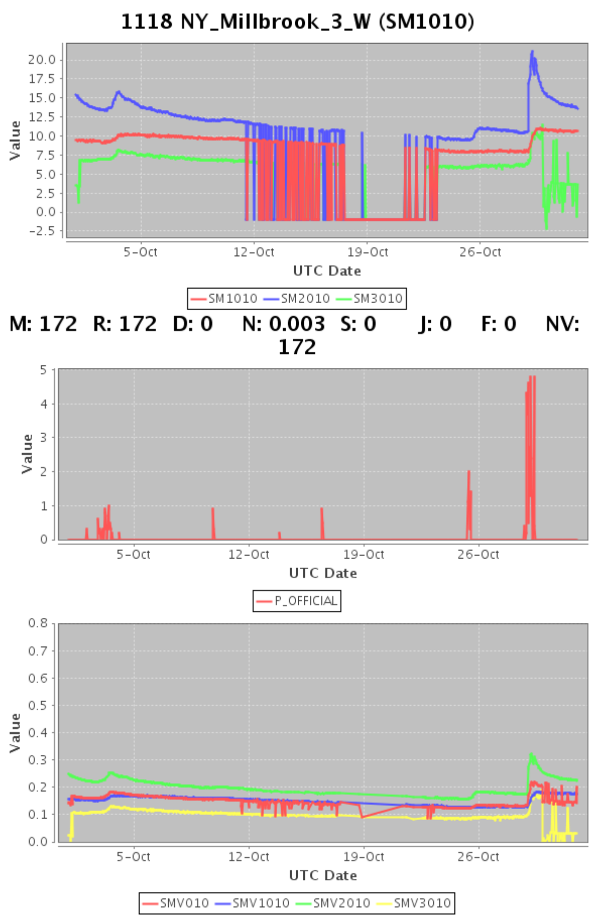


Figure 4. Example of USCRN diagnostic plots used for quality control of 10 cm soil moisture measurements at Millbrook, NY. Dielectric values for each of the three sensors (top), hourly precipitation at the site (middle), and volumetric values for each sensor and the average (bottom).

Also shown are sensor statistics.
M: Number of hours with missing value (-999)
R: Number of hours with a range flag
D: Number of hours with a datalogger door open flag
N: Noise ratio
S: Number of spikes (range, frozen, or door flags not included)
J: Number of jumps for this sensor (range, frozen, or door flags not included)
F: Number of hours with a frozen flag (NA for soil temp)
NV: Number of hours with no volumetric calculated (NA for soil temp)

Established a new virtual server for scientists
In coordination with NCEI's Information Technology Branch a new virtual server (VM) was created specifically for scientific research. The new VM gives scientists the ability to perform extensive and resource-intensive analysis of USCRN data. It also provides for delivery of data to researchers outside of NCEI.

Data Services to USCRN Customers
The USCRN ftp product suite provides customers with consolidated access to subhourly, hourly, daily, and monthly data files. In addition to providing access via ftp, the hourly and daily observations also continued to be transmitted over the Global Telecommunications System through NCEI's partnership with NOAA's National Weather Service. Improvements in 2015 included the creation of header files that can be appended to all FTP products for ease of use and a rewrite of the set of documentation for each product to improve content, clarity and organization.

Support for special requests from users was also provided in 2015. This included special requests for hourly wind speed data by the National Centers for Atmospheric Research. Data in response to a request from the Centers for Disease Control was provided to assist scientists evaluating output from computer models that are used in human health research. USCRN computer analysts also provided extensive support to the USCRN Science Team in the performance of complex data pulls and data analyses.

USCRN Science and Development Activities

Completion of Projects in FY15
A group of USCRN Science Team projects completed in FY15 started at an earlier time, and so have been described in detail in previous USCRN Annual Reports. A brief summary with updates is provided for each project leading to a publication in FY15.

1. Air Freezing Index (AFI) update and confirmation

Bilotta, R., J.E. Bell, E. Shepherd, and A. Arguez, 2015: Calculation and evaluation of an air-freezing index for the 1981-2010 climate normals period in the coterminous United States. *Journal of Applied Meteorology and Climatology,* **54**, 69-76. DOI: 10.1175/JAMC-D-14-0119.1.

The AFI is a common metric use to relate the severity of winter at a location to the expected penetration depth of frost in the most severe winter during the lifetime of a building project. This study showed that substantial reductions in AFI 100-year return period intervals have occurred in the last 60 years. USCRN air temperatures were used to confirm that AFI calculations at nearby cooperative observer network stations corresponded well during the recent overlap period, with a conterminous U.S. coefficient of determination between the network nearest-neighbor pairs of $R^2 = 0.933$.

2. Extending the soil moisture records of USCRN stations

Coopersmith, E. J., **J. E. Bell**, and M. H. Cosh, 2015: Extending the soil moisture data record of the U.S. Climate Reference Network (USCRN) and Soil Climate Analysis Network (SCAN). *Advances in Water Resources*, **79**, 80-90, doi:10.1016/j.advwatres.2015.02.006.

One of the limitations of the USCRN soil moisture data set is the brief time period through which it is available. However, since high quality precipitation data are available, it should be feasible to use these more lengthy USCRN time series to estimate soil moisture values, especially for the surface layer at 5 cm. Hourly soil moisture estimates were made with a diagnostic soil moisture equation calibrated using genetic algorithms (neural networks). Results demonstrated that only 2-3 years of hourly observations of both precipitation and soil moisture were required to produce estimated values that yield a root mean square error of less than 0.033 m^3/m^3. These extended time series will be considered for inclusion when generating estimated normals for soil moisture at USCRN stations.

3. Use of USCRN as a reference in comparison to the U.S. Cooperative Observer Program (COOP) Network

Leeper, R. D., J. Rennie, and **M. A. Palecki**, 2015. Observational perspectives from U.S. Climate Reference Network (USCRN) and Cooperative Observer Program (COOP) Network: temperature and precipitation comparison. *Journal of Atmospheric and Oceanic Technology*, **32**, 703-721, doi: 10.1175/JTECH-D-14-00172.1.

This study confirmed that there is a general tendency for air temperature observations at paired USCRN-COOP stations to be different, mainly due to the fan aspiration of the USCRN instruments as opposed to the natural aspiration of COOP instruments. The USCRN sensors were on average cooler at the time of daily maximum temperature (-0.48°C) and warmer at the time of daily minimum temperature (+0.36°C). However, large outliers were found in this relationship due to the often inconsistent observation times of the COOP observers. These time-of-observation shifts also commonly impacted comparisons of daily precipitation between networks, so much so that the only meaningful comparisons that could be made involved periods of precipitation surrounded by a full day of no precipitation on either side of the precipitation event. For precipitation events defined in this manner, USCRN stations recorded about 1.5% less precipitation than the COOP stations. This under catch issue with USCRN was traced to the 2008-2015 precipitation calculation algorithm, which was replaced by a new calculation algorithm during FY15.

4. Description of a new precipitation calculation algorithm for USCRN.

Leeper, R.D., M.A. Palecki, and E. Davis, 2015: Methods to calculate precipitation from weighing bucket gauges with redundant depth measurements. *Journal of Atmospheric and Oceanic Technology*, **32**, 1179-1190, doi: 10.1175/JTECH-D-14-00185.1.

The original 5-minute precipitation calculation algorithm worked very well, but in some circumstances could be too strict in requiring very close (0.2 mm) pairwise agreement in the rate of change of gauge depth as measured by the three load cells of a USCRN weighing precipitation gauge. The new Official Algorithm for Precipitation 2.0 (OAP 2.0) relies instead on calculating a weighting factor for each depth change measurement based on its agreement with the 3-sensor mean depth changes over a three hour moving window. Therefore, agreement in any particular 5-minute period does not have to be absolute, but the depth change time series that agree the most will be most heavily weighted; precipitation will not be missing when the paired depth changes disagree. The new algorithm yields a network-wide increase in total precipitation amount of 1.6%. More importantly, OAP 2.0 portrays the pattern of event precipitation rates over time during an event more accurately than did the original algorithm. This paper serves as the external confirmation of the fitness of the new algorithm needed for the Operational Readiness Review of the proposed changes before they were implemented in FY15. This implementation will be discussed below.

5. Impacts of evaporation on weighing precipitation gauges like used in USCRN Program.

Leeper, R.D., and J. Kochendorfer, 2015: Evaporation from weighing precipitation gauges: impacts on automated gauge measurements and quality assurance methods. *Atmospheric Measurement Techniques*, **8**, 2291-2300. doi: 10.5194/amt-8-2291-2015.

