US Climate Reference Network

Annual Report for Fiscal Year 2014

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Cover Photo:
Photo of the north slope of the Brooks Mountains in Alaska (Photo Credit – Rocky Bilotta)

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Report will be posted on the USCRN Website at

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

Many thanks to the USCRN Team members for their invaluable assistance in aiding in the preparation of this report and for their many contributions during FY14:

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 2014, 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 sites across the conterminous 48 states, 16 sites in Alaska, 2 additional sites in Hawaii, and 2 at international test sites. Stations are installed in open (where possible), rural locations very likely to have stable land cover/use conditions for several decades to come. A major paper about the network was published in the Bulletin of the American Meteorological Society, and the availability and quality of its new soil moisture observation suite was recognized through two further refereed publications.

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 16 operational USCRN stations (13 commissioned) in Alaska, with an eventual goal of having 29 commissioned stations by 2021. 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 FY2014

(1) Past the halfway point in Alaska

In FY14, three new stations were installed in Alaska in Deadhorse, Ivotuk, and Nowitna, thus bringing the network configuration in the state up to 16 out of a planned eventual total of 29 stations by FY 2022.

(2) **Climate monitoring and assessment**

A new tool for USCRN users called the Energy Product has been designed to compile daily statistics that are most relevant to home heating and cooling energy use, and also correlated with other types of energy use. For each station, the daily maximum and minimum temperatures and the solar radiation receipt are repeated from the normal Daily01 product. The remaining 16 variables include new calculations and compilations not available elsewhere in the USCRN Web site, including the maximum one-hour heat index daily and its time of occurrence. A cluster of heating variables follows, with 65°F threshold daily heating degree days and degree hours, and summations of the amount of time during the day that temperatures were less than the four thresholds of 65, 50, 32, and 20°F. The cooling cluster focuses on measures related to cooling buildings, including 65°F threshold daily cooling degree days, cooling degree hours for thresholds 65, 74, and 80°F, and summations of the amount of time during the day that temperatures were greater than four thresholds: 65, 85, 90, and 95°F. The chosen variables and thresholds are derived from sources in the U.S. energy industry. The Energy Product was the first USCRN user product approved by NCEI's Science Council, and the prototype was completed during FY 2014.

(3) **National frost depth maps**

Soil temperature data were used to identify the lowest layer of frost penetration at the USCRN stations in the conterminous U.S. This effort was an extension of previous work by Ronnie Leeper to map USCRN data for public presentation. The mapping tool for the public to see current observations is located at: http://www.cicsnc.org/pub/CRNSpatial/.

(4) Soil Moisture and Soil Temperature Research

Several projects were undertaken utilizing soil moisture and temperature observations of the USCRN. The most important of these projects was an effort to utilize the national scope of soil moisture and precipitation observations to characterize the 2012 Central U.S. Drought, which cost the U.S. tens of billions of dollars in crop losses and other impacts. The 2012 drought signature was detected nationally at all observational depths (5, 10, 20, 50, and 100 cm). Although 2013 precipitation reached levels similar to 2011, the national summer soil moisture signal at 50cm and 100cm depths did not reach pre-drought levels (Figure 4). The analyses reported in this study demonstrate how the USCRN can be used to monitor national soil moisture conditions relevant to the assessment of drought, and provide a standard set of soil moisture measurements to compare to other regional, state, and local networks. The link to the live frost depth map is under the Derived Products link.

The remainder of the report will cover 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 2015

FY 2014 Operational Activities in Alaska

Site Surveys: No site surveys were completed in FY 2014. (Figure 1).

Site Licenses Signed: Site license agreements were completed for two Alaskan sites (Deadhorse and Ivotuk) in FY 2014, with several others in progress.

Stations Installed: Three new stations (Deadhorse, Ivotuk, and Ruby) were installed in Alaska in FY 2014.

Stations Commissioned: One station (Glennallen) was commissioned in Alaska in FY 2014.

