US Climate Reference Network

Annual Report for Fiscal Year 2016

Compiled by the
National Oceanic and Atmospheric Administration
April 2017

Cover Photo:
Photo of the new USCRN station in the Tongass National Forest near Yakutat, Alaska. This station is the first one with a precipitation gauge placed on a platform to raise it above the extreme snow depths expected at the site at 132 inches above the ground. (Credit – Mark Hall)

Compiled on behalf of NOAA Jointly by:

NESDIS/National Centers for Environmental Information (NCEI)
151 Patton Avenue
Asheville, NC 28801-5001

OAR/Air Resources Laboratory (ARL)/Atmospheric Turbulence and Diffusion Division (ATDD)
456 S. Illinois Avenue
Oak Ridge, TN 37830

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

C. Bruce Baker, Director, ARL/ATDD
e-mail: bruce.baker@noaa.gov

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

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 FY16:

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

Preface and Introduction

During Fiscal Year 2016, the U.S. Climate Reference Network (USCRN) continued to make significant 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, 19 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 19 operational USCRN stations (18 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 FY2016

1. **Continuing to Push past the Halfway point in Alaska**
   In FY16, one new station was installed in Alaska in the Tongass National Forest in Yakutat, AK, thus bringing the network configuration in the state up to 19 out of a planned eventual total of 29 stations by FY 2022.

2. **Upgraded Power Systems at Five Stations in Alaska**
   Operating automated climate observing systems in Alaska presents some unique challenges both due to the typically harsh winter weather, as well as limited solar energy availability from December to February. Therefore, special emphasis was made during this year to upgrade the power systems at the sites in Deadhorse, King Salmon, Selawik, Sitka, and Tok. The upgrades involved reconfigured methane generators, the addition of wind generators, enhanced battery configurations, and changes to the power draw of selected instrumentation. These improvements will lead to more up-time of stations not on A/C power across Alaska.

3. **Software and Data System Improvements**
   A number of key data ingest, QC/QA, and website improvements have been made that include (a) an improved ingest software and database schema; (b) the reapplication of all quality control flags to raw station measurements in support of the new official precipitation algorithm 2.1; and (c) a significant software update to the USCRN Station Monitoring and Reporting Tool (SMART) software which has enhanced information content and improved reliability.

4. **Science and Development Activities**
   Progress continues in a number of areas including (a) Improvement of the data quality is critical to plans for the creation of a National Precipitation Index (NPI) product similar to the existing National Temperature Index; (b) continued work on the longstanding cooperation between the NASA Soil Moisture Active Passive (SMAP) Mission Calibration/Validation Team, consisting of USDA and NASA scientists; and (c) validating the North American Regional Reanalysis gridded soil moisture values with USCRN soil moisture data.

5. **New Sensor Technology**
   At the request of the Western Governors' Association (WGA), NOAA has taken the lead on the development and implementation of a National Integrated Drought Information System (NIDIS). As such, it is important for continual evaluation of new sensor technology, and an exhaustive comparative study was begun in the summer that will continue into FY17.

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, and Monitoring Activities
- Plans for FY 2017

FY 2016 Operational Activities in Alaska

Site Surveys: A significant program milestone has been met as all site surveys have now been completed for the 29 grid network in Alaska (Figure 1). This will give the program a way forward to complete the installation of the final 9 stations by the end of FY 2022.

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

Stations Installed: One new station (Yakutat) was installed in Alaska.

Stations Commissioned: Two stations (Nowitna and Selawik) were commissioned in Alaska.

In addition to the station installed in FY 2016 at Yakutat in the Tongass National Forest, one additional site is licensed and pending installation (Cordova). Licenses are pending from the 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 all 29 USCRN grids in Alaska (Figure 1). 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 2016. 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 2017, assuming funding arrives in a timely manner.

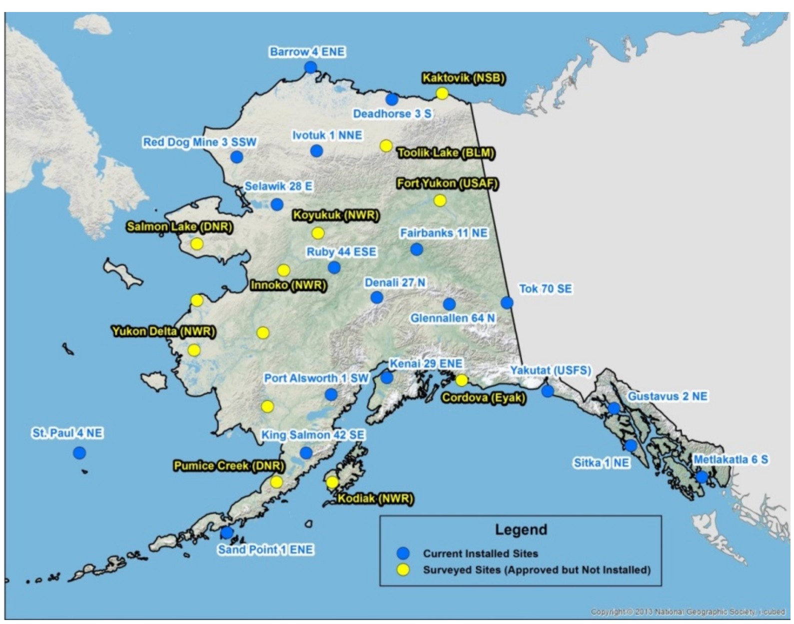


Figure 1. The map of USCRN stations in Alaska – existing and planned sites.

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%
2016	18	79.1%	78.6%

Table 2. USCRN in Alaska Data Receipt Rates (%) for FY 2016 by Quarter[1]

	Within 30 days	As of 9/30/16
Q1	91.0	91.0
Q2	84.1	84.6
Q3	96.7	96.7
Q4	98.6	98.6
Total	**92.6**	**92.7**

Table 3. FY 2016 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	9/2015
Ivotuk (Arctic Slope Regional Corp.)	05/07/2014	06/2014	9/2015
Ruby (Nowitna NWR)	05/29/2012	08/2014	9/2015
Selawik (Selawik NWR)	05/29/2012	08/2015	9/2016
Denali (Denali NP)	01/07/2015	08/2015	9/2016
Cordova (Eyak Corporation)	01/23/2013	TBD	TBD

[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.**

Yakutat (Tongass USFS)	06/28/2016	08/2016	TBD
Bethel (Yukon Delta NWR)	Pending	TBD	TBD
Fort Yukon (US Air Force)	Pending	TBD	TBD
Kodiak (Kodiak NWR)	Pending	TBD	TBD
Huslia (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
Toolik Lake (BLM)	Pending	TBD	TBD

FY 2016 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 FY16, the transition of the USCRN station operations of the OH Coshocton 8 NNE to the Ohio Agricultural Research and Development Center near Wooster, OH, was completed. In addition, the two stations at Goodwell, OK, continue to be run in parallel in order to continue to determine transfer functions from the old station (2E) to the new station (2SE).

Table 4. Overall USCRN Data Receipt Rates (%) for FY 2016 by Quarter (including Alaska)

	Within 30 days	As of 9/30/16
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**

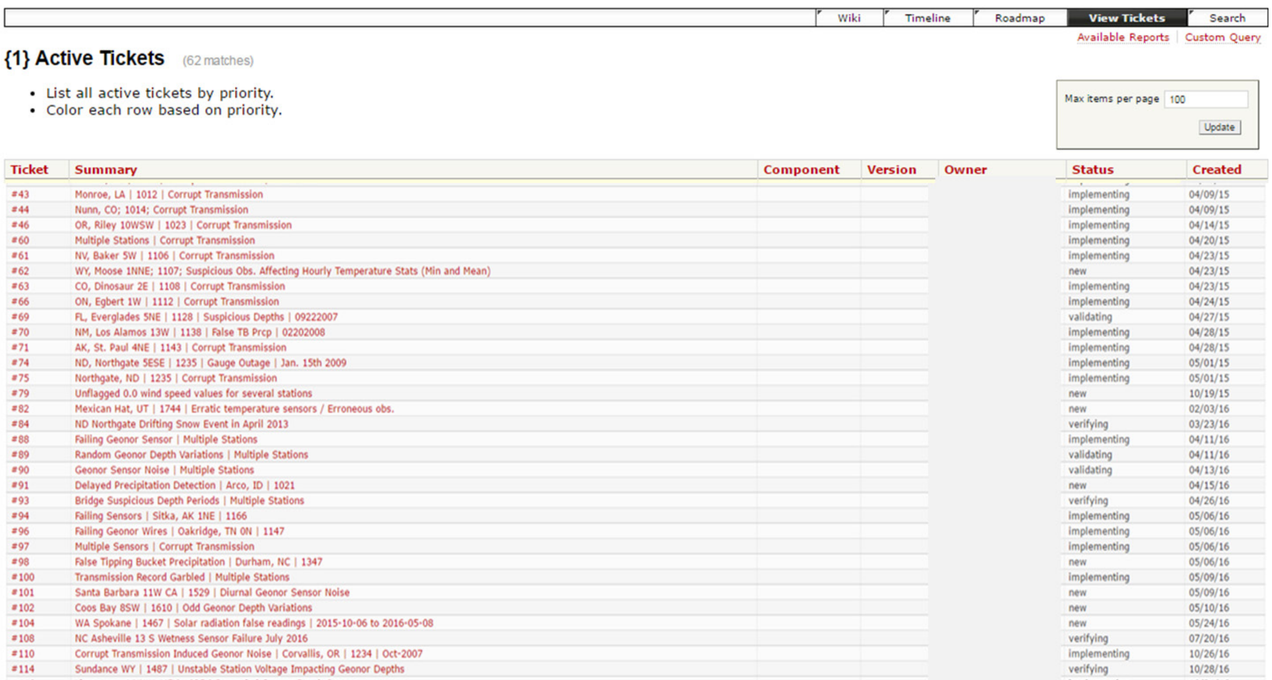
USCRN Data Processing, Monitoring, Access, and Product Systems

NOAA/NCEI continued to provide the operation and maintenance of USCRN data ingest, quality assurance, monitoring, access, and product systems in FY16. As in past years, the program's two computer programmers 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 various factors, many of which were associated with IT infrastructure. While doing this they also were able to make improvements to enhance the quality of USCRN data and improve performance of the USCRN database and access systems.

Ingest Quality Control and Performance Improvements

Numerous changes were made to USCRN's ingest software and database schema for the purpose of improving performance and implementing improved quality control. As a result, the Ingest software can now process large files without encountering memory issues, completing ingest of files twice as fast. It also can now retain a log of invalid observations for later evaluation.

Another significant change involved the functionality of processes that are used to invalidate inaccurate observations. This process was upgraded to make it easier to interactively apply quality control flags when exceptional situations occur that are outside the parameters that the USCRN automated algorithms can detect. Such quality control problems that are identified outside the automated quality control process are termed “exceptions”. The new system allows programmers to apply quality control flags for these exceptional circumstances via a manually updated list used by the ingest software. Each exception is thoroughly investigated by scientists, documented in USCRN’s issue tracking software (Trac; see Figure 2), vetted by the USCRN Configuration Control Board via Configuration Change Requests, and if accepted, added to the exception list. The updated list is committed to Subversion (an additional tracking and documentation mechanism), the software deployed, and scripts are run to flag and recalculate the affected data. To improve the efficiency and accuracy of the manual input of exceptions on the exception list, the ingest software was upgraded to support aliases for collections of element names. See section the Manual Flagging of Observation Exceptions for additional details.



Wiki | Timeline | Roadmap | View Tickets | Search

Available Reports | Custom Query

{1} Active Tickets (62 matches)

- List all active tickets by priority.
- Color each row based on priority.

Max items per page 100 Update

Ticket	Summary	Component	Version	Owner	Status	Created
#43	Monroe, LA | 1012 | Corrupt Transmission				implementing	04/09/15
#44	Nunn, CO; 1014; Corrupt Transmission				implementing	04/09/15
#46	OR, Riley 10WSW | 1023 | Corrupt Transmission				implementing	04/14/15
#60	Multiple Stations | Corrupt Transmission				implementing	04/20/15
#61	NV, Baker 5W | 1106 | Corrupt Transmission				implementing	04/23/15
#62	WY, Moose 1NNE; 1107; Suspicious Obs. Affecting Hourly Temperature Stats (Min and Mean)				new	04/23/15
#63	CO, Dinosaur 2E | 1108 | Corrupt Transmission				implementing	04/23/15
#66	ON, Egbert 1W | 1112 | Corrupt Transmission				implementing	04/24/15
#69	FL, Everglades 5NE | 1128 | Suspicious Depths | 09222007				validating	04/27/15
#70	NM, Los Alamos 13W | 1138 | False TB Prcp | 02202008				implementing	04/28/15
#71	AK, St. Paul 4NE | 1143 | Corrupt Transmission				implementing	04/28/15
#74	ND, Northgate 5ESE | 1235 | Gauge Outage | Jan. 15th 2009				implementing	05/01/15
#75	Northgate, ND | 1235 | Corrupt Transmission				implementing	05/01/15
#79	Unflagged 0.0 wind speed values for several stations				new	10/19/15
#82	Mexican Hat, UT | 1744 | Erratic temperature sensors / Erroneous obs.				new	02/03/16
#84	ND Northgate Drifting Snow Event in April 2013				verifying	03/23/16
#88	Failing Geonor Sensor | Multiple Stations				implementing	04/11/16
#89	Random Geonor Depth Variations | Multiple Stations				validating	04/11/16
#90	Geonor Sensor Noise | Multiple Stations				validating	04/13/16
#91	Delayed Precipitation Detection | Arco, ID | 1021				new	04/15/16
#93	Bridge Suspicious Depth Periods | Multiple Stations				verifying	04/26/16
#94	Failing Sensors | Sitka, AK 1NE | 1166				implementing	05/06/16
#96	Failing Geonor Wires | Oakridge, TN 0N | 1147				implementing	05/06/16
#97	Multiple Sensors | Corrupt Transmission				implementing	05/06/16
#98	False Tipping Bucket Precipitation | Durham, NC | 1347				new	05/06/16
#100	Transmission Record Garbled | Multiple Stations				implementing	05/09/16
#101	Santa Barbara 11W CA | 1529 | Diurnal Geonor Sensor Noise				new	05/09/16
#102	Coos Bay 8SW | 1610 | Odd Geonor Depth Variations				new	05/10/16
#104	WA Spokane | 1467 | Solar radiation false readings | 2015-10-06 to 2016-05-08				new	05/24/16
#108	NC Asheville 13 S Wetness Sensor Failure July 2016				verifying	07/20/16
#110	Corrupt Transmission Induced Geonor Noise | Corvallis, OR | 1234 | Oct-2007				implementing	10/26/16
#114	Sundance WY | 1487 | Unstable Station Voltage Impacting Geonor Depths				verifying	10/28/16
#116	Limestone 4 NNW, ME | 1035 | Degraded Geonor Depth Sensor				implementing	10/31/16

Figure 2. Example of exceptions logged in the USCRN Trac system. Each registered exception is classified as new until it enters the process of being validated, reviewed, implemented and verified.