The average rate of evaporation from an unprotected Geonor gauge in Boulder, CO, was 0.12 mm/hr during a summer test comparison with a similar gauge protected from evaporation by mineral oil. While this is a known issue, examination of the gauge depth record and the calculation of precipitation indicated that the calculation methodology can be quite sensitive to the evaporative loss. The old pairwise agreement method used originally in the USCRN precipitation calculations was more sensitive to evaporation than the new weighted average method, with the former underestimating precipitation at the start of rain events following periods of rapid evaporation.

Precipitation Data Set Development and Research

The major science achievement of FY15 was the completion of the process for approval and implementation of Official Algorithm for Precipitation 2.0 (OAP 2.0). In addition to publishing a description of the algorithm and its impact on USCRN precipitation values, a set of detailed documentation was generated for an NCEI Operational Readiness Review (ORR) that validated OAP 2.0 scientifically and technically:

USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Requirements. 4 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Description. 26 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Software Flow. 4 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Maintenance. 3 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Production. 7 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Reprocessing. 5 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Quality Assurance. 7 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Source Code. 2 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: IT Security. 10 p.

USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: Archive & Access. 24 p.
USCRN Program, 2015: Official Algorithm for Precipitation, Version 2.0: User Engagement. 8 p.

The documentation was augmented by meetings with the NCEI Customer Engagement Branch and with the NCEI regional climate service directors, followed by a technical implementation notice to Weather Wire users. A news release was also produced and distributed by NCEI so as to inform the external user community.

All calculated precipitation values have been recalculated from the start of the 5-minute increment era when the wetness sensor was installed, and the current ingest is using the new algorithm. Considerable time was spent by the science team inspecting the resulting values, confirming that the production database has the same values as the test database, and identifying causes for any differences that were not anticipated.

In addition to the application of the new algorithm, a process was started to identify and correct long standing precipitation exceptions to the ingest quality control system that were not flagged automatically by the software but were nonetheless found to be erroneous by careful science team examination. Exceptions are first considered by the USCRN Configuration Control Board, and then addressed as recommended by the science team if the findings are not overturned by the Board. This process is expected to continue into Q2 of FY16. After exception processing is complete, the USCRN precipitation data will be ready for several major projects that have undergone design and development during FY15, including the creation of a National Precipitation Index similar in concept to the existing National Temperature Index, and a multifaceted effort to characterize USCRN precipitation extremes.

The simplest approach to characterizing precipitation extremes is to conduct case studies of important heavy precipitation events. Several such events are described below in the Monitoring section of this report. However, one extended heavy rain event in the central U.S. during May 2015 illustrated the complications arising from the short periods-of-record of the USCRN stations individually and as a network. A more complete discussion of this episode is located in USCRN

News at:
http://www1.ncdc.noaa.gov/pub/data/uscrn/publications/events/Extreme May 2015 Precipitation.pdf

Multiple episodes of heavy precipitation inundated the area from Wyoming and South Dakota south to Oklahoma and Texas. The 25 U.S. Climate Reference Network (USCRN) stations shown in Figure 5 received enough precipitation for May 2015 to qualify as one of their five wettest months, regardless of time of year, and 9 USCRN stations experienced their wettest calendar month on record. For 22 of the 25 stations, this was their wettest May on record. The period of record for these stations varies from 7-12 years, so while these ranks might have been different if stations had longer records, the number of locations impacted coupled with the large geographic coverage of the extreme precipitation totals is particularly noteworthy.

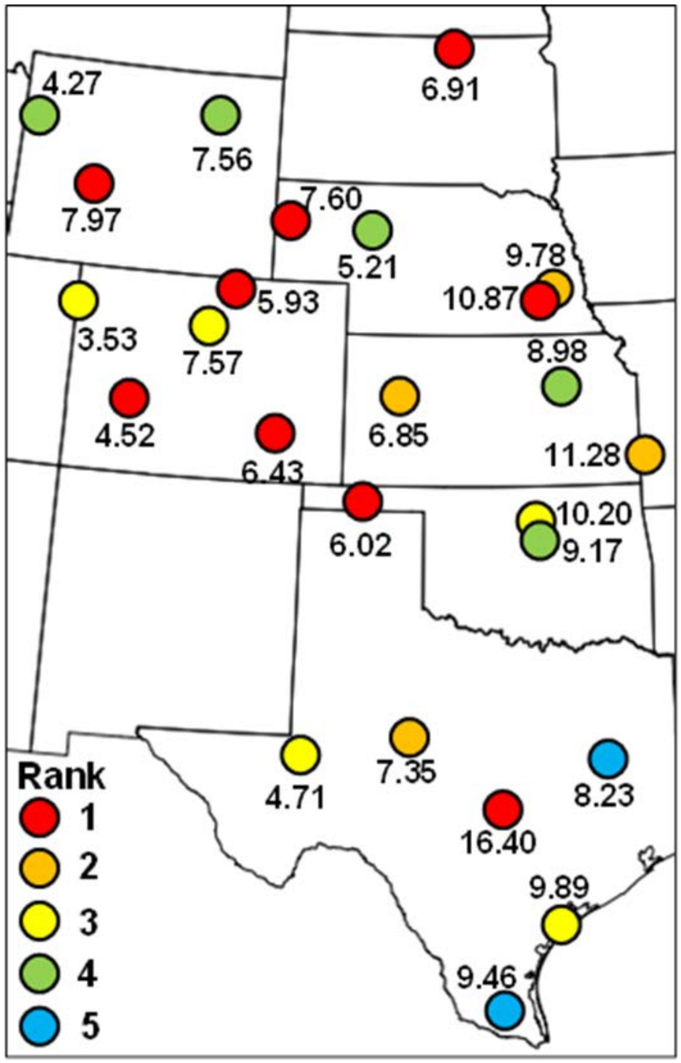


Figure 5. The dot color indicates the overall rank of May 2015 precipitation compared to all months at 25 USCRN locations with a top 5 wettest rank. Numbers are precipitation totals in inches.

Large swaths of Oklahoma and Texas received more than 20 inches of rain in May 2015 as indicated by denser networks of observations and radar estimates. The purpose of USCRN is not to capture every weather event or climate anomaly in every location, but to generate a representative set of statistics to measure climate change for the U.S. as the 21st Century progresses. Therefore, it is an indicator of the importance and geographic scope of the event that so many USCRN stations sustained record and near-record rainfall totals. The heaviest precipitation report came from the USCRN station near Austin, Texas, which received 416.6 mm (16.40 inches) of rain in May 2015. During one flash flood event in the Austin area, 38.1 mm (1.5 inches) of precipitation fell in just 20 minutes around 9:00 PM CDT on May 23rd, indicating the dangerous nature of these heavy precipitation events (Figure 6). The 5-minute resolution observations of the USCRN station precipitation record was a crucial factor in characterizing these extreme event statistics, both in near-real time and as one aspect of climate change being tracked over time nationwide. Construction of a comprehensive USCRN heavy precipitation event climatology will begin during FY16.