In addition to the stations installed in FY 2014 at Deadhorse, Ivotuk Airstrip, and Nowitna NWR (Ruby), two additional sites are licensed and pending installation (Selawik NWR and Denali National Park and Preserve). 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, and US Air Force site at Fort Yukon.

Surveys have been completed in 23 grids of the 29 grid network in Alaska (Figure 1). The project expects that the final 6 remaining grids, located in western and southwestern Alaska, will be completed by FY 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 2014. 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 2015, assuming funding arrives in a timely manner.

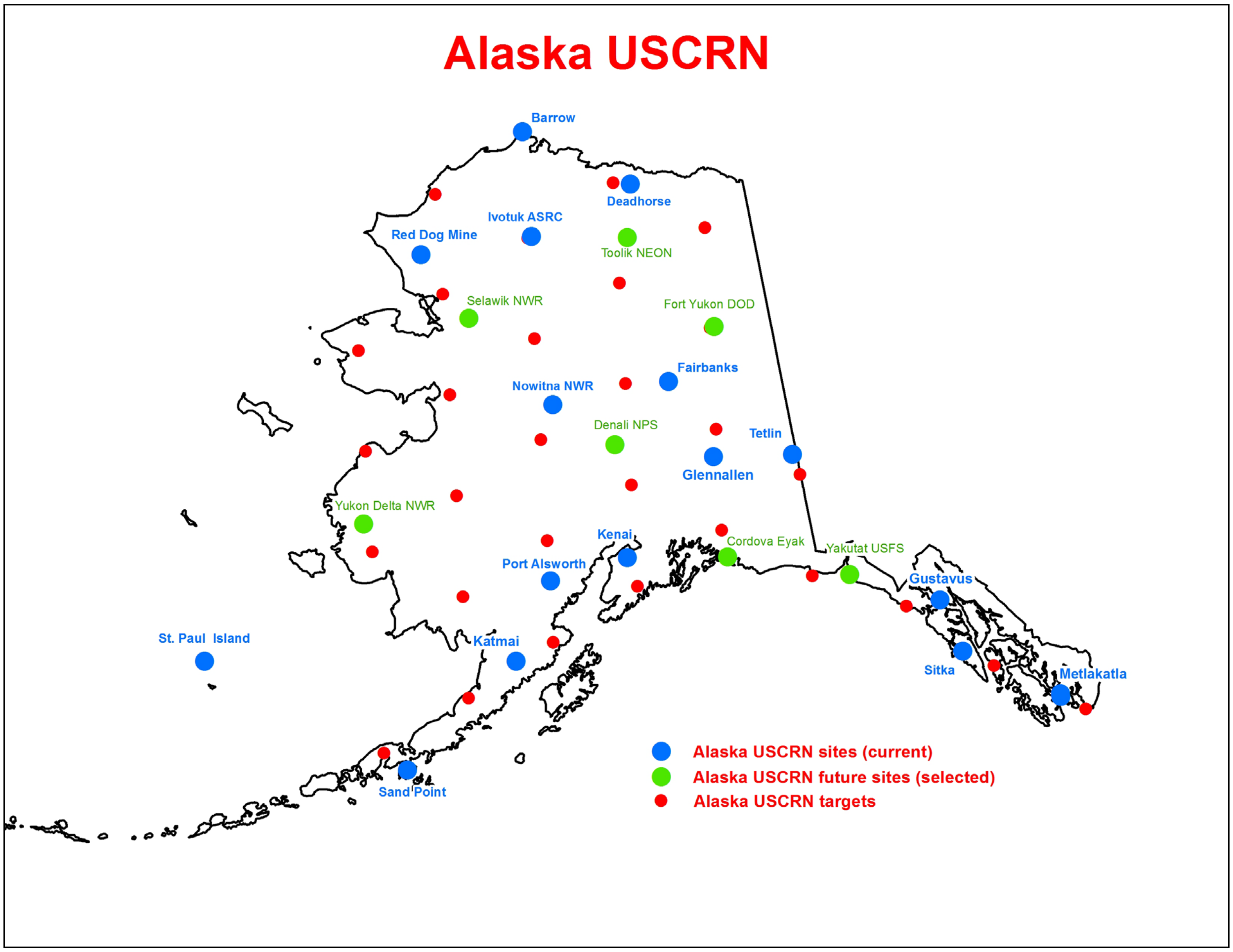


Figure 1. The map of USCRN in Alaska grids (centered on the red dots), along with existing and planned USCRN sites.