An additional improvement made in 2016 involved a metadata correction for 15-minute depth measurements, which were made early in USCRN’s period-of-record before the upgrade to 5-minute depth measurements. The metadata tags that were originally used for 15-minute measurements were repurposed for 5-minute measurements without reassigning the existing 15-minute measurements to a different metadata tag. As a result, without this improvement, any attempt to use the 5-minute dataset would give misleading results whenever 15-minute measurements were unintentionally included.

Official Precipitation Algorithm 2.1 and QC Reprocessing

Additional improvements were made as part of the upgrade of the Official Precipitation Algorithm from v2.0 to v2.1 (see Science and Development Activities section write-up). As part of this upgrade, refinements were made to USCRN's automated quality control range-checks for relative humidity and fan speeds. In order to apply these changes, the USCRN database had to be reprocessed. This involved reapplying all quality control flags to raw station measurements, recalculating all derived elements, and overwriting previously stored data. With the software configuration at that time, the reprocessing was estimated to take three months to complete, throughout which customers would see a mixture of the different quality control and precipitation algorithms. To reduce this time to a manageable period, several parts of the USCRN Ingest software were redesigned. This resulted in the processing taking only two weeks, a fraction of the time previously possible. After the reprocessing, precipitation and quality control flags were evaluated to ensure their correctness.

Station Monitoring and Reporting Tool (SMART) Improvements

In order to enhance information content and improve reliability, USCRN's Station Monitoring and Reporting Tool (SMART) software was significantly modified in 2016. This software tool provides engineers, scientists, and maintenance personnel with information on the status of each instrument on all USCRN stations. Features added include color-coding reported events so that their importance and longevity can be known at a glance. Instruments that have failed or have operated below maximum efficiency for a period less than one week are coded yellow, those between one and two weeks are coded blue, those beyond two weeks are coded black, and stations outages are coded red. In addition, graphic markers were added to indicate sensors that are under manual quality control, and a tabular format that is more condensed and more readable was added. In addition to the feature improvements, several long-running difficulties were resolved. The software no longer depends directly on the USCRN Ingest software, and can operate from any environment that offers access to the USCRN database. This has drastically simplified the software along with improving its reliability.

Archive Submission Agreement Revision and Implementation

An initiative was undertaken to develop two new Submission Agreement (SA) and process flows in FY16. One was completed and the second will be completed in FY17. A new SA for USCRN's FTP products and processed data was developed with NCEI's Archive Branch (DSD/AB) and went into effect during FY16. The software was modified to meet new requirements for archive data and metadata format. Files are generated and automatically sent to Archive on the specified schedule in the required format. The second archive process is needed to ensure raw and experimental USCRN data are properly documented and archived. This is to include ingested data from LRGS and NOAAPort sources and experimental data from the sites at Sterling, VA, Johnstown, PA, Marshall test bed in Boulder, CO, and Tiski, Russia. Working with personnel in AB, work flows were developed and draft documentation written including new and updated Readme files. Data from the experimental sites was collected and organized in preparation for submission to the archive in FY17. DSD/AB is providing ongoing guidance on the proper formats for submission of all data to the archive, and USCRN's software will be modified to match the requested data flow and format.

Multigraph and Website Updates

Due to changing practices in the Java and web browser ecosystem, USCRN's original graphing software, known as Multigraph, is becoming obsolete. To meet evolving security requirements, there was a need to transition from graphing tools based on Java Applets to tools based on JavaScript. To avoid interruption of services to partners that may have legacy web browser applications, a transitional upgrade was implemented on the USCRN website. The website continues to provide users the ability to visualize USCRN graphs using Java applets if their web browsers continue to provide only applet support. Otherwise a JavaScript-based distribution of Multigraph is now provided. This new distribution of Multigraph does not yet have every feature of the original, but new features continue to be added to meet user needs. These include new features such as highlighting of flagged values and accumulating line graphs for precipitation that have been specially requested by ATDD engineers and quality control specialists. Additionally, static and dynamic webpages have been improved. Geonor gauge reports have been implemented to aid ATDD engineers in monitoring stations while news and documentation pages have been actively updated.

Production Server Migration and Upgrade of OpenDCS/LRGS Server

The server running USCRN production processes is approaching its end-of-life. To avoid any interruption of operations and mitigate potential issues, the USCRN programmers migrated each software process one-by-one to a new production environment established as a virtual server. Most processes have been successfully migrated and the remaining changes will be complete in early FY17. This transition was additionally useful as an opportunity to catalogue and clean several years of files that were temporary or otherwise unnecessary for development and operations.

Along with the migration to a new production-level server, USCRN's OpenDCS (previously called LRGS) software has been upgraded to the latest software release. This software is responsible for managing the acquisition of USCRN data from Wallops, VA and the EDDN data distribution service at the USGS EROS Data Center in Sioux Falls, South Dakota. This upgrade was mandatory since Wallops and EDDN, the primary and secondary data sources for USCRN data were required to improve security through implementation of better encryption and user authentication. Since the upgrade all LRGS and DOMSAT services have run without issue.

Operational quality control processes for soil moisture/temperature data

Following the implementation of improved processes for quality control of soil moisture/temperature in FY15, further changes were made in FY16 to streamline and improve the efficiency of this largely manual task which must be performed monthly. At most USCRN locations, measurements of soil temperature and soil moisture are made at five depths from 5 to 100 cm in three plots surrounding the USCRN tower. The large number of sensors combined with the environment in which the sensors operate requires continuing attention to identify potential instrument problems. The USCRN computer programmers continued to support USCRN scientists in the monthly assessment through on-the-fly production of soil measurements plots including plotting sensors individually, and producing 3-panel graphs with statistics on soil sensor values (dielectric constants, precipitation, and volumetric soil moisture). These are shared with researchers and ATDD for the evaluation of sensor performance, providing for a more thorough quality control process for soil moisture and temperature measurements. In addition, monthly soils summary documentation for scientists and management began to be produced and information pertinent to upcoming annual maintenance visits was provided to ATDD each month.

Other Quality Control and Processing improvements

As part of the OAP v2.1 reprocessing, software documentation was updated, USCRN products were recreated, and data and comparative analysis were provided to the USCRN scientists for comparing and assessing changes associated with the version upgrade. Out-of-range/incorrect data values for relative humidity and Geonor wire depths were properly flagged during the precipitation reprocessing. Quality control ranges for these variables had changed in recent years but had not been retroactively applied to the data in the database. This reprocessing applied the proper ranges to every variable for the period of record data.

North Carolina Arboretum Data Analysis

The site host of the Asheville Arboretum requested an analysis of how temperature and precipitation affected attendance. To do this, USCRN programmers supported scientists by extracting attendance records from old database files that were provided by the Arboretum from an antiquated system that made data extraction and assimilation difficult. The data extraction was successful, and approximately two years of anonymous attendance records were recovered and provided for the analysis.

<u>USCRN Science and Development Activities</u>

The USCRN Science Team made a great deal of progress on two critical tasks: 1) completing the manual quality control of tens of thousands of suspicious gauge depth values detected by the quality control additions to the new precipitation algorithm; and 2) continuing the scientific examination of the precipitation and soil moisture observations and the development of use-driven products. The latter set of activities included external collaborators. In addition, the team quality controlled and curated the observational data, using a newly developed method to flag manually bad observations that were not detected by automated quality control. Participation in the World Meteorological Organization's Solid Precipitation Experiment (WMO-SPICE) continued, both as a contributor of data using the CRN/NCAR testbed at Marshall CO, and as active participants in the scientific analysis. Finally, several brief but interesting studies were undertaken to illustrate the utility of USCRN station observations to a local site host, and to units in the U.S. National Park System.

Precipitation QC and Extremes

While no publications have yet resulted from the FY 16 precipitation work, it did consume more than half the science work time spent in this year. Improvement of the data quality is critical to plans for the creation of a National Precipitation Index (NPI) product similar to the existing National Temperature Index. The improved data will also be used in generating new estimated monthly normals required for the NPI development. An initial test of the ability of the USCRN to represent the national precipitation record was conducted prior to the completion of all quality control improvements. Monthly precipitation totals averaged across all 114 stations compared to NOAA Global Historical Climate Network precipitation data for the same locations revealed a very high correlation, much closer than a reanalysis model also included in the comparison (Figure

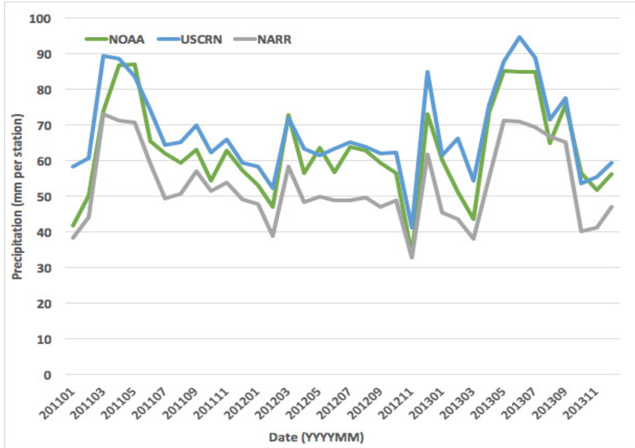


Figure 3. National monthly precipitation average at USCRN locations for: USCRN stations (blue), NOAA GHCN stations (green), and the North American Regional Reanalysis Model (gray).

During the summer of 2016, the USCRN Science Team hosted a NOAA Hollings Scholar, Emma Scott, for a summer internship. She was able to lay the groundwork for a major project examining extreme precipitation statistics as USCRN stations. Precipitation event lengths from 5 minutes to 30 days were calculated every 5 minutes, and then sorted by amount to identify the most extreme event for each station and time interval, and also use these calculations to count the number of independent events that exceeded the 1-year, 2-year, and 5-year return period values derived from NOAA Atlas 14. The record extremes also proved useful in identifying some previously undetected outliers that were flagged. Most importantly, it appears that the USCRN network detects many more heavy precipitation events of sizes less than 1 day than expected from NOAA Atlas 14 (Figure 4). This has two important implications: 1) heavy precipitation events have become more frequent in the USCRN era compared to the NOAA Atlas 14 thresholds, based on 30-40 years of data; and/or 2) the USCRN gauges are simply better at catching precipitation during heavy events. Further research is currently being done to examine these possibilities and prepare this project for publication.

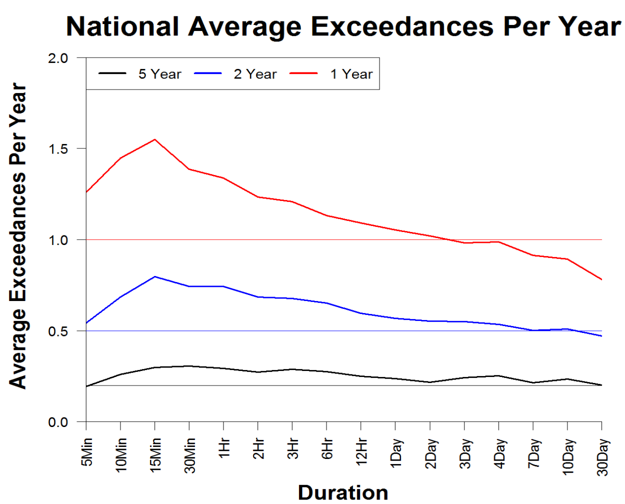


Figure 4. USCRN stations see up to 50% more precipitation events that exceed 1-year, 2-year, and 5-year return period thresholds for events of less than one day length.