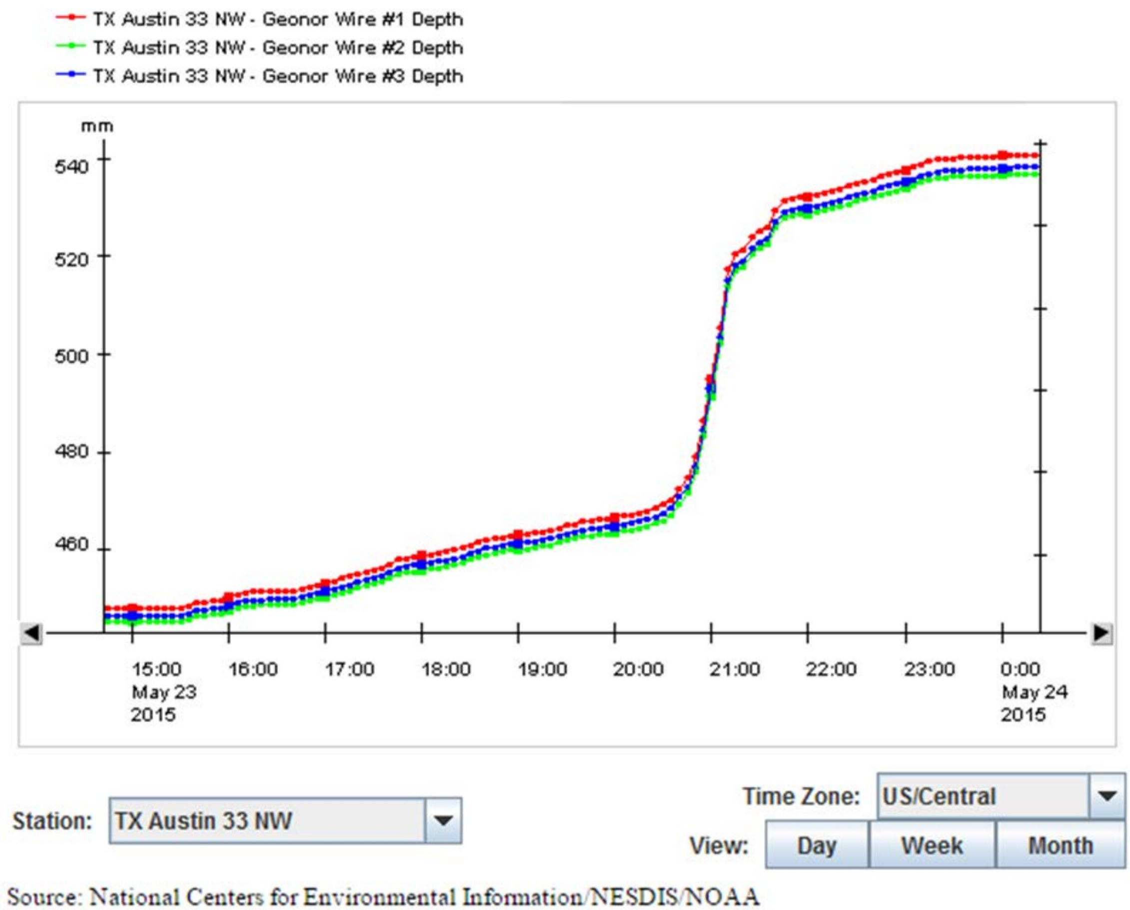


Figure 6. Increasing gauge depth during an extreme flash flood event in the area of Austin, TX, on the evening of 23 May 2015. At its peak, 38.1 mm (1.50 inches) of rain fell in 20 minutes centered on 9 PM CDT (2100 CDT).

Soil Moisture Data Set Development and Research

Two major projects started in FY14 and continued into FY15 have recently been completed and two papers accepted for publication in FY16:

Bell, J., R. Leeper, M. A. Palecki, E. Coopersmith, **R. Bilotta, and T. Wilson**. Evaluation of the 2012 drought with a newly established national soil monitoring network. *Vadose Zone Journal*, doi:10.2136/vzj2015.02.0023, in press.

Coopersmith, E., M. H. Cosh, R. Bindlish, and **J. Bell**. Comparing AMSR-E Soil Moisture Estimates to the Extended Record of the U.S. Climate Reference Network (USCRN). *Advances in Water Resources*, doi: 10.1016/j.advwatres.2015.09.003, in press.

Examination of the 2012 drought in the conterminous U.S. revealed a truly national event that was evident in national compilations of USCRN soil moisture. Figure 7 shows the steep decline in soil moisture at all depth levels from 2011, a relatively wet year in the northern U.S., to 2012, a year of drought intensification in the central and northern U.S. It is also interesting to note that surface soil layers at 5, 10, and 20 cm recovered substantially in 2013, but the 50 and 100 cm layers did not, reflecting the delay in the drought wave reaching those levels in 2012, and indicating that the moist wave had not yet reached those layers in summer 2013. This analysis demonstrates the utility of the USCRN soil moisture measurements in monitoring large scale drought events and their evolution. The project also showed that the USCRN network is sufficiently dense to address regional drought issues.

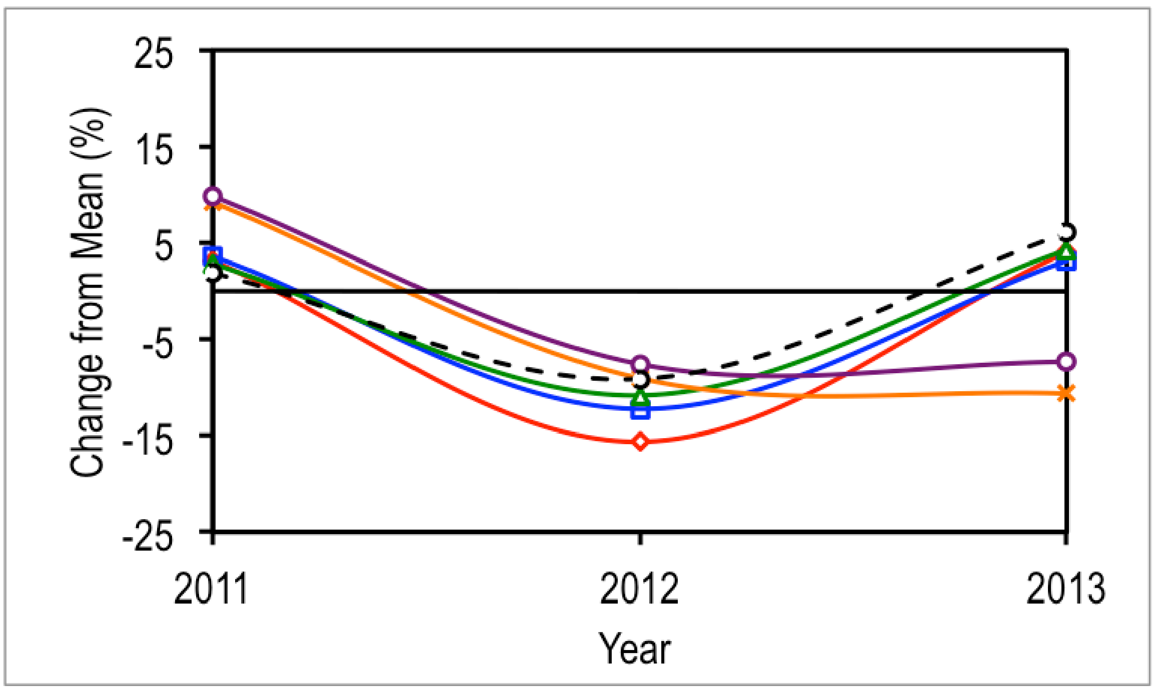


Figure 7. Solid lines indicate the average percent change in summer (JJA) soil moisture from the three-year average (2011-2013). Each line represents the 5cm (red line, diamond), 10cm (blue line, square), 20cm (green line, triangle), 50cm (orange line, cross), and 100cm depths (purple line, circle). Dashed black line indicates the average percent change in total precipitation for each

hydrological year from the three-year average (2011-2013). Figure 7 from Bell et al. (in press). The second recently published paper by Coopersmith et al. (in press) utilized the statistically modelled and extended USCRN 5 cm soil moisture time series first discussed in Coopersmith et al. (2015). The Advanced Microwave Scanning Radiometer (AMSR-E) has been used to estimate surface soil moisture amounts since 2002, and is a predecessor to the current generation of soil moisture measuring satellite, the Soil Moisture Active Passive (SMAP) Mission launched in 2015. This study indicates that the model-extended USCRN soil moisture time series corresponds as well to the AMSR-E soil moisture measurements as the actual *in situ* measurements, confirming the validity of model extended time series of USCRN 5 cm soil moisture measurements. In fact, these data were used to reconstruct the USCRN national soil moisture record back to the summer of 2005. The resulting time series through 2013 indicates the truly significant magnitude of the national soil dryness signal occurring during the 2012 drought (Figure 8).