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%

Table 2. USCRN in Alaska Data Receipt Rates (%)

		Within 30 days	As of Oct 1, 2014
2014	Q1*	99.0	100.0
	Q2*	95.4	100.0
	Q3*	99.6	100.0
	Q4	99.8	99.8

*Data from AK King Salmon, AK St. Paul Island, and AK Sitka were recovered via annual manual download during the annual maintenance visit.

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

FY 2014 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). The program is planning to switch from OK Goodwell 2 E to OK Goodwell 2 SE during FY15, after having examined the impacts of the gray water pivot irrigation system located within 100 meters of the original (2 E) site. Unlike the case of Goodwell, the USCRN Program faces a substantial challenge in performing a rapid transition between the OH Coshocton 8 NNE and a new location selected at the Ohio Agricultural Research and Development Center near Wooster, OH (Figure 2). After the USDA left the property, no area government entity chose to take over the property, and the General Services Administration of the U.S. Federal Government auctioned the property for private sale. Therefore, the station transition will not include any overlap time. However, since the new location is over 28 miles from the old location, homogenization through overlapping records would have been less effective than at Goodwell in any case. New approaches to linking USCRN station measurements to underlying gridded normals will be used to facilitate including the new Ohio station in national temperature index products as soon as FY 2015 Q3.

Table 4. USCRN Data Receipt Rates (%)

		Within 30 days	As of Oct 1, 2014
2014	Q1	99.8	100.0
	Q2	99.9	100.0
	Q3	99.7	99.7
	Q4	99.9	100.0
	Total	99.8	99.9

Figure 2. Snyder Farm USCRN site choice at the Ohio Agricultural Research and Development Center near Wooster, OH, looking south.

Data Ingest and Processing

Improvements to Data Processing, Monitoring, Data Access, and Product Quality
The USCRN program was impacted by the loss of two senior programmer analysts in early FY14. Progress in several areas came to a stop as tasks were reprioritized and reassigned to the remaining staff which included one new programmer. This transition involved several months of training on the CRN database, SQL Developer, CRNscript, SMART, CRN products, LRGS, ingest and acquisition, unit testing, and other aspects associated with modifying existing CRN tools and software, and development of new tools that work within the existing software infrastructure.

Tasks that were put on hold in FY14 included the following.

- Modernization of web-based reports and data access.
- Development of CRN Multigraph improvements and modernization to HTML5 and Javascript.
- Migration of LRGS data collection service to new server in keeping with new IT requirements.
- Improving processing of dual transmission stations in Alaska.
- Development of submission agreement for Marshall Test Bed data including from SPICE project.
- Transition of Anomaly Tracking System (ATS) from NESDIS to system and training of ATDD engineers and technicians.

Although there were fewer achievements associated with software development in FY14 than in past years, several important tasks were completed and resulted in significant improvements to CRN processes.

Data Stewardship and Quality Assurance

Rewrote LRGS Client Software: The LRGS client software is used to collect data that are transmitted from USCRN stations. This software manages data from four sources, ensuring that when data are unavailable from a primary source other sources can be used to continue an uninterrupted stream of data. The sources in order of priority are 1) data retransmitted from Wallops and collected at NCEI via DCP data service, 2) data retransmitted from the EROS data center in Sioux Falls, SD and collected at NCEI via ftp, 3) data retransmitted from Wallops and collected at NCEI via the local readout ground station dish on the roof, 4) data archived on each station's datalogger and collected via PDA during maintenance site visits (subsequently ftp'd to NCEI from ATDD).