Soil Moisture Utilization and Applications

During FY15 and FY16, the USCRN Science Team collaborated with groups of external researchers who used USCRN soil moisture observations to assess the validity of algorithms used to translate passive microwave remote sensing brightness temperatures to estimate of surface soil moisture:

Chan, S. K., R. Bindlish, P. E. O'Neill, E. Njoku, T. Jackson, A. Colliander, F. Chen, M. Burgin, S. Dunbar, J. Piepmeier, S. Yueh, D. Entekhabi, M. H. Cosh, T. Caldwell, J. Walker, X. Wu, A. Berg, T. Rowlandson, A. Pacheco, H. McNairn, M. Thibeault, J. Martínez-Fernández, Á. González-Zamora, M. Seyfried, D. Bosch, P. Starks, D. Goodrich, J. Prueger, **M. Palecki**, E. E. Small, M. Zreda, J. Calvet, W. T. Crow, and Y. Kerr, 2016: Assessment of the SMAP Passive Soil Moisture Product. IEEE Trans. Geosci. Rem. Sens., 54 (8), 4994-5007. doi: 10.1109/TGRS.2016.2561938

Coopersmith, E. J., M. H. Cosh, R. Bindlish, and **J. Bell**, 2015: Comparing AMSR-E soil moisture estimates to the extended record of the US Climate Reference Network (USCRN). Advances in Water Resources, 85, 79-85.

This work continued the longstanding cooperation between the NASA Soil Moisture Active Passive (SMAP) Mission Calibration/Validation Team, consisting of USDA and NASA scientists predominantly. USCRN provides access to soil moisture measurements used for direct comparisons, and, eventually, the development of models of soil moisture with depth. A particularly productive relationship exists with USDA ARS scientist Michael Cosh and his research associate Evan Coopersmith. Their cooperation with the USCRN Science Team extends our ability to reach the remote sensing user community and aid them in developing more useful soil moisture products for many users. The AMSR-E study in particular involved extending the existing soil moisture time series using the longer USCRN precipitation record and a genetic algorithm for relating precipitation to soil moisture. This was successful in building a time series with a RMSE of less than 0.033 m^3/m^3, and doubling the time period length for comparison to the satellite record.

Coopersmith and Cosh also collaborated with the Science Team on further efforts to characterize USCRN and USDA SCAN (Soil Climate Analysis Network) soil moisture observations so as to improve their utility to the user community:

Coopersmith, E.J., M. H. Cosh, **J. E. Bell**, and W. Crow, 2016: Multi-profile analysis of soil moisture within the climate reference network. Vadose Zone Journal,15(1)

Coopersmith, E. J., M. H. Cosh, **J. E. Bell**, V. Kelly, M. Hall, **M. A. Palecki**, and M. Temimi, 2016: Deploying temporary networks for upscaling of sparse network stations. International Journal of Applied Earth Observation and Geoinformation, 52, 433-444. doi: 10.1016/j.jag.2016.07.013

The latter study was the culmination of a field campaign performed at two USCRN stations near Millbrook, NY, and Crossville, TN, where a temporary network of additional soil moisture probes was installed with the assistance of USCRN partners at the NOAA Atmospheric Turbulence and Diffusion Division (ATDD) and the USDA. The comparison (Figure 5) showed

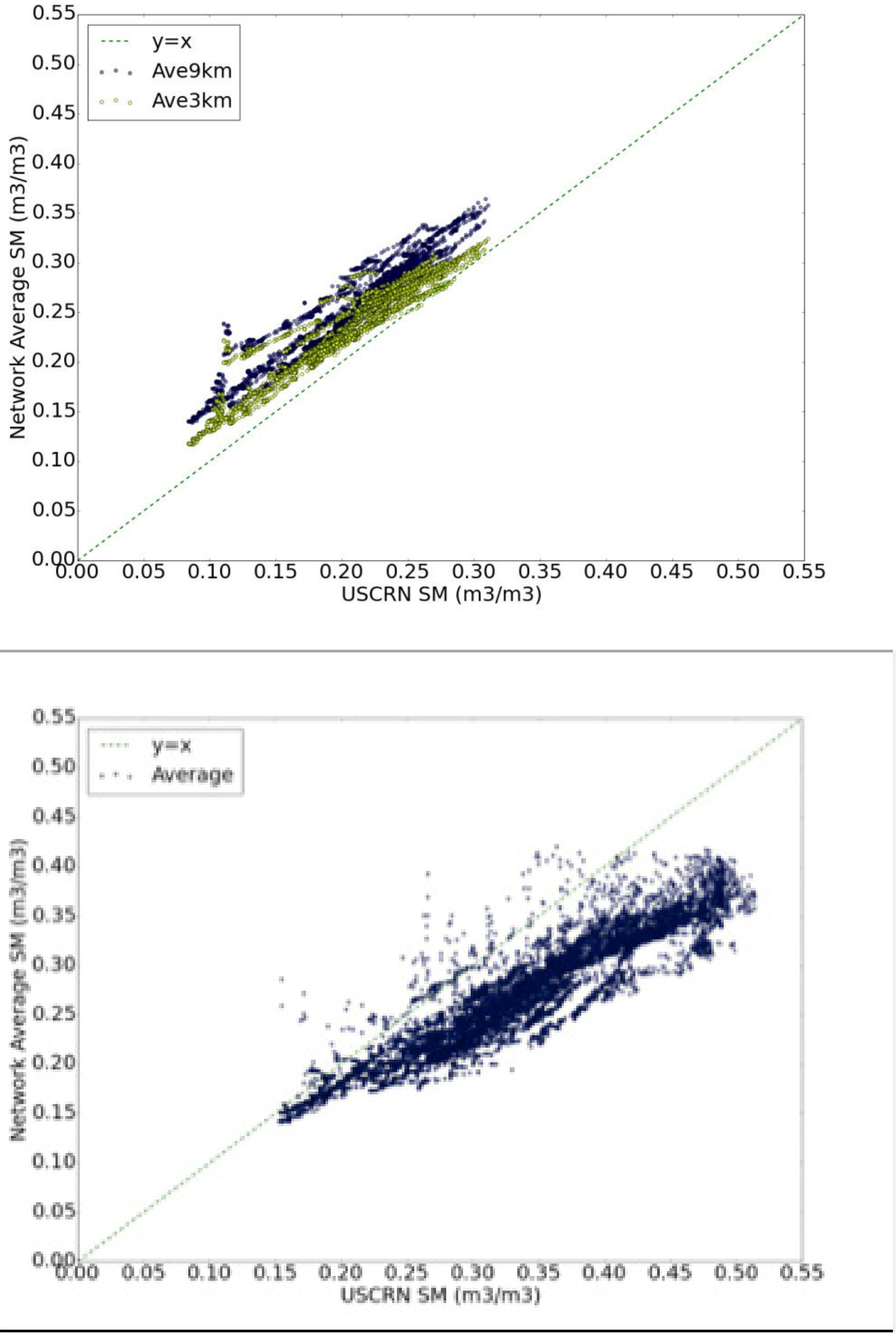


Figure 5. USCRN soil moisture vs. temporary network average at 3km (green dots) and 9km (blue dots) scales at Millbrook (top - a) and USCRN vs. temporary network at Crossville (bottom - b).

that the relationship of the soil moisture at 5-cm depth at the USCRN station at Millbrook was linear but slightly drier than the area it represents, while the soil moisture at 5-cm depth at Crossville station was both wetter than its surroundings and had a distinctly nonlinear relationship with the surrounding area when conditions were most moist. This study illustrates the value of having a multi-sensor environment in calibrating single point soil moisture measurements to their surrounding areas.

The final paper accepted for publication during FY16 was designed to compare modeled and measured soil moisture:

Leeper, R.D., J. E. Bell, C. Vines, and **M. A. Palecki**. An evaluation of the North American Regional Reanalysis simulated soil moisture conditions during the 2011 to 2013 drought period. J. of Hydrometeorology. doi: 10.1175/JHM-D-16-0132.1.

This is especially important in terms of validating the North American Regional Reanalysis (NARR) model that is widely used in myriad applications, and also addressing the more fundamental question of how to compare station and grid soil moisture values. As shown earlier in Figure 3, more precipitation was observed in the USCRN network than at the same grids in the NARR model. However, it was found that the NARR model soil moisture tended to be wetter than the USCRN soil moisture observations, a distinctly puzzling outcome caused by the soil model constraints and assumptions within the NARR model (Figure 5a). However, the Science Team was able to show that if both the USCRN and NARR soil moisture data sets were standardized in a similar manner, their month-to-month variations were much more closely related than their raw magnitudes (Figure 5b). This finding leaves open the possibility of utilizing the model soil moisture data for many purposes, as long as a user standardizes the soil moisture data for applications or restores the standardized values to magnitude values using a calibration to observations.

This work has led to the determination that USCRN soil moisture values need to be associated across geography and with other observation networks and models through a process of standardization that is based on Z-scores. This proves to be especially true when monitoring drought with USCRN soil moisture data. It is very difficult to relate soil moisture magnitude to drought status directly, as the same levels of soil moisture indicate wholly different drought status at locations with disparate soil characteristics and climates. For example, the same soil moisture levels in southern Nevada and in east Texas may indicate that the Nevada site is wetter than normal, while the Texas site is drier than normal (Figure 6a). If these values are standardized to the local climatology and these standardized departures accumulated over time, a much closer match to other indicators of drought status is found (Figure 6b). This work is the beginning of the major FY17 project to produce soil moisture indices using USCRN soil moisture measurements that will be useful for monitoring drought status across the conterminous United States.

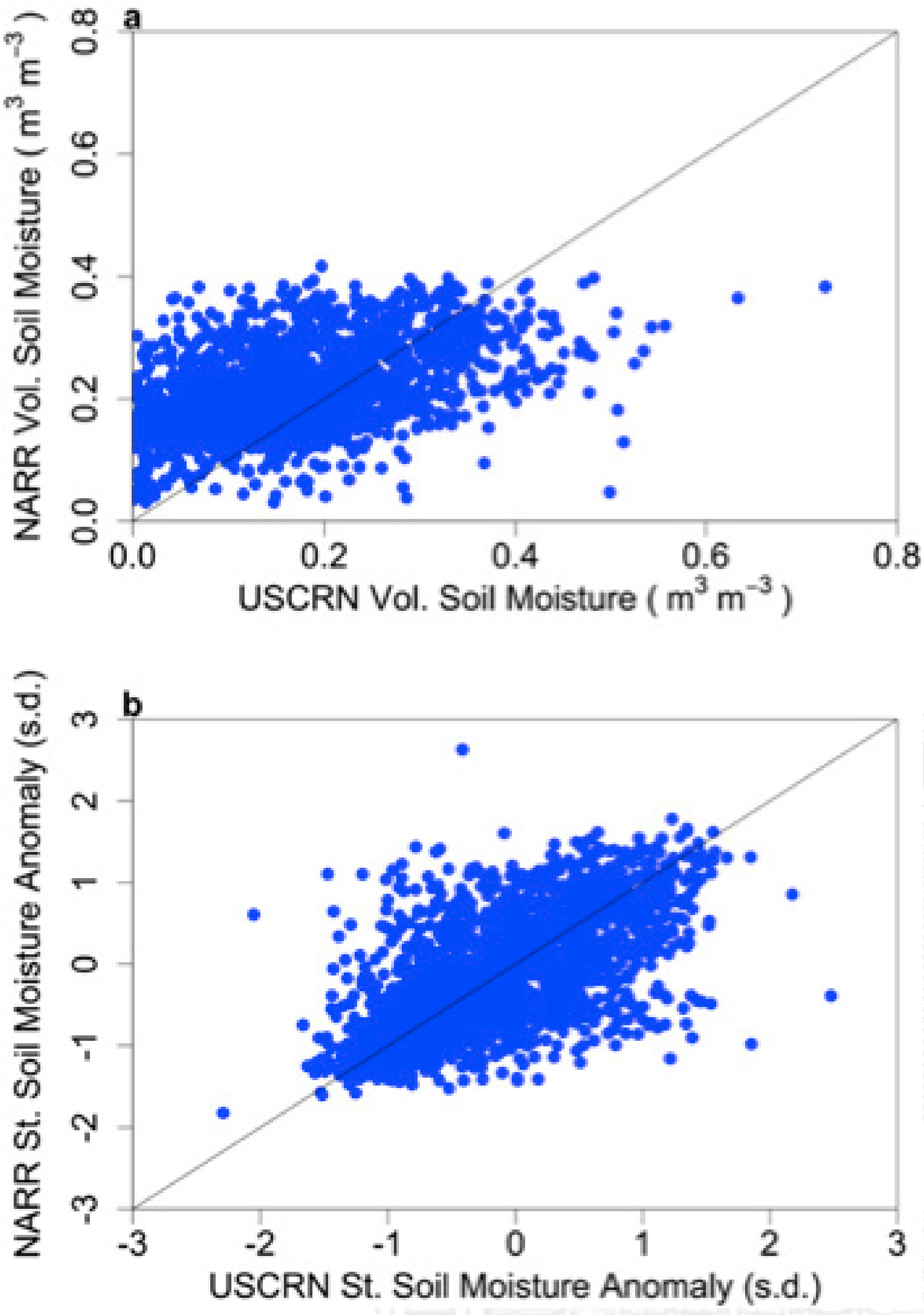
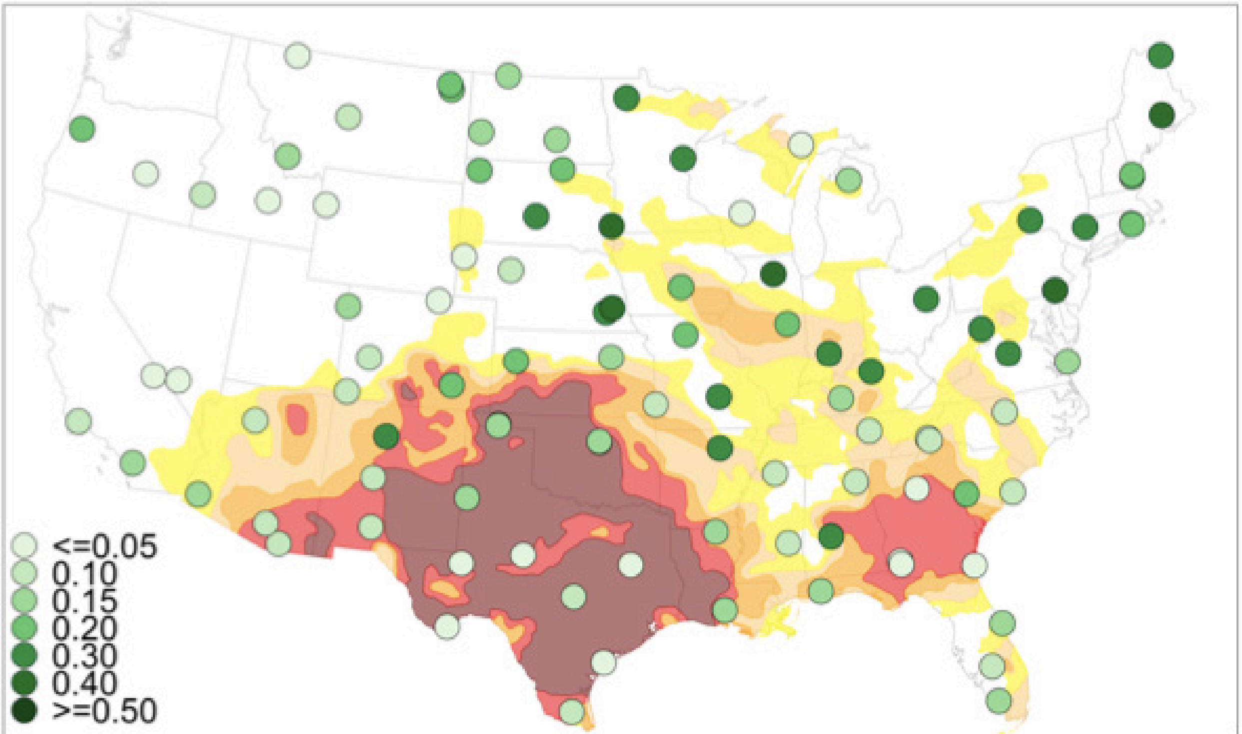