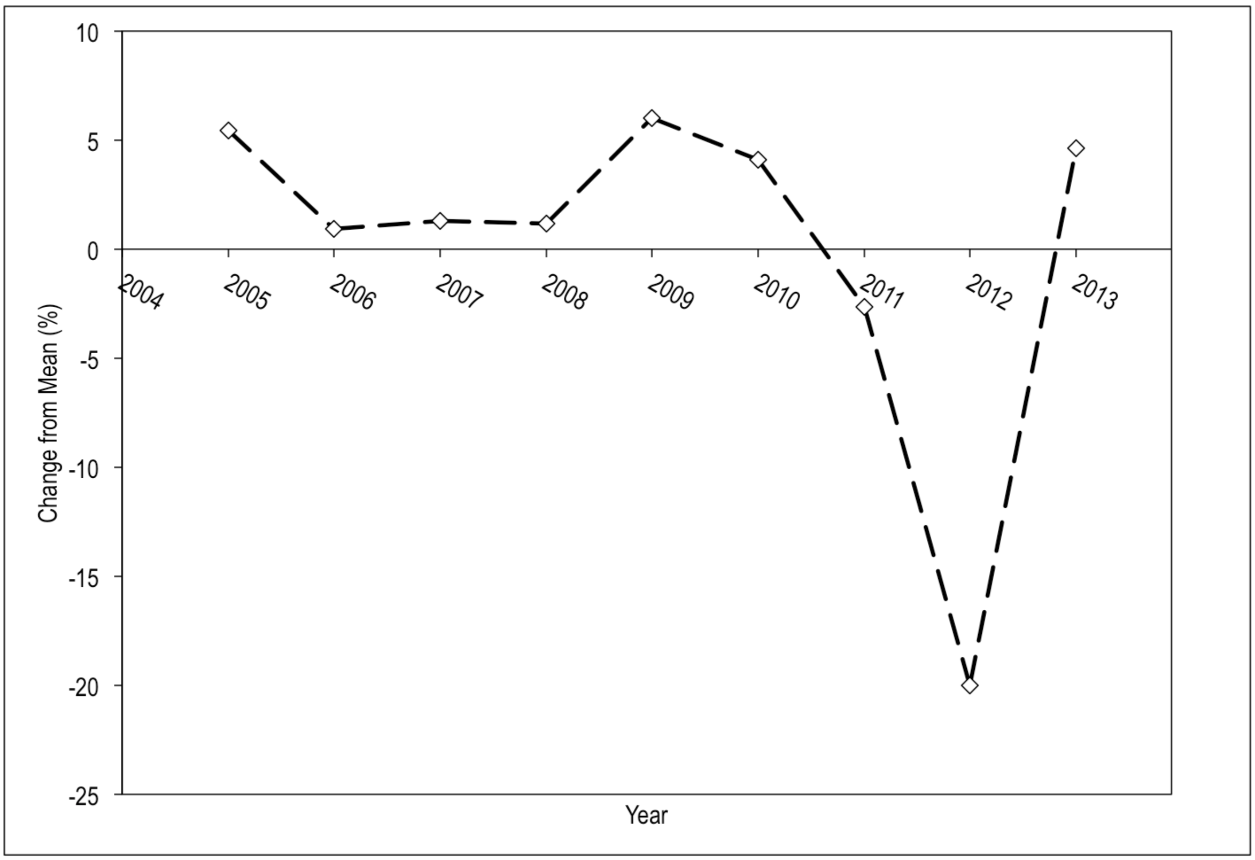


Figure 8. Percent difference from average in modeled 5 cm soil moisture values for summer months (JJA) for USCRN stations. Average soil moisture conditions were calculated from the entire period of record (2005-2013). Figure 8 from Bell et al. (in press).

Substantial progress was made on several other soil moisture projects during FY15. The soil moisture representativeness project conducted at the Crossville and Millbrook USCRN sites has revealed high temporal correlations between point and area soil moisture time series, but that absolute values of soil moisture can be quite different between the two. Interestingly, the USCRN station at Crossville, TN, is located in a position that tends to be moister than the stations placed in the surrounding 3 km, while the USCRN station at Millbrook, NY, is in a relatively dry place in its local area. The degree to which the USCRN at Millbrook is drier than its surroundings depends on scale, with the values at the station strongly drier compared to the entire 9 km grid surrounding the station, while somewhat dry but considerably closer to the values for the 3 km grid of test sites directly around the station, especially when wet. This is seen in both the cumulative distribution functions of the three measurements (point, 3 km, and 9 km), and in their percent difference time series (Figure 9). This research provides important insight into the utility of *in situ* measurements for validation of satellite and model estimates of soil moisture, and will be published in FY16.

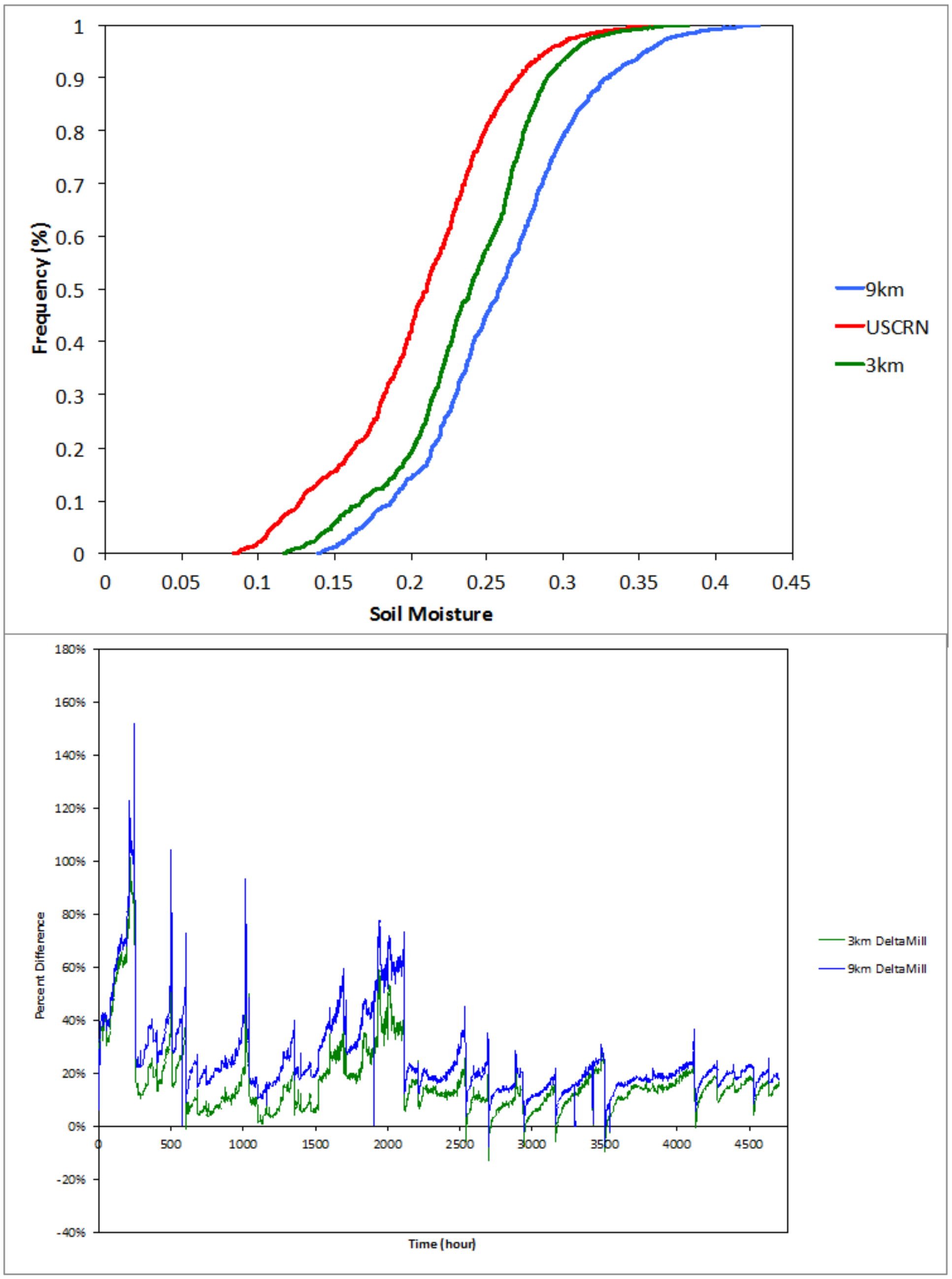


Figure 9. Cumulative distribution frequency plots and percent difference plots to demonstrate differences between the USCRN stations (red line) and the 3km (green line) and 9km (blue line) temporary grids near Millbrook, NY.

The representativeness study is being completed in support of the SMAP calibration/validation team use of sparse networks (i.e., individual stations) for validating satellite soil moisture estimates. Another activity done in support of SMAP is a gravimetric sampling program for about 15 stations in the central U.S. Actual samples of soil are gathered by cooperators at these stations at times when various soil moisture amounts are present, and these samples are weighed wet and weighed dry. The wet minus dry difference gives the weight of water in the soil sample, which can then be converted to volumetric soil moisture using the bulk density of the soil. As FY 15 ended, samples for several stations were still being processed, but results are useful at most stations completed so far. For example, in Figure 10, a regression equation was developed between the Manhattan, Kansas, USCRN station 5 cm soil moisture (as converted from the soil probe dielectric measurements) and the gravimetric samples. The slope and intercept indicate that the USCRN raw values slightly underestimate soil moisture when conditions are dry, and slightly overestimate soil moisture when conditions are moist (Figure 11). These results indicate the calibration would be useful for all the stations in the network, even if samples would need to be collected slowly as resources allowed. A set of calibration adjusted 5 cm depth soil moisture data will be released in FY16.

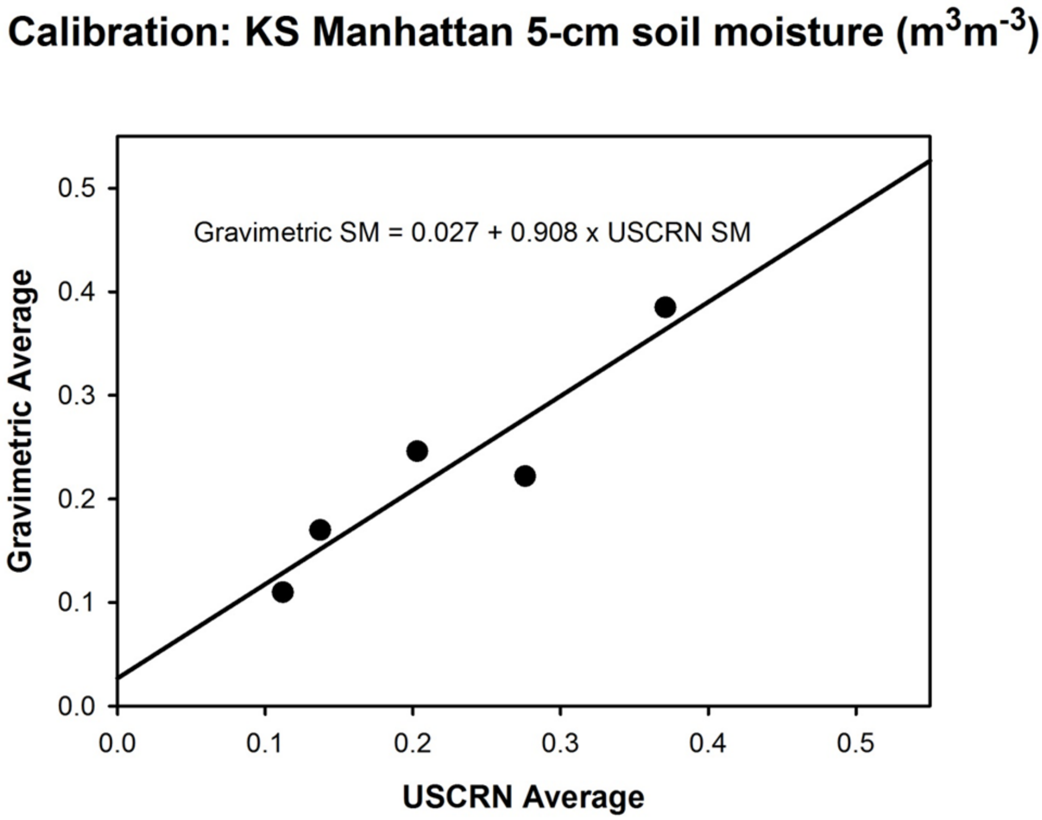


Figure 10. The relationship between volumetric soil moisture as determined by the USCRN station at 5 cm depth versus the averages of multiple gravimetric samples taken on 5 calendar dates with a range of soil moisture.

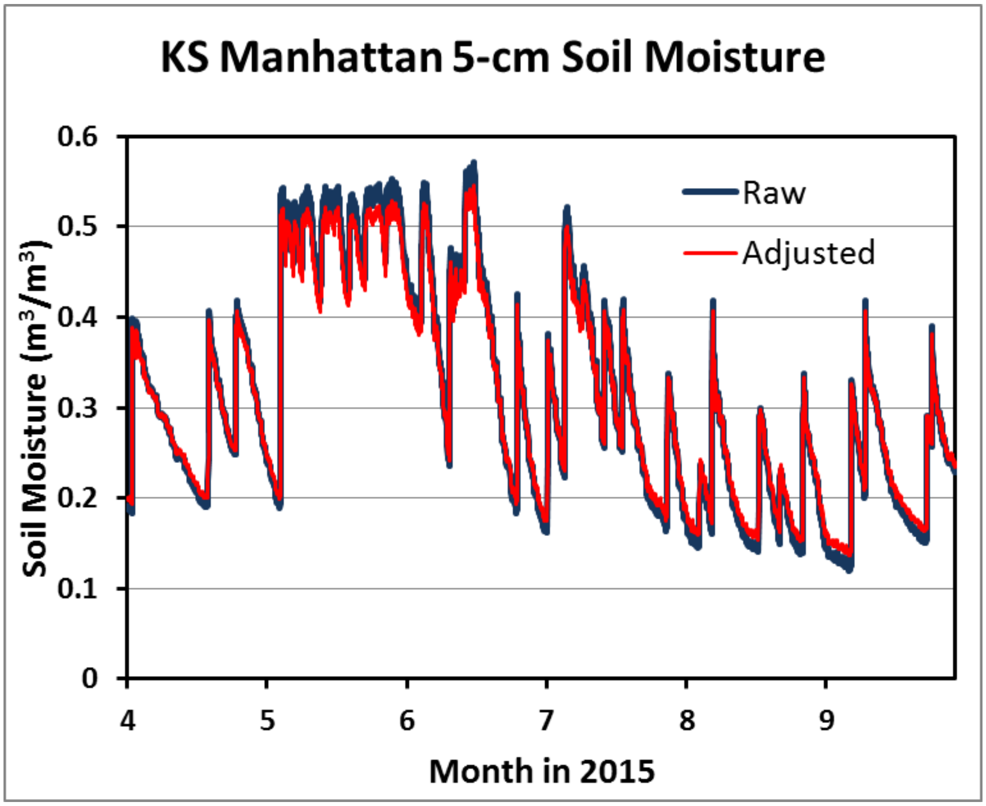


Figure 11. USCRN station near Manhattan, KS, raw soil moisture measurements at 5 cm (blue) compared to values adjusted using the equation in Figure 6 (red).

Another use of USCRN is as a reference network would be to compare *in situ* soil moisture observations to model output. One of the most important model types is a reanalysis model, which is designed to ingest all available atmospheric data and create a simulation that best describes those known data but also estimates conditions in other locations in a thermodynamically and dynamically balanced way. A project ongoing at the end of FY15 has as its goal the comparison of the North American Regional Reanalysis (NARR) surface soil moisture output and coincident but independent *in situ* measurements of soil moisture by the USCRN. The NARR calculates soil moisture based on atmospheric fluxes of heat and moisture predicted by the model, for a location at the middle of each 32 km resolution grid cell. The nearest grid cell on land was paired to each USCRN station, and precipitation and soil moisture differences were calculated and aggregated regionally and nationally for each month in 2011-2013. Interestingly, the NARR model output produced less precipitation than observed at USCRN stations (-13.6 mm/month), but conversely had wetter soils than observed (+0.05 m^3/m^3) on a national basis. Figure 12a shows that these nationally-averaged differences vary from month to month during the three year period, but are always positive. However, this does not mean that the model results are not useful, as the model produces a very similar cumulative distribution function to the observed data set (Figure 12b). Therefore, the model can reproduce the relative dynamic motion of soil moisture state, even though the absolute values may be off somewhat. This work will be published in FY16.