Figure 6. The relationship of 5-cm depth soil moisture observed at USCRN station locations to that of NARR grids at the same locations: a) volumetric soil moisture (m^3 m^{-3}) and b) standardized soil moisture anomalies.



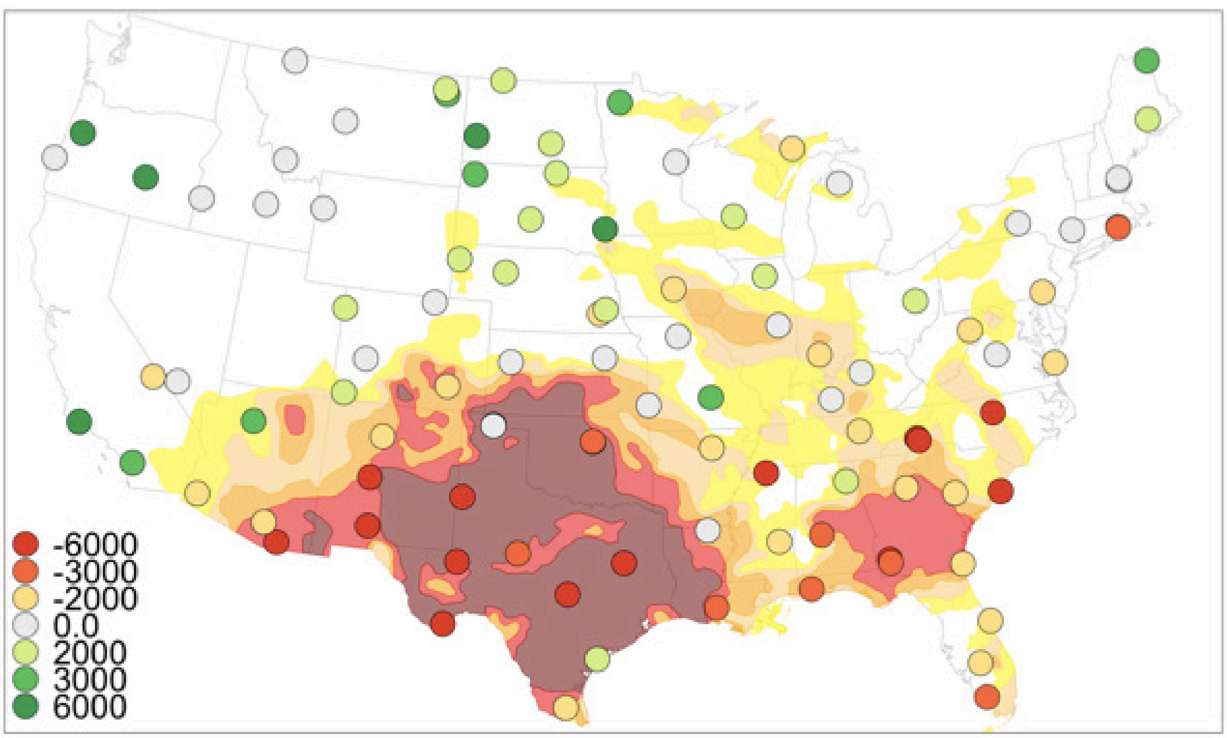


Figure 7. USCRN soil moisture at stations (dots) compared to the U.S. Drought monitor maps for the same time in 2011: a) volumetric soil moisture ((m^3 m^{-3}) and b) cumulative standardized soil moisture anomalies. Note that the standardized values relate more closely to the USDM status.

Manual Flagging of Observation Exceptions

As part of the development of the USCRN Official Algorithm for Precipitation 2.0 (OAP 2.0) in FY15, additional output fields were created during the calculation of precipitation from weighing gauge depths. While these were originally designed to examine the performance of the algorithm during challenging situations, the output also keenly identified periods of abnormal behavior not captured by the quality control procedures in place. The resulting information allowed for the generation of a list of potential exceptions that would result in inadvertent calculation of precipitation in response to a variety of physical and electronic faults causing noise in the depth data. These cases were examined exhaustively by experts; and variables and periods of time that were found to be defective were marked for exception flagging. Ten exception types have been approved by the USCRN Configuration Control Board (CCB) and processed since the beginning of FY 16, involving numerous stations and time periods.

An example from the Salem, MO, station involved depth changes upward and downward caused by electrical current fluctuations (Figure 8). When current exceeds a high voltage level during cold weather battery recharge, the weighing system does not work properly, causing wire vibration counts to decline and the depth derived from wire vibration counts to lower abruptly. If the wetness sensor is on as the normal condition returns, some portion of the depth signal rebounding upward can be mistaken for precipitation if the upward motion otherwise meets quality control criteria. This problem is largely associated with the early years of the network deployment and upper voltage limits are now controlled with an engineering solution.

Another issue detected by the new quality control output of the OAP 2.0 system is wire noise. The weighing bucket system would occasionally experience electrical failures such as occurred in the Port Alsworth, AK, station in 2011 (Figure 9). This case was very clear and did not require the new OAP 2.0 output to detect. However, more subtle wire noise issues that had escaped undetected were found. For example, at the Bodega, CA, station in 2014, an issue with the electrical system caused a coordinated diurnal signal in the depth (Figure 10). Since all three depths changed in a coordinated fashion, precipitation was calculated inadvertently. Often, the issue is even more difficult to detect, and may involve only one of the three depth measurements having noise that occasionally phases in and out with changes in the other depth measurements.

These and other troubled depth measurements in the USCRN database have been flagged so that they are not used. Changes of this type are rigorously vetted by two climate observation experts, and then proposed to the USCRN CCB. After approval, the station/depths in question are considered to be exceptions to normal quality control and are compiled in lists that are permanently preserved. Therefore, a record is kept of all types and occurrences of exceptions. The flag set does not destroy the observations, which are kept for all time, but do prevent normal calculation of precipitation for Web and text products.

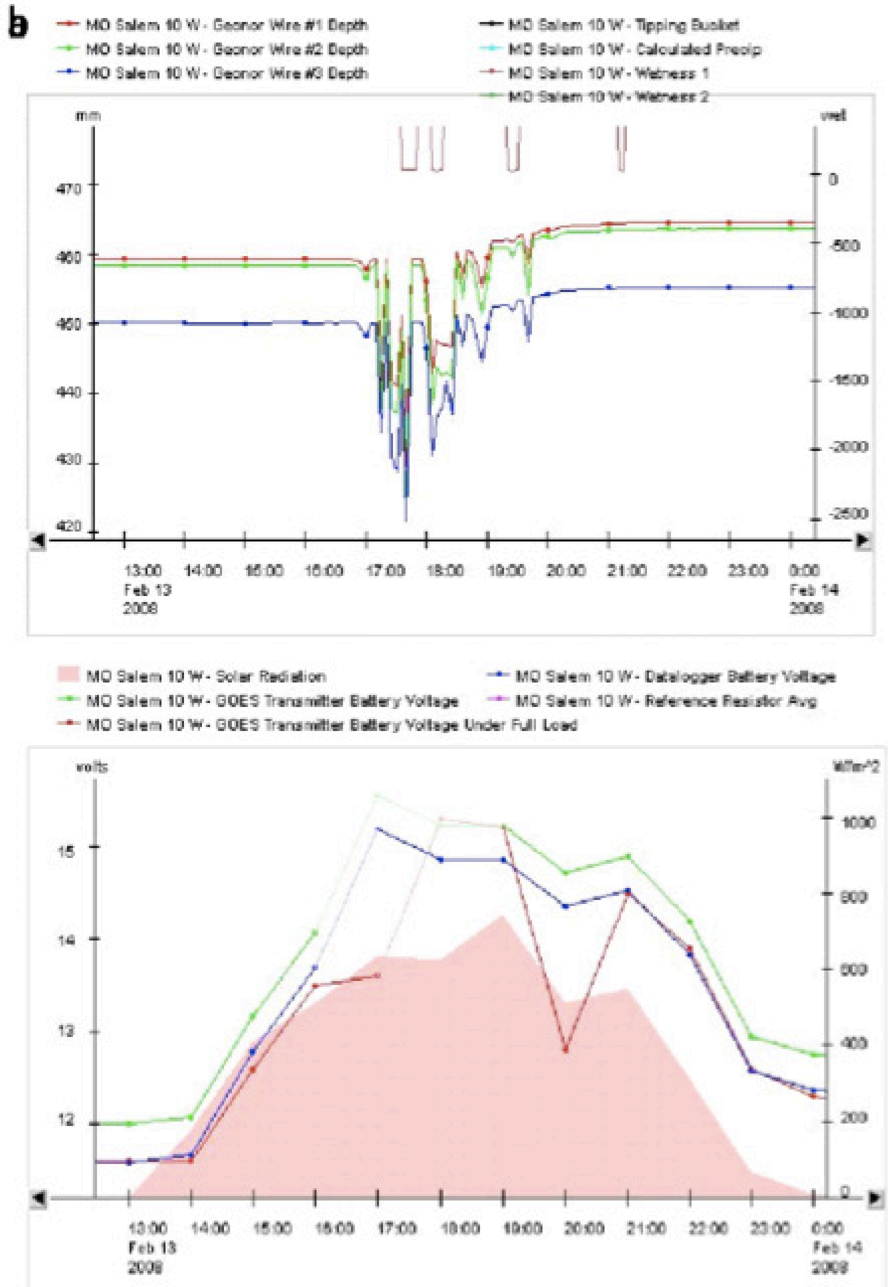


Figure 8. Salem 10 W, MO: a) Geonor gauge depths for depth sensors 1 (red), 2 (green) and 3 (blue) and the wetness channel 1 (maroon); b) battery voltages between Feb. 13th 2008 13L00 UTC to Feb. 14th 2008 00:00 UTC when over-voltage likely caused observed Geonor depths to become erratic.