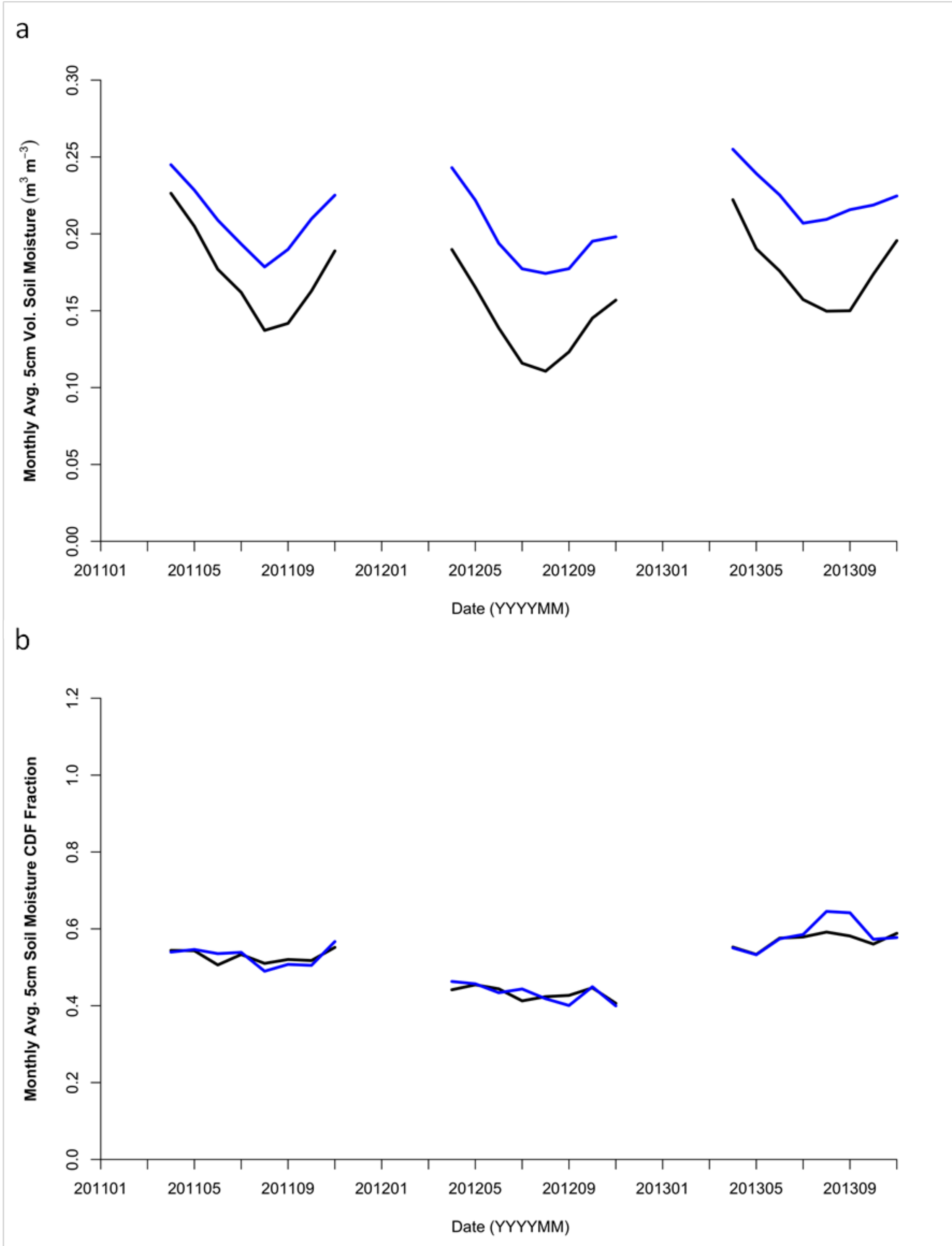


Figure 12. Time series of USCRN (black) and NARR (blue) national monthly averaged (a) volumetric soil moisture and (b) soil moisture CDF fraction. Cold season months are excluded because USCRN soil moisture measurement technology does not produce valid results for frozen soil.

Field and Testbed Activates

WMO-Solid Precipitation Intercomparison Experiment field measurements came to a close in 2015. In the spring of 2015 a meeting was held in Zaragoza, Spain to finalize the lead authorship of all the relevant final report and manuscript topics. Among the main precipitation topics to be addressed are errors associated with the measurement of trace precipitation, biases caused by wind speed, the effects of precipitation type and air temperature on the amount of precipitation recorded, differences between manual precipitation measurements and automated precipitation measurements, false accumulation during periods without precipitation, and errors associated with precipitation measurements from different types of weighing gauges, tipping bucket gauges, and non-catchment type gauges. In addition, a comparison of snow on the ground sensors will be made.

NOAA personnel have been actively involved with this project since it was conceived in 2010, and will remain involved until the final report is published in late 2016. NOAA/ARL/ATDD personnel are responsible for creating transfer functions that can be used to correct for precipitation under-catch in weighing gauges, for synthesizing a primary standard precipitation measurement at sites where only a tertiary standard exists, and for evaluating the site-specific effects of wind direction and snow depth on the wind speed measurements that are used to create precipitation transfer functions for all the gauges under test.

Monitoring Activity Highlights

New Network Record Wind Speed

A possible tornadic thunderstorm passed close to the Whitman 5 ENE USCRN site in western Nebraska mid-morning of June 21st 2015 (Figure 13). The storm produced a new USCRN record 10 second wind gust of 74 mph (33.02mps)(See 2nd graph below) . This value may seem low compared to other networks where gusts are typically measured for durations of only 1 to 3 seconds and at heights of 20 to 33 ft. (6 to 10m) above ground. The wind sensors at USCRN sites are exposed at only 5ft. (1.5m) above ground. If adjustments are made for these differences the peak gust at 33 ft. would likely have been about 85 to 90 mph (Figure 14).

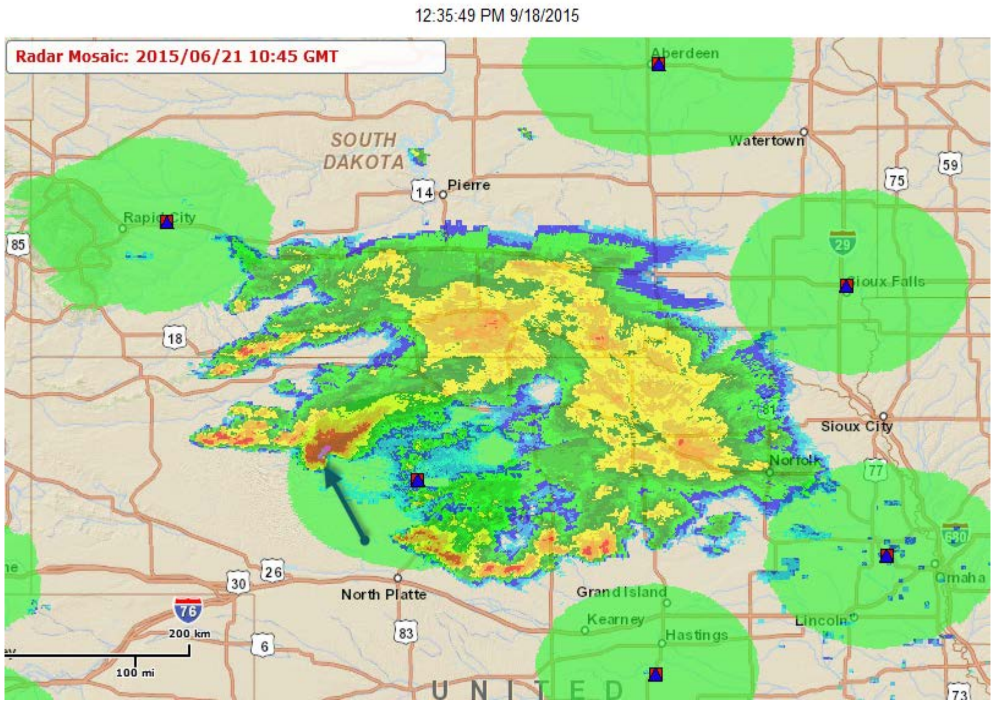
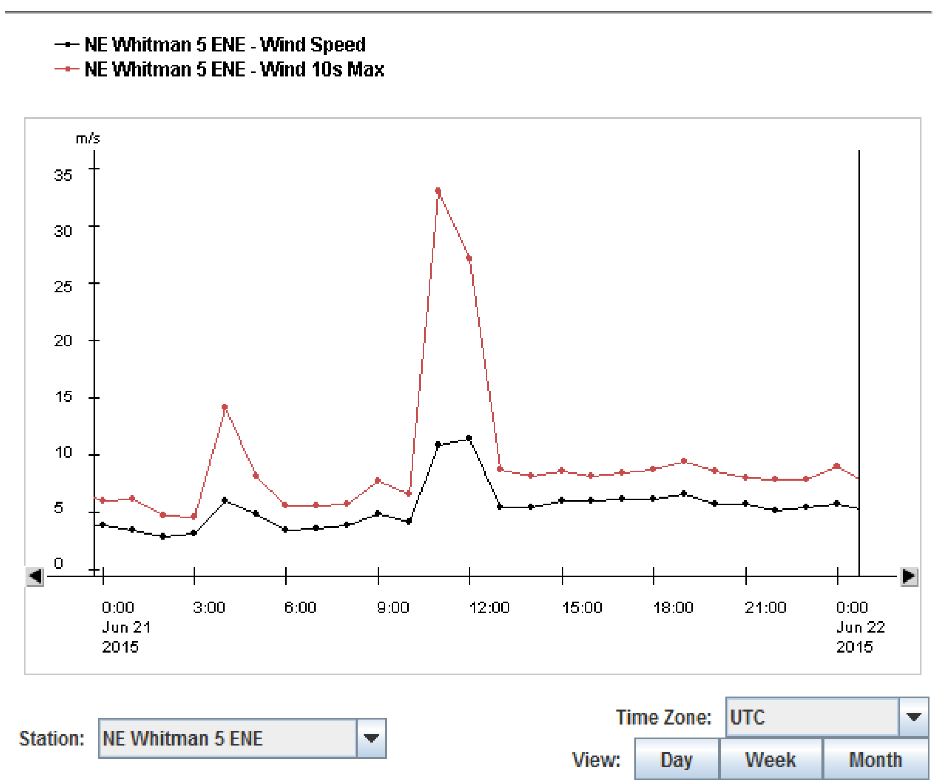


Figure 13. Radar image of western Nebraska on June 21, 2015. Whiteman 5 ENE USCRN station is located at the point of the green arrow.



Source: National Centers for Environmental Information/NESDIS/NOAA

Figure 14. Peak 1.5 meter wind speed for NE Whitman 5 ENE on June 21, 2015.

Comparison of minimum temperatures between two USCRN sites in NE Montana. Despite both sites being exposed to the same air mass, each is exposed to different local wind environments. This is particularly true during the night hours when the wind may become calm at one site and not the other. Figure 15 shows that on the morning of Jan. 4, 2015 (yellow arrows) the reported temperatures are only about 1 degree C/2F apart as winds pushed a cold air mass over the stations. However, several days later when the winds decreased, the Wolf Pt. 29 ENE site became calm and on the mornings of Jan. 7 and 12, 2015 (red arrows), the minimum temperatures at Wolf Pt. 29 ENE dropped to 11 and 13 degrees C/20 and 24F colder than those at the Wolf Pt. 34 NE site.

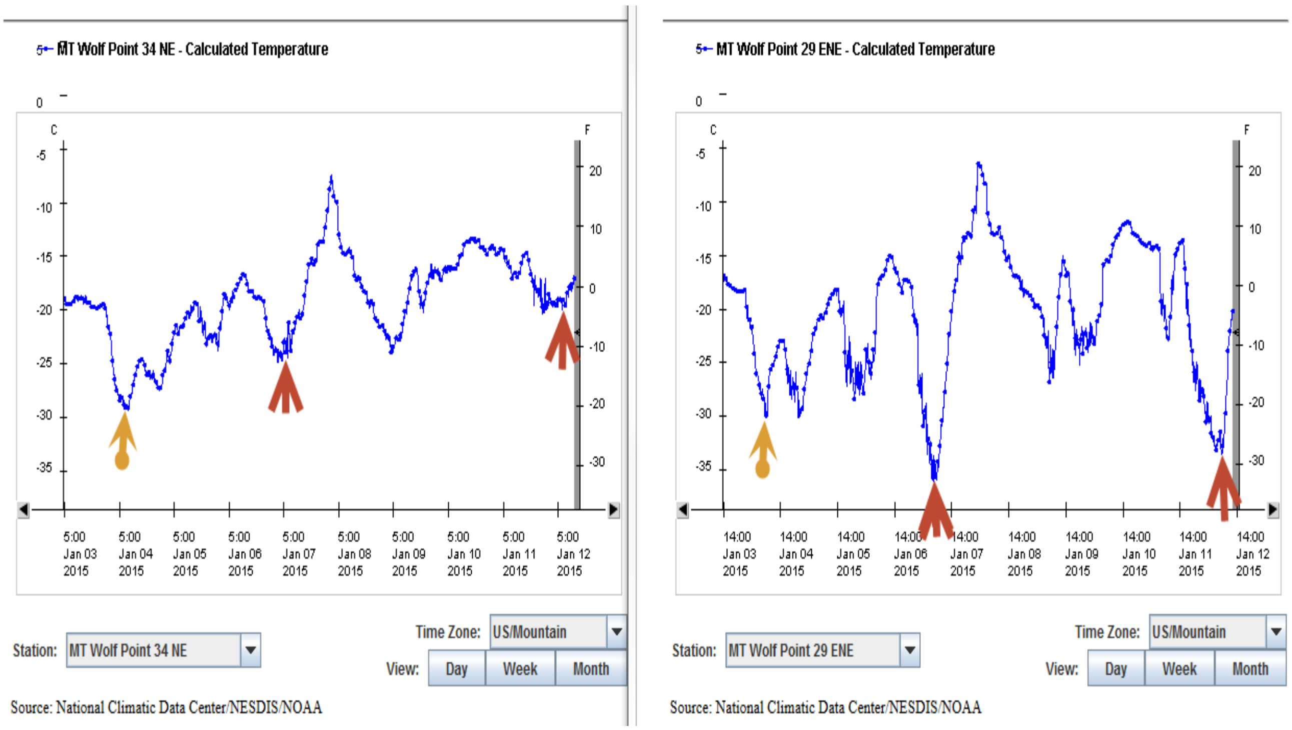


Figure 15. Minimum temperature comparisons between MT Wolf Point 34 NE (left) and MT Wolf Point 29 ENE (right).

Rapid temperature rise in shallow soil temperatures at the Shabbona 5 NNE, IL site.
In the last few years soil temperature and soil moisture sensors have been installed at five different depths at many of the USCRN sites. They are installed at 5, 10, 20, 50, and 100 cm (2, 4, 8, 20, and, 40 inches). Soil conditions at a few sites were too hard to allow engineers to dig to the deeper levels, and most of those sites only have sensors at the 5 and 10 cm levels. The figure below shows the change of soil temperature at all five depths over the period from Feb. 12 to March 20, 2015 at the Shabbona site in Northern Illinois (Figure 16). What is of interest is the rapid warming of the 5 and 10 cm temperature sensors (red and green lines), rising from about -9C (+16F) on Feb. 20 to +8C (+46F) by Mar. 17. Also of interest is the approximate five day pause in the rise of the temperatures at the 5 and 10cm depths between Mar. 7 and 12. This was primarily due to the extra calories of heat that was required to thaw the frozen water (ice) in the top layers of the soil. Once that was accomplished, the near surface soil temperatures were able to continue their late Winter- early Spring warming. One other item of interest is that the temperatures at the 50 and 100cm depths (tan and purple lines) continued to cool slightly despite the warming of the soil layers above.