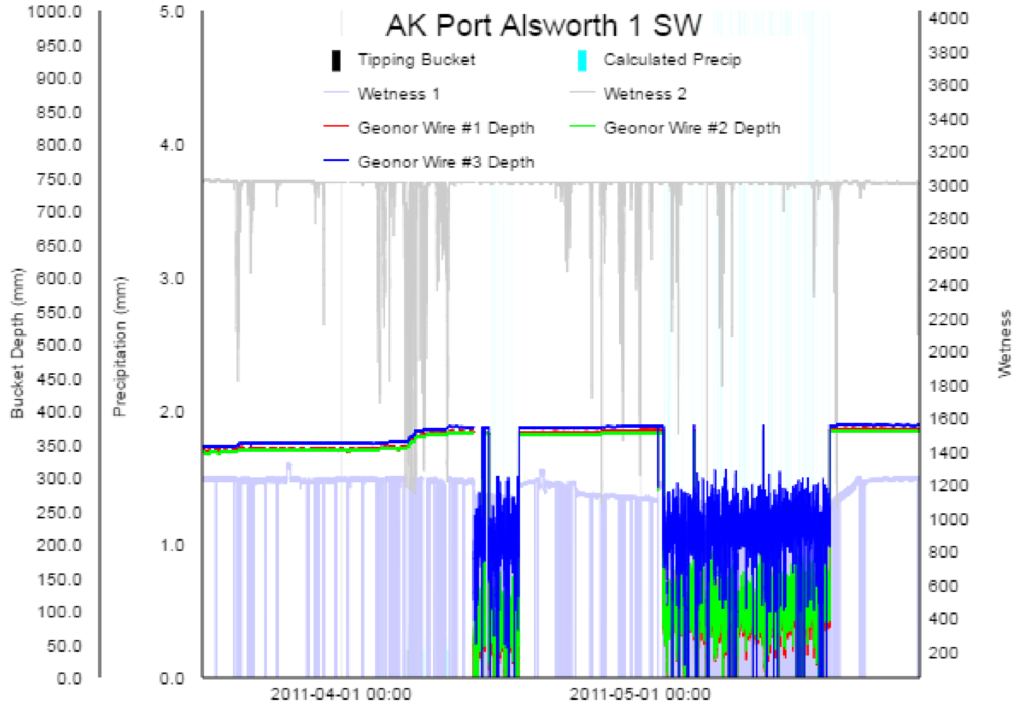


Figure 9. Reported Geonor depths from the three sensors (red, green, and blue) and detected wetness (gray and light blue) over the months of April and May 2011, which clearly show two periods where observed depths had large synchronized noise pattern.

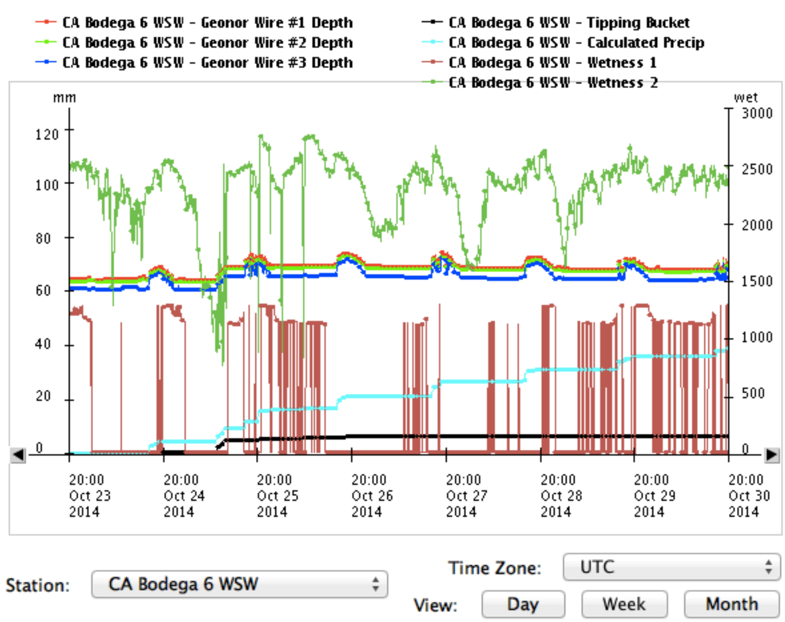


Figure 10. Reported Geonor depths from the three sensors (red, green, and blue), detected wetness (dark red and light green), and accumulated Geonor (light blue) and TB (black) precipitation at Bodega, CA, from Oct. 23rd to Oct 30th of 2014, which show the diurnal noise signal from the depth sensors and accumulated false precipitation over this period.

USCRN and WMO Solid Precipitation Intercomparison Experiments

As a contributor to the WMO Solid Precipitation Intercomparison Experiment (SPICE), ARL/ATDD has helped support the measurements recorded at NOAA/NCAR winter weather testbed in Marshall, CO. ARL/ATDD has also helped lead WMO-SPICE and develop corrections for different types of shielded gauges. The Geonor T-200B weighing gauge used in the NOAA Climate Reference Network (CRN) was one of two of the reference weighing gauges used for WMO-SPICE. In addition, the Small Double Fence Intercomparison Reference (SDFIR) used in the CRN compared quite well to the full-sized Double Fence Intercomparison Reference (DFIR) shield used as the automated reference within WMO-SPICE. When tested at the NOAA/NCAR testbed, the bias of the uncorrected SDFIR measurements was almost unmeasurable (Table 4). Likewise the SDFIR RMSE was much smaller than any of the other shields tested (Table 5), and was of a similar magnitude to measurements taken within two identical shield types (data not shown). For this reason the corrected measurements were not significantly improved over the corrected measurements (Table 5), which makes it unique among the windshields that were tested.

Shield	Uncor RMSE	Uncor Bias	Cor RMSE	Cor Bias
Unshielded	0.30 mm, 28.6%	-0.17 mm, -16.2%	0.18 mm, 16.8%	0.00 mm, 0.4%
Single Alter	0.22 mm, 23.6%	-0.11 mm, -11.7%	0.15 mm, 15.4%	0.00 mm, -0.1%
Double Alter	0.21 mm, 21.6%	-0.10 mm, -10.6%	0.14 mm, 13.8%,	0.00 mm, 0.1%
Belfort Double Alter	0.16 mm, 17.5%	-0.05 mm, -5.6%	0.13 mm, 14.6%	0.00 mm, -0.9%
SDFIR	0.14 mm, 14.7%	-0.03 mm, -3.6%	0.13 mm, 14.2%	-0.01 mm, -1.6%

Table 5. Root mean square errors (RMSE) and biases in the uncorrected (Uncor) and corrected (Cor) 30-min precipitation from gauges under test estimated using the DFIR precipitation measurements as the standard.

An Evaluation of New Soil Moisture/Temperature Sensor Technology

NOAA has identified an increasing demand for drought related information not only from stakeholders in drought-affected regions but also in areas where impacts from climate change may result in more frequent short term droughts. At the request of Western Governors' Association (WGA) to address the need, NOAA has taken the lead on the development and implementation of a National Integrated Drought Information System (NIDIS). Observations, including precipitation and soil moisture are critical to developing products for drought assessment, planning and drought forecasts. NIDIS has supported soil moisture monitoring activities for USCRN, including the procurement of sensors, installation, data acquisition integration, data ingest, and quality control/quality assurance for observations at well over 100 sites in the U.S. The soil moisture data from the USCRN network complements the existing USDA National Water and Climate Center Soil Climate Analysis Network (SCAN) by providing soil moisture and soil temperature measurements in all of the states not supported by SCAN, while adding additional soil moisture measuring capacity in 70 locations in the central and western U.S., areas of the country particularly vulnerable to drought. Most importantly, the soil moisture / soil temperature measuring approach of the USCRN adhere to the principles of climate observation expressed in the 1999 NRC report: "Adequacy of Climate Observing Systems". One of these principles is the requirement for triple redundancy. This entails 3 separate independent measures of the same variable in order to quantify variability in the measurements themselves as well as identify when a particular sensor may drift and cause a bias. This of course has significant implications with regard to overall network monitoring cost and maintenance, but is absolutely necessary for long term monitoring. For the nearly 119 USCRN site, this is well over 1500 probes that need to be monitored, and replaced when the sensor fails. A thorough description of the soil moisture and temperature observations in the USCRN, including the utility of having triple redundancy are described in a publication by Bell et al. (2013).

An integral component for operating a research network like the USCRN, is evaluating new sensor technology for possible incorporation into the network. The technology for determining soil moisture in both SCAN and USCRN was developed in the 1990s, and although it has known biases in highly saline or high clay content soils, provides an acceptable measure of volumetric water content for most soil types. Recently, because of the recognized importance of soil moisture measurements and advancements in sensor technologies, new sensors have been introduced that in theory could provide more accurate measurements for a wider range of soil types and soil conditions. Testing and evaluations of new sensors needs to be done in order to insure compatibility with the currently deployed technology and to minimize any potential biases or baseline shifts in the data records.

During the summer of 2016, sensors from Acclima (model TDR-315L) and Decagon (GS1) were compared with the current sensor used in the USCRN (Stevens Hydra II Probe). The sensors were installed in a test bed containing homogeneous soil. Observations of soil moisture from all sensor types (4 replicates) were compared to each other as well as to volumetric water content determined from gravimetric sampling, which is the standard for direct measurement of soil moisture. There were no observable differences between the probe types. In addition, the daily changes in moisture were tracked closely and were nearly identical for all three sensor types. The temperature readings from the Acclima and Hydra probes were also compared in a controlled environment. The measured temperatures agreed to within 0.1 C, but the Hydra probes responded more slowly to sudden changes in temperature. The Acclima TDR-315L is a viable alternative as a replacement probe for the Hydra, as it compared favorably with the Stevens Hydra II. Acclima TDR-315 sensor should not introduce an unaccountable change in the data record.

References

- 2015. Acclima True TDR-315 User's Manual: Meridian, ID, Acclima, Inc.
- 2015. GS1 Soil Moisture Sensor Operator's Manual: Pullman, WA, Decagon Devices, Inc.
- 2015. The Hydra Probe Soil Sensor User's Manual: Portland, OR, Stevens Water Monitoring System, Inc.
- Bittelli, M. 2011. Measuring soil water content: a review: HortTechnology, vol. 21, no. 3, p. 293-300.
- Johnson A., 1962. Methods of measuring soil moisture in the field: Geological Survey Water-Supply Paper 1619-U.
- Lekshmi, S., Singh, D., Baghini, M., 2014. A critical review of soil moisture measurement: Measurement, no. 54, p. 92-105.
- Topp, G., Davis, J., and Annan, A., 1980. Electromagnetic determination of soil water content: measurement in coaxial transmission lines: Water Resources Research, vol. 16, no. 3, p. 574-582.
- Robinson, D., Campbell, C., Hopmans, J., Hornbuckle, B., Jones, S., Knight, R., Ogden, F., Selker, J., and Wendroth, O., 2008. Soil moisture measurement for ecological and hydrological watershed-scale observatories: a review: Vadose

Zone Journal, vol. 7, no. 1, p. 358-389.

Monitoring Activity Highlights

Notable Weather Events As Reported By The USCRN Network During 2016

Jan 10-13: A shallow stable air mass in the Caldera surrounding the Los Alamos site became established late night of the 10th and despite an overall warming of the in situ air mass of about 10C (18F) between the dark hours of the 10th and those of the 11-14th, the approximate hourly temperature oscillations continued through the dark hours each night. Such rapid excursions are not unusual at this site; however it is unusual for them to continue at such a magnitude for four days. The event ended in a flourish with a 5 minute drop in temperature of 28F (15.3C) and 10 minutes later a 10 minute rise of 29°F (16°C); see Figure 11.

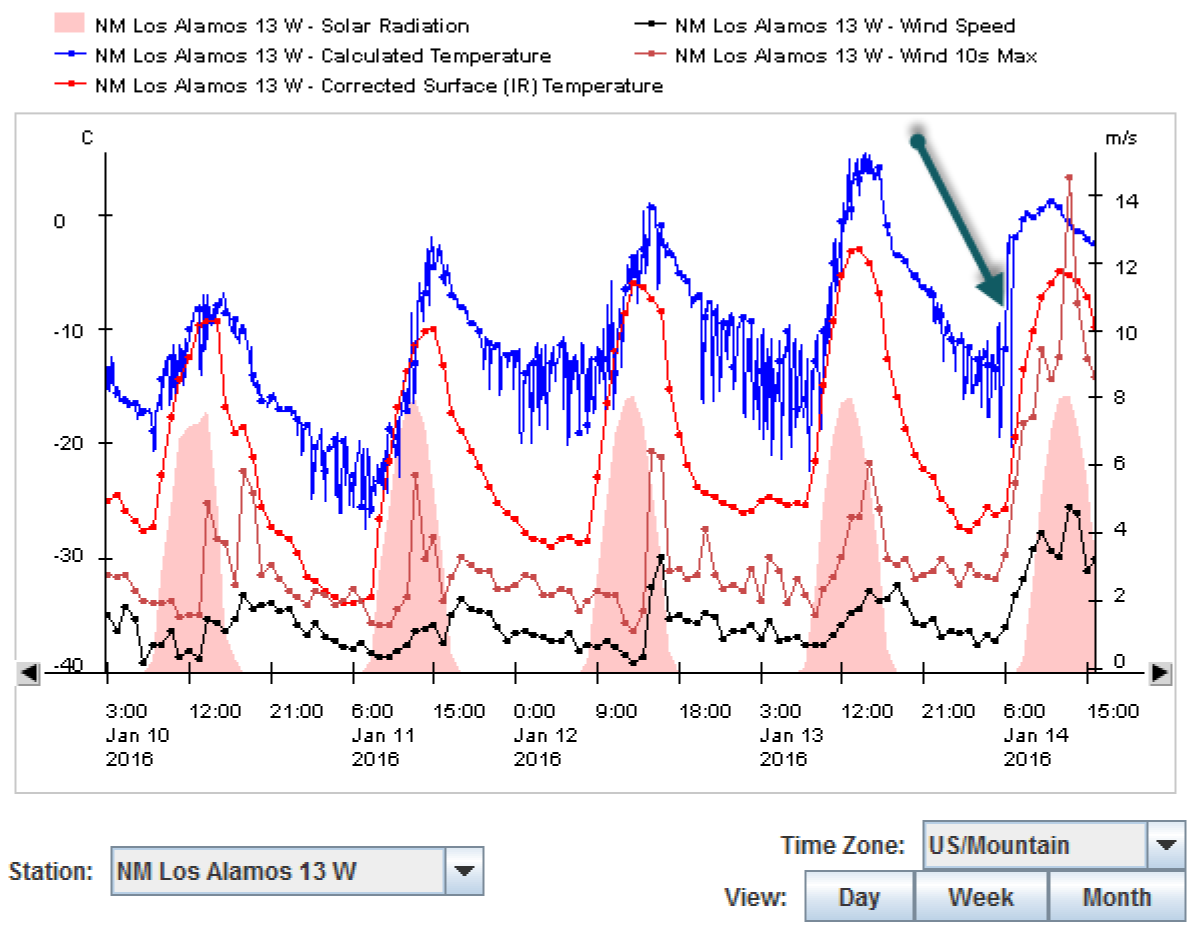


Figure 11. Green arrow indicates the point of the greatest temperature change.