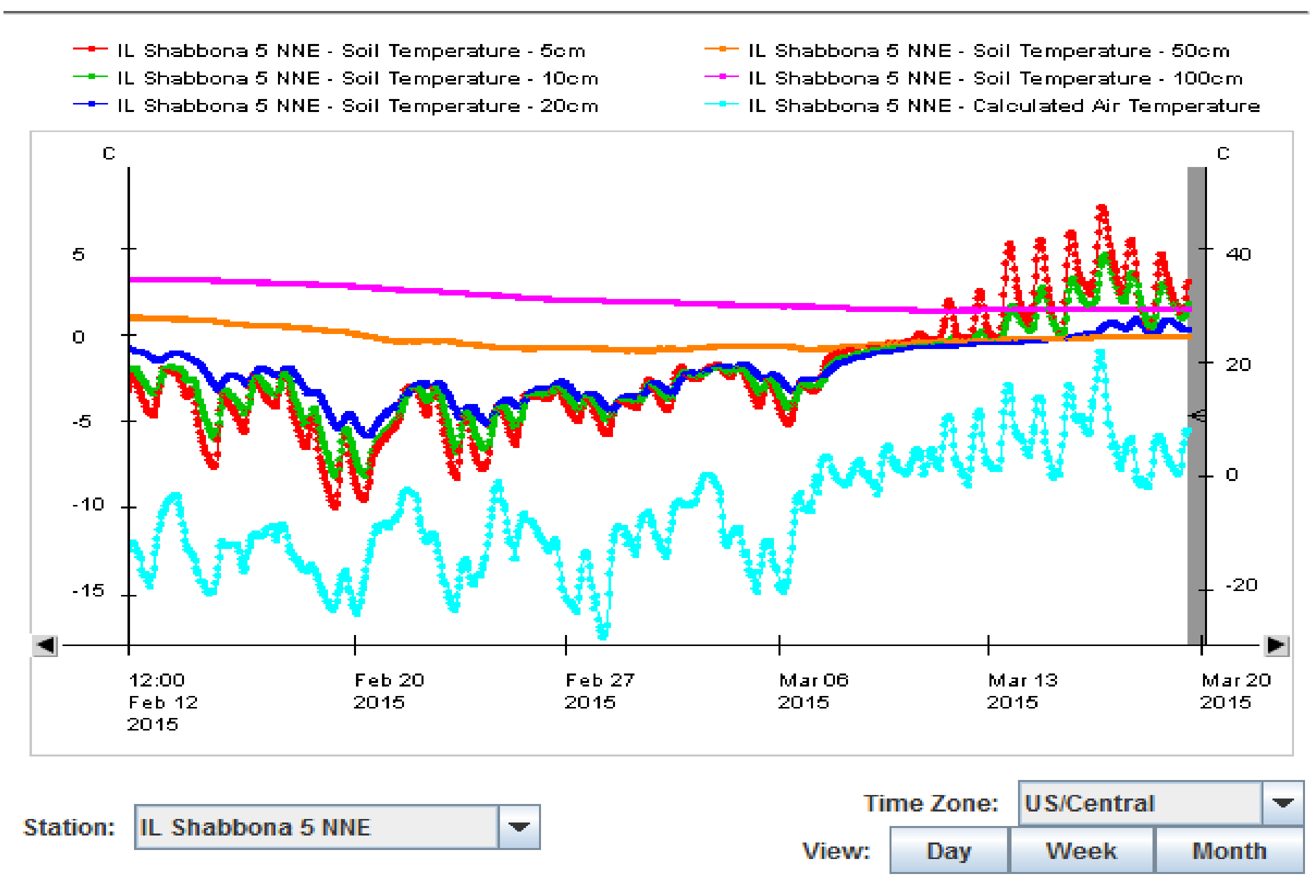


Figure 16. Variance in soil temperature changes at IL Shabbona 5 NNE.

Record wetness on the slopes of Mauna Loa, HI.

A record wet August at the USCRN site on the slopes of Mauna Loa, HI (Figure 17). Total rainfall for the month was 7.70"/195.6mm. The previous wettest August was 3.06"/77.72mm set last year (2014). Perhaps of greater significance is that it was also the greatest total for any month in the station's 10 year period of record. The previous wettest month was 6.02"/152.9mm set in December 2007.

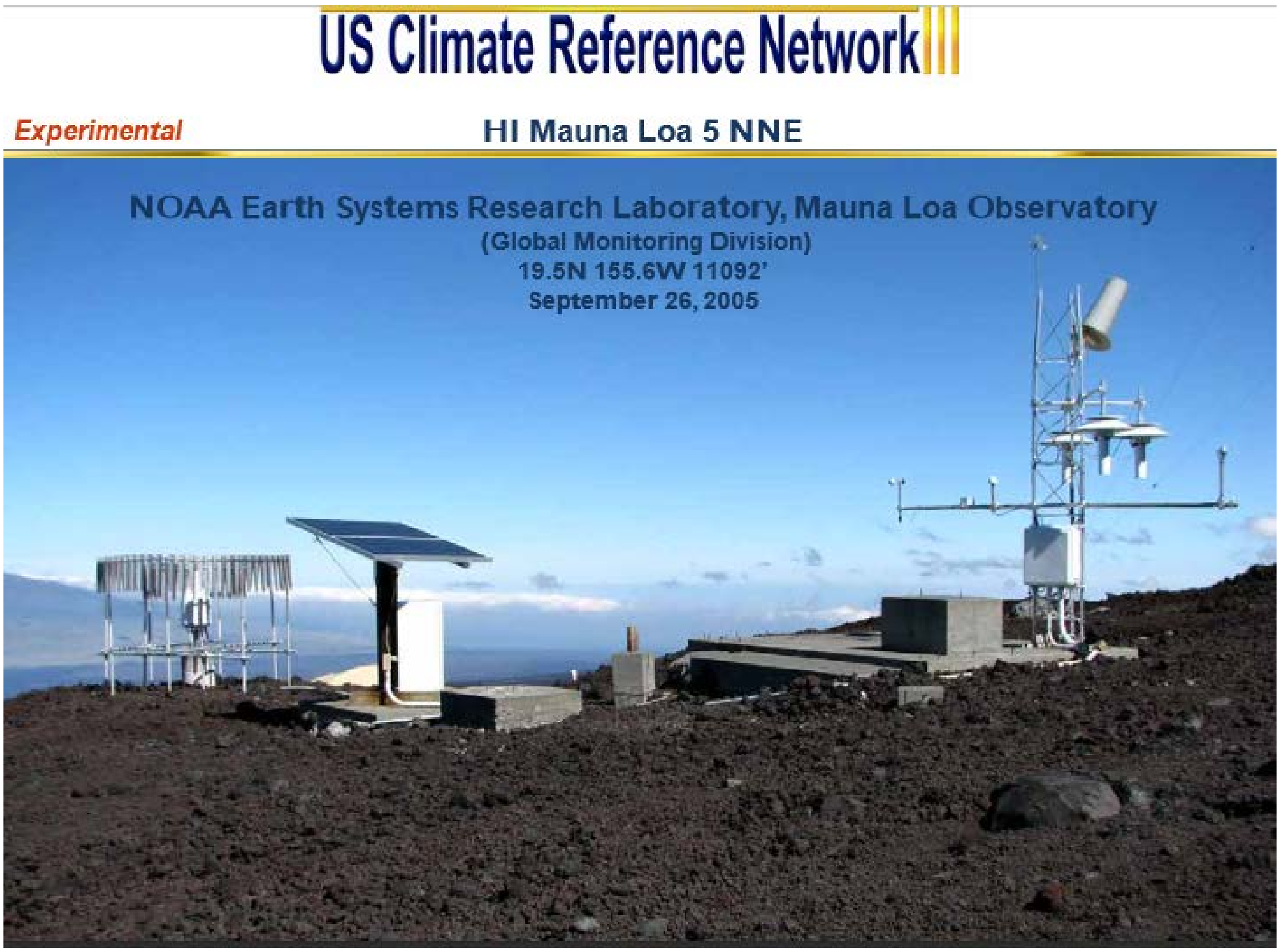


Figure 17. General site view of the USCRN station at HI Mauna Loa 5 NNE.

Extreme Rainfall Event Captured At The USCRN Site at La Junta, CO.
On September 22, 2015 a field of "monsoon" moisture moved Northeast through Southeastern Colorado. Slow moving thunderstorms developed mid-afternoon with two of the cells developing over the climate station and produced a total of 3.85 inches in 60 minutes. This total was by far above the 11 year period of record amount of 1.88". When compared to the analysis of all previous recorded rainfall events in the area the 3.85 inch amount was ranked as a once in a 750 year event by the **NOAA-14 Point Precipitation Frequency Estimate Atlas.** (Figure 18 below shows a radar scan of the storm cells and the location of the USCRN station).

Figure 18. Local NWS radar during the September 22, 2015 heavy precipitation event at La Junta.

Plans for FY16

A number of long-term science projects described above will continue during FY16, and several new projects will commence:

- Processing of precipitation exceptions should be completed by the end of FY16 Q2, thus allowing the start of exciting new science initiatives exploring precipitation extremes using the USCRN high temporal resolution observations later in FY16.
- A national precipitation index product will be developed during FY16.
- Soil moisture representativeness project will be completed and a paper submitted by the end of FY16 Q2.
- Comparisons of USCRN soil moisture observations to NARR soil moisture output will be completed and a paper submitted by the end of FY16 Q2.
- Experience gained in the FY15 soil moisture studies will be applied to the development of a drought monitoring index based on USCRN *in situ* observations. Multiple approaches will be explored in FY16.

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

- Make improvements to the USCRN web site to make access to data and information easier by employing more user-friendly entries to the various USCRN resources.

- Modernize Monthly reports on the USCRN website, making changes necessary to ensure data are consistent with other USCRN products.

- Upon approval by the USCRN Configuration Control Board complete final integration and deployment of the new precipitation algorithm into the USCRN Ingest software.

- Collaborate with Data Access and Analysis Branch to identify and implement methodologies for improving the speed and efficiency of USCRN database entry and updates.

Hardware testing and deployments will continue:

- A site survey trip to Alaska will take place during the summer 2016 season.

- 1-2 new station(s) will be deployed in Alaska during the summer 2016 building season bringing us closer to the eventual final total of 29 stations across Alaska.

- As many stations enter their second decade of service, the routine implementation of a refresh of critical equipment at stations around the network include the need for new back-up batteries, improved solar panels, replacement soil sensors, and repairs to precipitation shield fencing.

USCRN continues to play a larger role in monitoring U.S. climate change as it has entered its second decade of service; and the challenge is to continue the high-level of performance and data receipt that more and more users are taking advantage of.