Figure 12. 3-D view of the Caldera. Red dot is the approximate location of the Los Alamos USCRN site.

Jan. 25. The site hosts for our station at McClellanville 7NE, SC conducted a "controlled burn" of the grass in the field that surrounds the site, and as would be expected, heat produced by the fire artificially elevated the temperatures for about a 5-minute period. Quality assurance software correctly assessed this event as an anomaly and flagged the erroneous value(s). This proper flagging prevented the entry of a false maximum temperature for the day of 75F (24C) instead of the correct value of 58^{o}F (14.5^{o}C). (See Figure 13 below of the temperature-humidity graph).

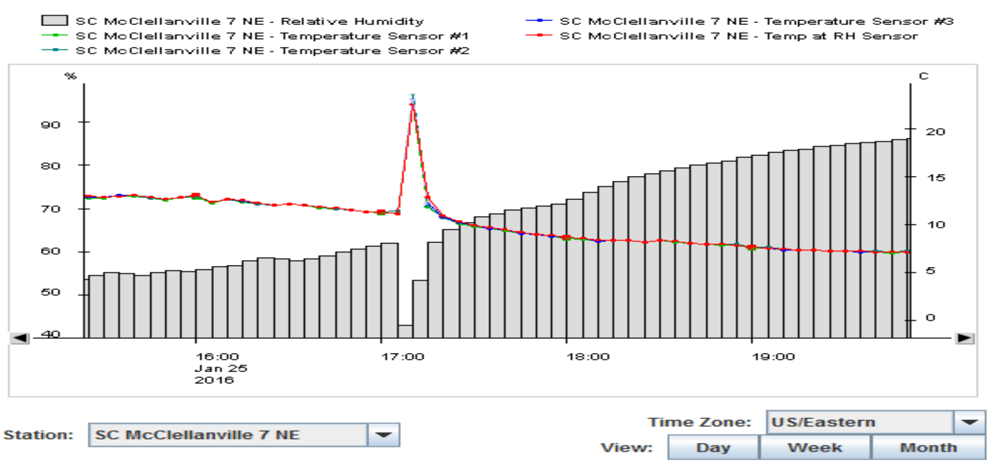


Figure 13. Temperature and Humidity Graph from McClellanville, SC USCRN Station

That is awesome, you guys are on top of things! Does the attached picture answer your question? :o)
Prescribed burn of the surrounding field.

Figure 14. Photograph of the site and comments above given by the cooperative site host.

Heavy Precipitation Event in Louisiana Captured by USCRN

The U.S. Climate Reference Network (USCRN) station located in the Upper Ouachita National Wildlife Refuge near Monroe, LA, was near the center of a major multi-day heavy rain event in early March 2016 that caused severe flooding in much of northern Louisiana and portions of surrounding states. Beginning on March 8th at 6:50 PM local time, 13.17 inches (334.6 mm) of rain fell in a 24-hour period, a once in every 500-year return period event (Table 6). Interestingly, the largest one-hour total during the event was only 1.62 inches (41.2 mm), which is simply a once a year return period event. It was the steady and persistent rainfall over an extended period of time (Figure 15) that made the event so unusual; a literal atmospheric river of moisture from the tropics moved north into the region. The rain did not stop within that 24-hour period, but the rate did decrease later. After 7 days, a total of 18.20 inches (462.3 mm) was received, which was also a once every 500-year return period event.

Table 6. The heaviest amounts of precipitation for periods of a given length during the event, and the expected return period for each based on local historical records.

Duration	Date/Start (CST)	Amount (Inches)	Return Period (Years)
5 Minutes	Mar 8 / 7:30 PM	0.42	1
10 Minutes	Mar 8 / 7:30 PM	0.73	1
15 Minutes	Mar 8 / 7:30 PM	0.98	2
30 Minutes	Mar 8 / 7:25 PM	1.33	1
60 Minutes	Mar 9 / 4:00 PM	1.62	1
2 Hours	Mar 8 / 7:25 PM	2.39	2

3 Hours	Mar 9 / 3:35 PM	3.08	5
6 Hours	Mar 9 / 11:15 AM	4.72	10
12 Hours	Mar 9 / 10:35 AM	7.11	50
24 Hours	Mar 8 / 6:50 PM	13.17	500
2 Days	Mar 8 / 12:15 PM	16.30	500
3 Days	Mar 8 / 3:20 PM	17.75	500
4 Days	Mar 8 / 5:30 PM	18.12	500
7 Days	Mar 6 / 8:40 PM	18.20	500

From March 1-15, 2016, the precipitation total reached 18.34 inches (465.8 mm), which is the wettest month since the Monroe USCRN station was installed in January 2003. The second wettest month was October 2009, when 18.00 inches (457.3 mm) fell. Interestingly, tropical cyclones did not impact the station precipitation totals in either month. The climatological Spring of 2016 at Monroe is already the third wettest climatological Spring for the station, and that is only 15 days into the three-month season from March to May.

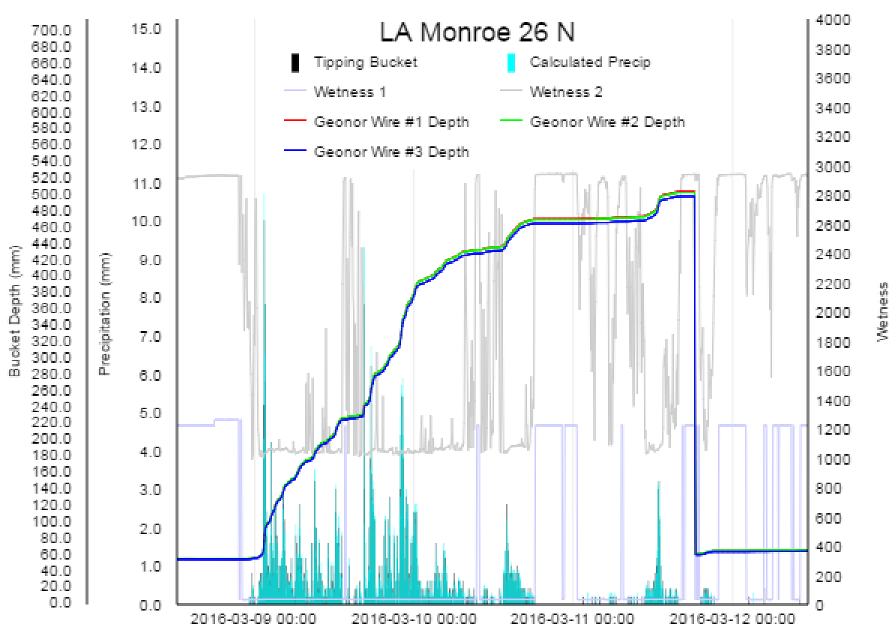


Figure 15. Precipitation accumulation in the LA Monroe 26 N weighing bucket gauge, with individual 5-minute values in light blue and the depth of precipitation in the gauge indicated by the rising solid trace. The gauge was drained during a break toward the end of the event to avoid overtopping the 600 mm capacity.

The USCRN station was located near the core of heaviest rain during this event (Figure 15), but several locations reported even larger precipitation totals. The Monroe Regional Airport measured 20.26 inches (514.6 mm) in four days, while a cooperative program observer nearby recorded 26.96 inches (684.8 mm) of rain in 6 days. This amount represented fully half of the normal annual precipitation being received in those 6 days, and was considered by experts to represent a one in one thousand year event. Many locations in Louisiana and southeastern Texas experienced record flooding, exceeding that seen in tropical storm landfalls, and the widespread nature of the

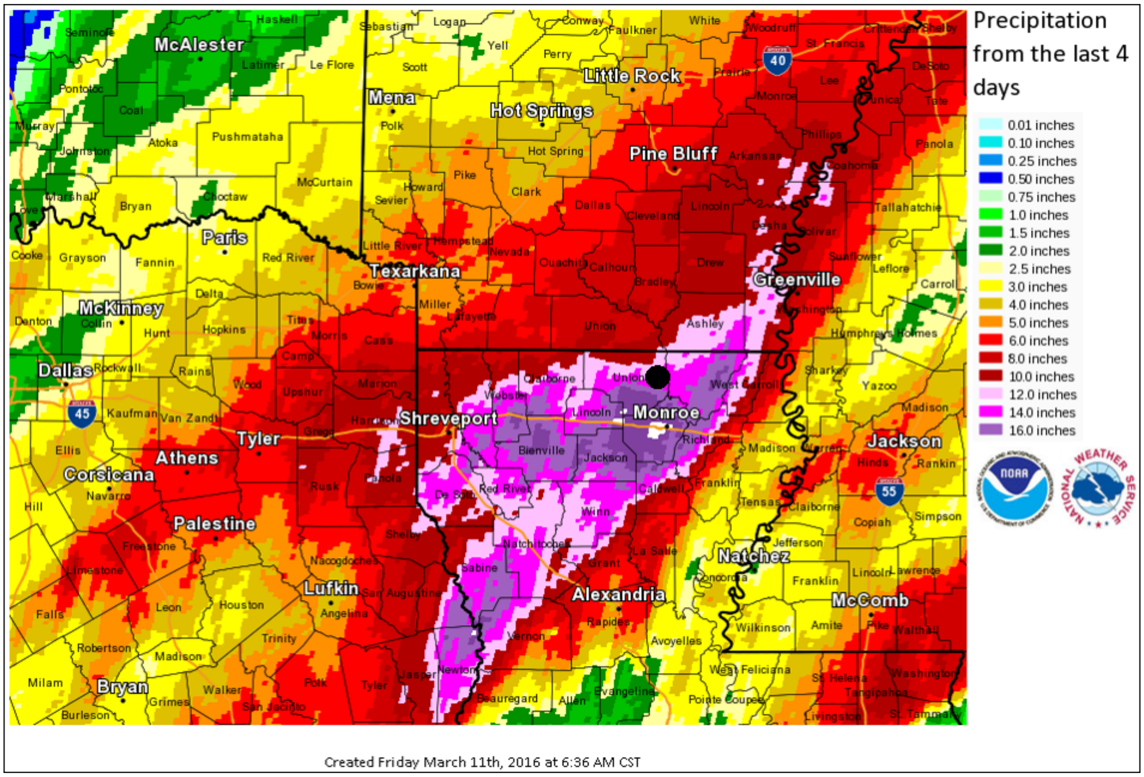


Figure 16. National Weather Service radar estimated precipitation totals for the event of March 8-11, 2016. The black dot is the location of USCRN stations LA Monroe 26 N.

precipitation is depicted in Figure 16. By mid-month, most rivers in northern Louisiana have started to recede, but the flood wave continued south, causing new flooding several days after the last drop of rain fell. The Sabine River, which separates Louisiana and Texas, reached record highs downstream from the Toledo Bend Dam, which released water at a record rate to avoid the dam being overtopped. The record flooding by the Sabine River (Figure 17) caused tremendous damage in Deweyville, TX, and cut off Interstate 10, the main east-west route through the region. A Major Disaster Declaration was issued on March 13 for the initial flooding in Louisiana, and this is expected to be expanded in geographic scope.

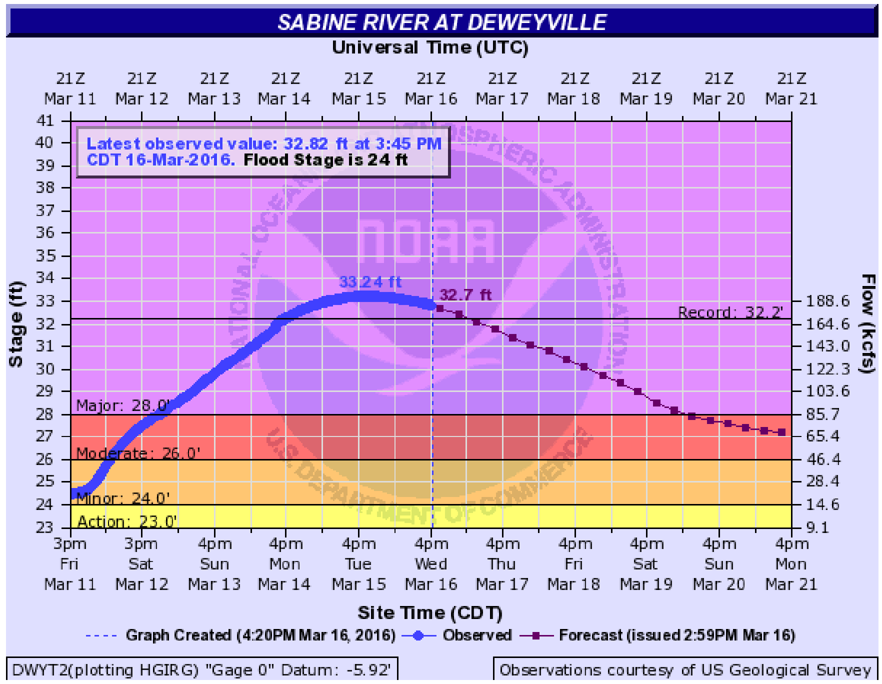


Figure 17. Record flooding at Deweyville, TX, on the Sabine River 4 days after the rain.
May 29:

Apparent anomalous relative humidity (RH) value confirmed by observations from Oakley 19 SSW, KS, USCRN site. The relatively low value resulted from an early morning "heat burst" that lowered the RH values from 82% at 0335LST to 46% at 0420LST. The 57% value shown on the map (red arrow Figure 18) was observed at 0400LST (1000UTC) (green arrow Figure 19. The corresponding rise in the ambient air temperature during the event was 14°F (7.8°C).

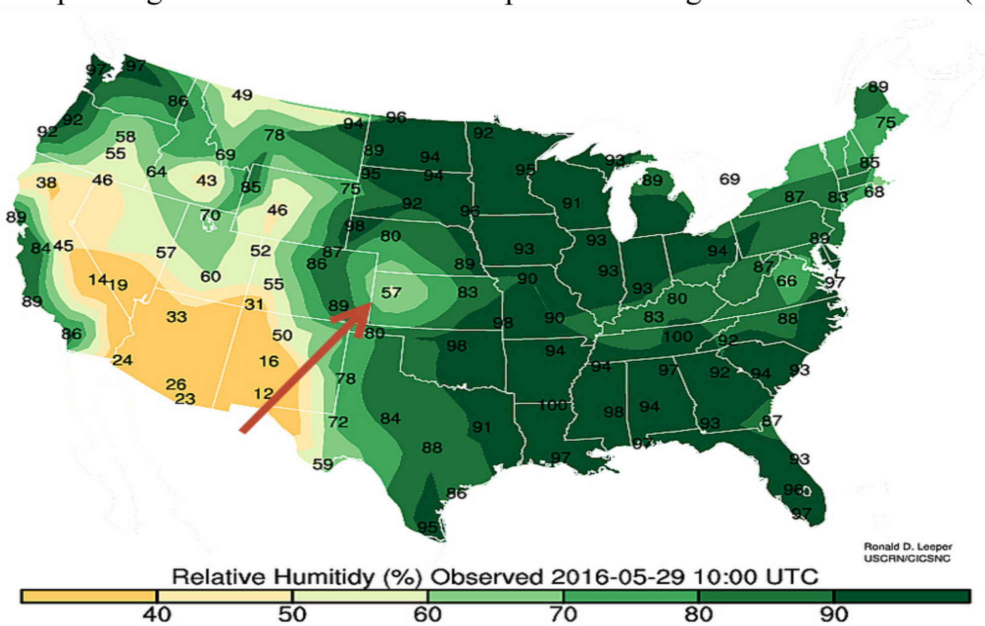


Figure 18. National MAP of RH Values (%)

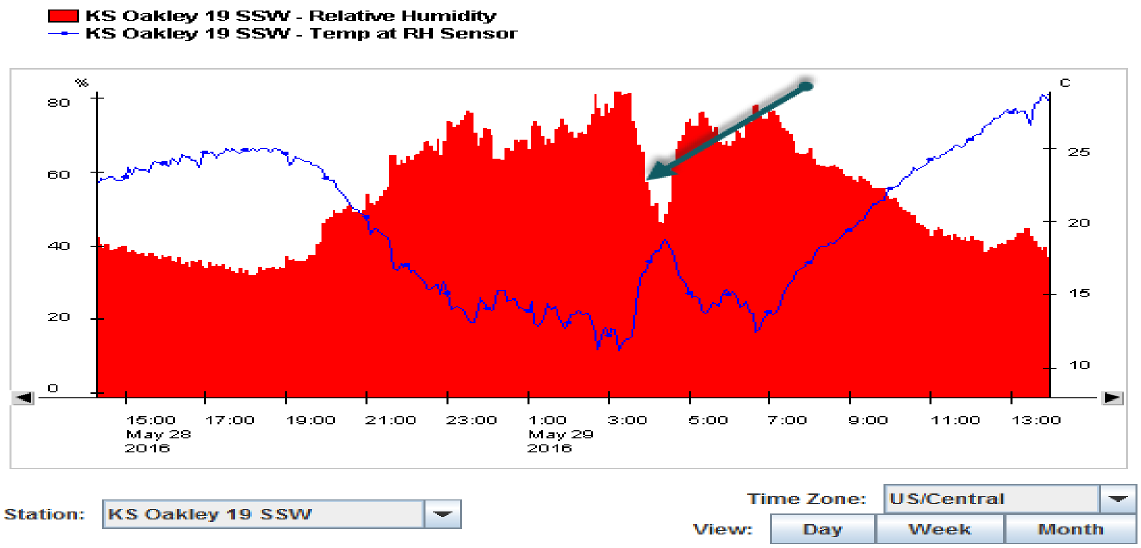


Figure 19. Temperature and RH at Oakley, KS USCRN Station

June 21-22. Record rain event at Northgate 5 ESE, ND. During the late night of June 21 and early morning of the 22, 2016 the USCRN site recorded a new station extreme rainfall total of 4.79" (121.7mm) with calendar day totals of 4.08" (103.7mm) and 0.71" (18.0mm). The previous station record event total for any month was 4.26" (108.2mm) set on July 7-8, 2009. Table 7 below shows a breakdown of the rainfall amounts and their expected return periods based on NOAA Atlas 14. Figure 20 below shows the radar accumulation for the storm. Black line highlights the position of the station which is located just south of the Canadian border in Saskatchewan.

Table 7.

Time (hours)	Rainfall (Inches)	Return Period (Years)
1	2.60	200
2	3.75	1000
3	3.80	400
6	4.51	500
12	4.79	300

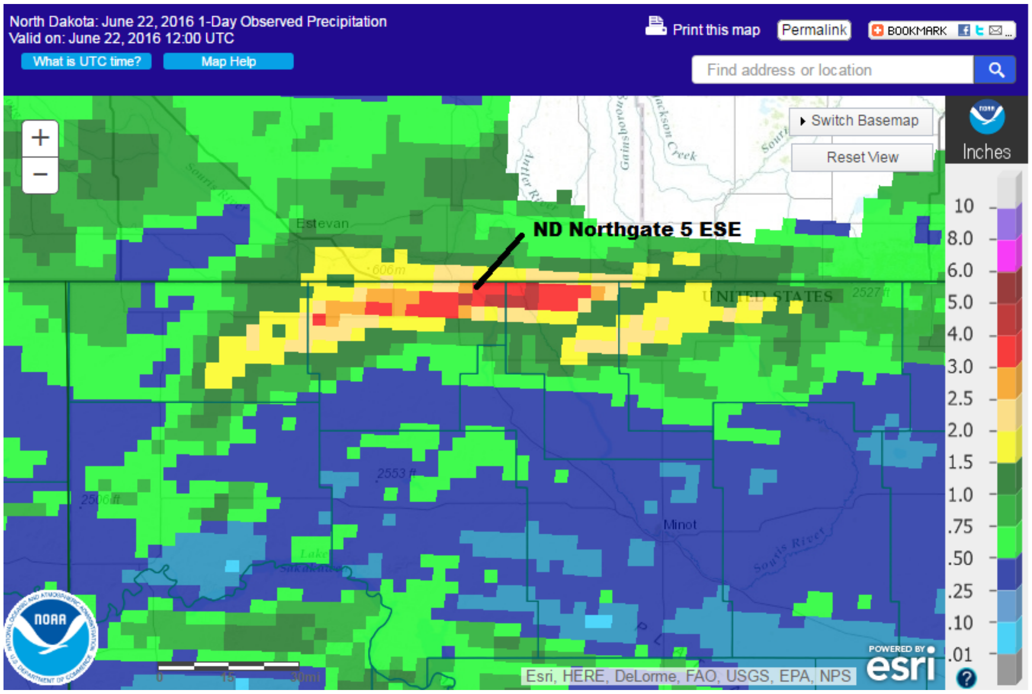


Figure 20. Northgate, ND Doppler Weather Radar Image for June 22, 2016

July 11. Another record rain event in the Northern Plains. An area of complex thunderstorms moved slowly over Northeast Minnesota on the 11th and brought flooding rains to much of the area. The location of the USCRN station at Sandstone 6W, MN was in between the two areas of maximum totals highlighted in the purple and dark grey colors of the radar accumulation total map below (See Figure 21), however it still recorded new station records for 12 and 24 hours with 6.03" (153.2mm) and 7.19"(182.7mm) respectively. The previous records were 3.43" (87.2mm) for both 12 and 24 hours on June 21, 2013. In addition to the July 11 record event, there were several other significant rains that helped set a new station record for July as well as any month with 10.95" (278.2mm). The previous record was 9.53" (242.0mm).

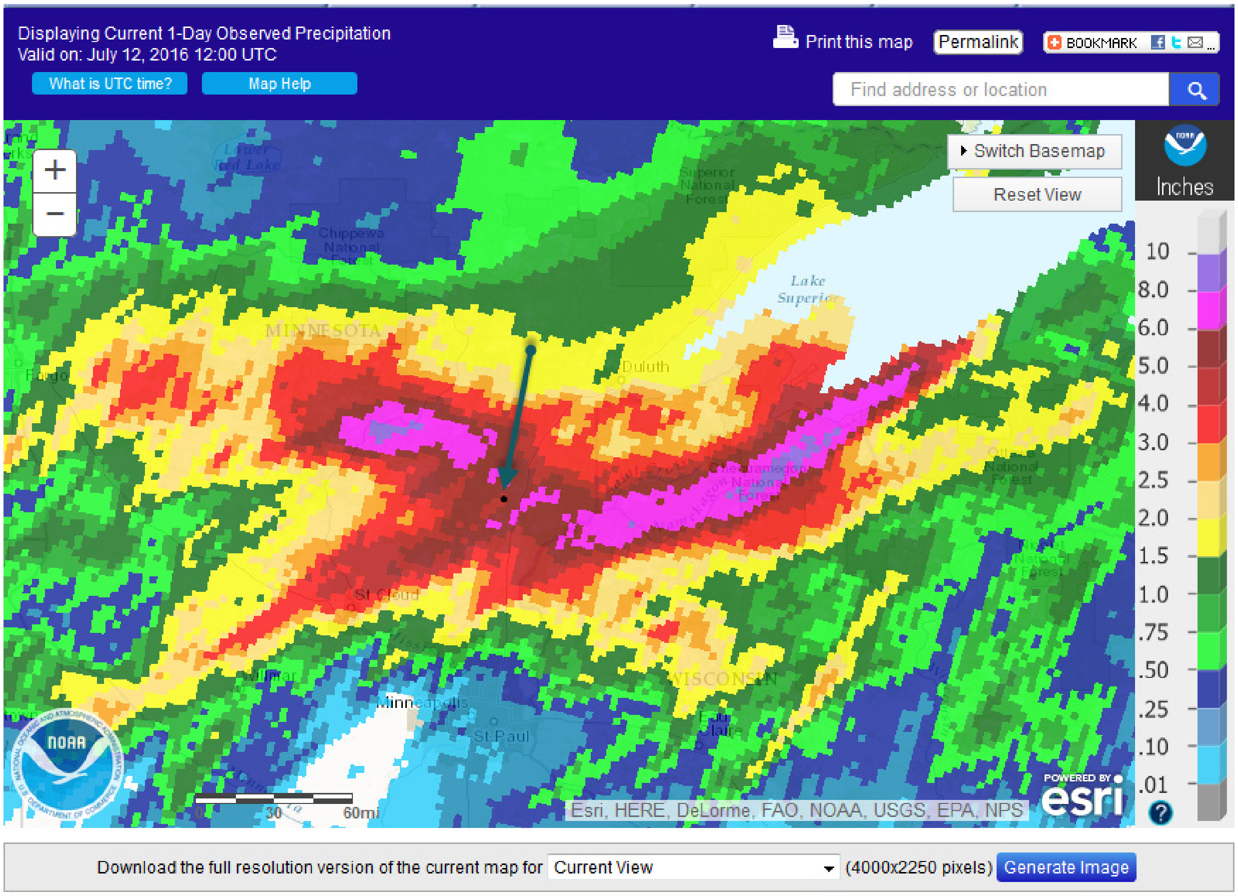


Figure 21. NWS Radar estimated total rainfall for the July 11th event.

July 22-23. Dramatic ambient temperature and relative humidity changes at the Santa Barbara 11W, CA USCRN station, as can be seen in Figure 21.

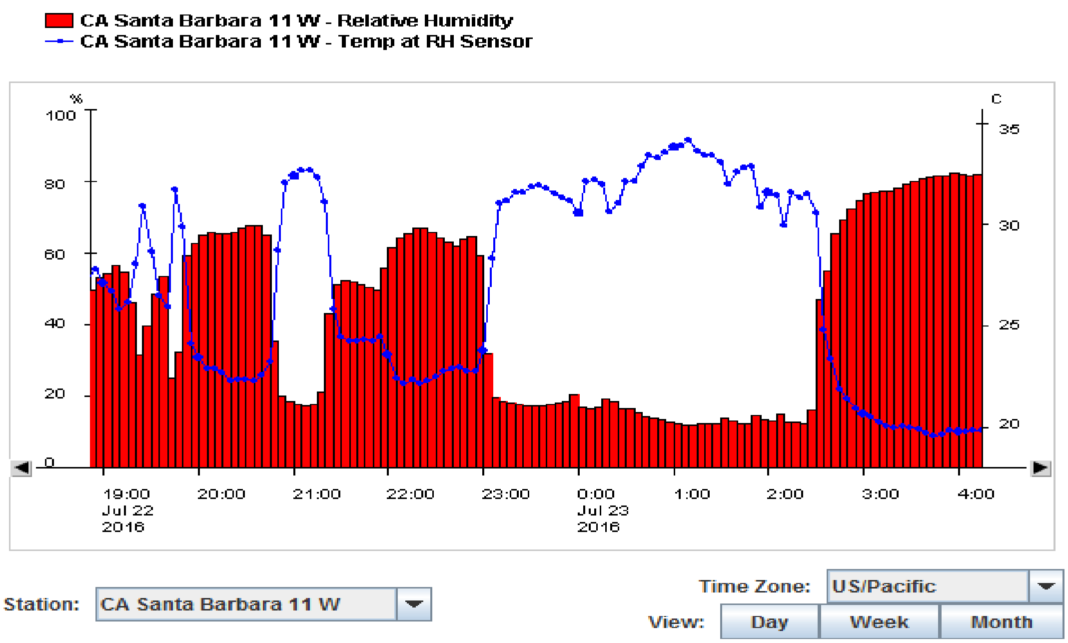


Figure 22. Santa Barbara, CA Temperature and RH Plot

Figure 22 depicts 5-minute temperatures for the USCRN site (blue line). The green dots represent the corresponding 5 minute temperatures observed at the Santa Barbara, CA Airport only 2.25 miles ENE. The airport site remained in the marine layer for the first two hours of the event then slowly warmed over the next 4 hours where they pretty well mirrored the temperatures of the USCRN site.

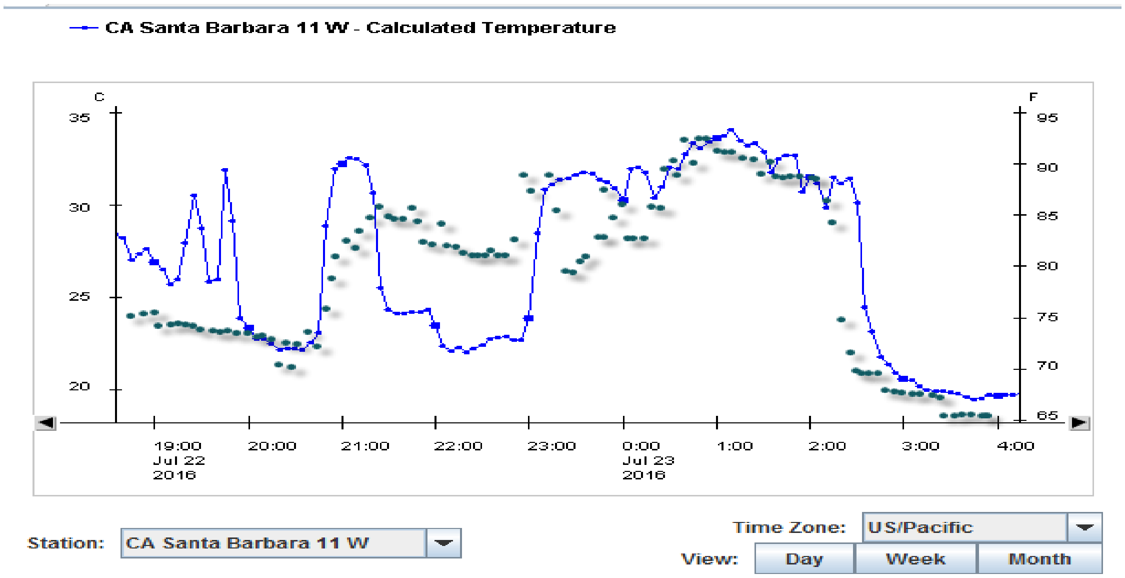


Figure 23. Calculated Temperature at Santa Barbara USCRN Station

The two weather stations are located at the end points of the two arrows. The 3-D image shows the close proximity of the mountains that assist in the compressional warming of the downslope winds that are occasionally strong enough to displace the cooler more stable air associated with the marine layer.

Figure 24. Map of the Santa Barbara area.

A Second Flooding Rain Event in Louisiana Captured by a USCRN Station

The USCRN station at Lafayette, Louisiana, recorded an all-time record two-day storm total of 22.89 inches on 11-12 August 2016; this was also the largest two-day total for any USCRN station in the conterminous U.S., exceeded only by a two-day event at the USCRN station in Hilo, Hawaii, of 26.29 inches recorded in February 2008. The total at Lafayette also exceeded the 13-year station history maximum monthly total of 18.88 inches, set in June 2003. This event has an expected return period of over 500 years, meaning that for any given year, there is a 0.2% chance of this much rain falling in two days. Interestingly, the other USCRN station in Louisiana, near Monroe, also had a 1-in-500 year 2-day rainfall event earlier in 2016, when 16.30 inches of rain fell starting at around noon on March 8 (the amount to qualify as a 500-year event is less in northern Louisiana). The chance of two 500-year events occurring in one place in one year is 0.0004%, or once in 250,000 years. However, since these locations are almost 200 miles apart, the odds of both occurring in one year are closer to 0.2% due to the locations being independent of each other. It is still extremely unusual to have two independent events occur of such magnitude in one state in one year. Finally, the 30-day precipitation total for Lafayette station was 34.76 inches from 24 Jul – 22 Aug 2016, the third largest station 30-day maximum in network history, second only to USCRN stations at Hilo, Hawaii, and Quinault, Washington. The August 2016 total at Lafayette was 30.22 inches, exceeding June 2003 by more than 12 inches.

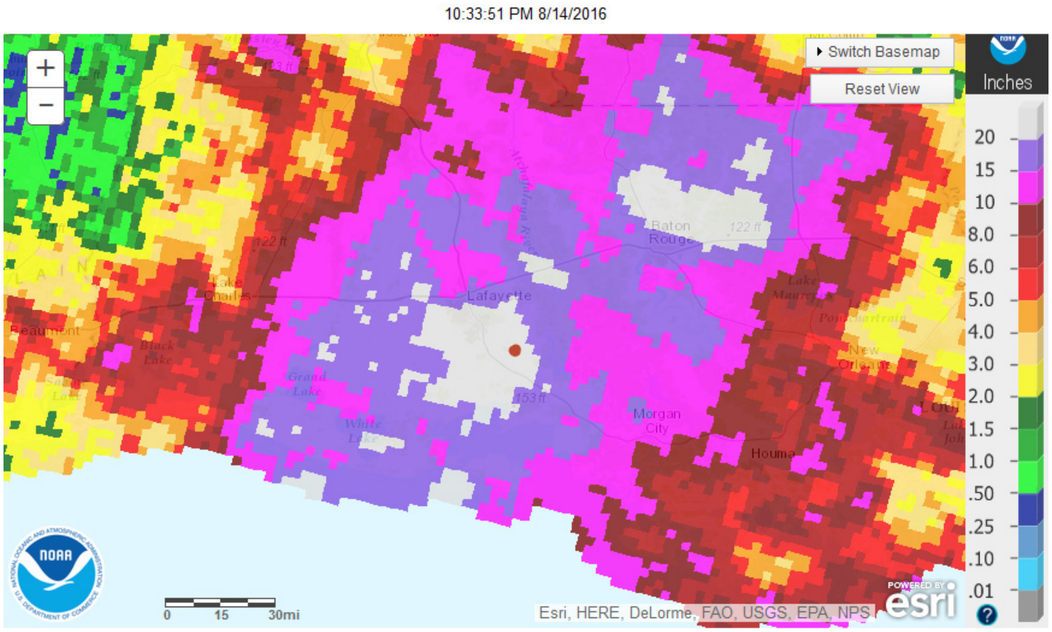


Figure 25. NOAA National Weather Service radar estimate of precipitation, 7-14 Aug 2016. The red dot is the location of the USCRN station near Lafayette, Louisiana.

While the damage caused by the rain event in March was significant, the August rain event greatly eclipsed that event in impact due to the much greater precipitation total and larger area impacted. The 7-day radar estimate of precipitation exceeded 20 inches by the morning of August 14 over two large areas near Lafayette and Baton Rouge (white areas in Figure 25), and exceeded 10 inches over most of the central area of the state (magenta areas in Figure 25). As of August 25, over 112,000 families had filed for assistance with FEMA, more than 60,000 homes and thousands of businesses were seriously damaged, and 20 Louisiana parishes were declared disaster areas. Water rose so quickly that more than 30,000 needed to be rescued by boat and high wheelbase vehicles, and 13 died. Major interstates were flooded, and over 100 state highway closures limited travel for days after the peak of the rain event.

The USCRN station near Lafayette operated throughout the event. However, during the morning of the 13th, the primary rain gauge filled to capacity. While this might have ended precipitation data collection in some networks, the USCRN maintains a back-up tipping rain gauge. It records liquid precipitation by counting how many times a container holding the equivalent of 0.01 inches of precipitation is filled and tips over. While not as accurate as the primary weighing bucket gauge, it has no limit on capacity so it kept recording on the 13th. Figure 26 shows the period when precipitation was recorded by the weighing gauge (red bar) and tipping gauge (gray bar). The USCRN site host was able to drain the bucket and restore the primary gauge once the site could be accessed a few days later.

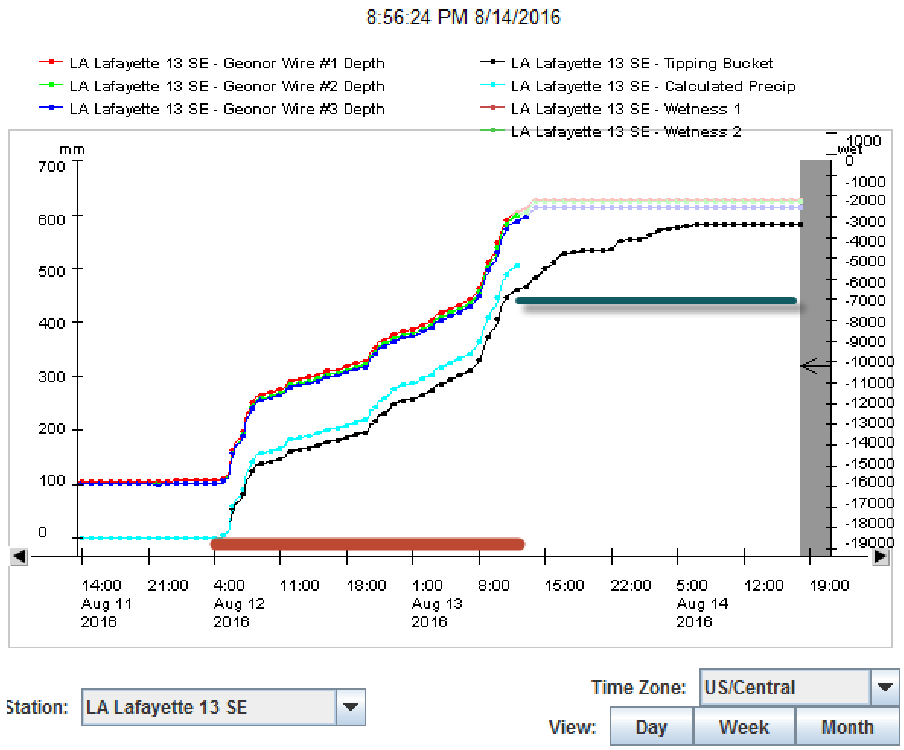


Figure 26. Precipitation graph from the USCRN Lafayette station on 11-14 August 2016. The red bar shows when the primary rain gauge operated; the green bar shows the secondary gauge.

Plans for FY17

A number of long-term science projects will continue or commence during FY17:

- Development of a standardized soil moisture product for USCRN stations to support operational drought monitoring activities.
- Examination of the potential for using NCEI 5-km gridded 1981-2010 averages in generating estimated normals for USCRN stations.
- Development of a national precipitation index prototype product.
- Experience gained in the FY16 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 FY17.
- USCRN soil property measurements will be published in FY17 as a supplement to a journal article describing CRN soil properties and their importance for CRN soil moisture measurements.
- A description of precipitation errors, biases, and wind speed corrections for the precipitation wind shields and precipitation gauges used in the USCRN and elsewhere will be published as a journal article in FY17.

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

- Upgrade of the processing system to reduce the computational overhead in management of primary and secondary observations at dual transmission sites, to establish a foundation for making database updates such as replacement of inaccurate Geonor measurements with tipping bucket measurements, and to shift from on-the-fly calculations of summary of day/month data to using stored values that are consistent across all CRN products and tables.

- Improvements completed for ingest and database systems to increase speed at which new or reprocessed observations including PDA data can be ingested by reducing the number of operations on the database to the bare minimum necessary.
- Development of plans and initiation of changes to ingest software packages to incorporate upcoming changes to GOES ID numbers as part of the CS1 to CS2 GOES transmitter transition that begins in 2017 and will be completed by 2025 network-wide in time with the complete switchover from the CS1 to CS2 GOES transmitter protocol.
- Development of plans and begin to implement changes to the database and ingest systems to incorporate new soil elements as part of the soil sensor upgrade effort.

Hardware testing and deployments will continue:

- 1-2 new station(s) will be deployed in Alaska during the summer 2017 building season bringing us closer to the eventual final total of 29 stations across Alaska. The two sites being targeted are Cordova in the southern portion of the state, and Toolik Lake in the northern part of the state and collocated with a National Science Foundation National Ecological Observatory Network (NEON) station.
- 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.