The LRGS Client software was a collection of previous-generation scripts that ran at regular intervals. This approach required a high degree of coordination, and was difficult to adjust in any way. To simplify and improve the reliability of the client software, new scripts were written in Python language that performed the same tasks in a simpler and less fragile way. The naming of the files that these scripts produced was also changed to make their origin easier to identify (i.e, which source they originated from).

Developed and Deployed new Acquisition Software: The CRN 'Acquisition' software is responsible for taking the data following collection from the various sources and distributing it for ingest into the CRN database. Originally a collection of Perl scripts, collectively referred to as CRNWare, this software moved files from local file system directories and from remote FTP servers; breaking large files into smaller files and performing basic validation. Although this software functioned for the purpose designed, its original design would not accommodate use in a tiered environment (development, testing, and operations). The software also was not capable of distributing files to other machines, or preserving metadata about where files originated. To correct these shortcomings, and simplify maintenance, a Java-based application was developed to replace the Perl scripts. The new software is more easily configured, distributes files through all tiers, and preserves file metadata.

Upgraded Ingest Software to Interface with Acquisition Software: Following the acquisition process the CRN "Ingest" software inserts the data into the CRN database. The new acquisition software acts as a messaging-queue, retaining files until they are retrieved by the CRN ingest process. The upgrade to the Acquisition software required minor modifications to the ingest software by adding configuration values and introducing a network connection between running instances of the Ingest and Acquisition. The improvements also eliminated several problems caused by out-of-order file processing. For instance in cases such a server going offline and then returning to service hours later could result in older files being acquired after more recently observed data. Such out-of-order file sequencing would in the past prevent official observations from being calculated. In addition the improvements now enable the ingest system to prioritize the files that it processes, ensuring that CRN can ingest newer LRGS data before historic PDA data.

In addition to these enhancements, an inventory of approximately 700,000 files in the CRN "datashed" was accomplished in FY14. The CRN "datashed" contains all files that have been ingested during the life of the network. This inventory process included the coding of checks and verification of file types and sources, file dates, and consistency of filenames. In addition a high-level inventory outlining the numerous file types, sources, total size, and number of files in each yearly directory was completed. A break-down of each file type on a daily basis (showing the year/month/day subdirectory, number of files in each subdirectory and total byte size) also was accomplished along with the retrieval, decoding and parsing of CRN metadata information in a uniform way, regardless of data source. This inventory is essential to future efforts to reprocess the CRN period of record data. This is expected to occur in FY15 with the introduction of a new precipitation algorithm.

Data Access and Analysis

NetCDF Archive Software: CRN data are archived in NetCDF format. When the CRN archive software was first developed in 2013, its design included a separate NetCDF file for each station-day on record. To improve the efficiency of file manipulation in the archive, the file creation software was rewritten to produce the data in a combined monthly file.

Improved Database Performance: As the amount of data in the CRN database has grown in size over the past several years there has been a gradual slowdown in the performance of the CRN Oracle database. Response times to user requests for data and reports delivered via the

CRN website slowed even more in FY14, and requests often exceeded the time-out threshold of two minutes. With the increase in response times, the need for improvements to the database reached a critical level.

The source of the problem was two-fold. The first problem was not specific to the CRN program but rather associated with IT server infrastructure designed with a sub-optimal configuration that resulted in extremely slow retrieval of data. To solve this problem, CRN developers worked with database administrators to move the CRN database to a new file system that offered greater performance. This resulted in significant improvements in response time, but it subsequently became clear that a redesign of the CRN database was also needed to further improve system performance. Near the end of FY14 work began on the introduction of Oracle table partitioning and a reduction in the number of necessary table joins. Other changes associated with these improvements are expected to be completed in early FY15/Q2. When completed users are expected to see dramatic improvements in the speed with which data queries and requests for CRN reports are returned.

Decommissioned USRCRN Stations: Funding for the **Regional** CRN network ended in FY14. The National Weather Service provided notification via Service Change Notice 14-25 that preparations were underway to begin decommissioning the network. The first step in this process was to deactivate the data feed to NWS websites; CRN programmers made preparations to cease the collection and ingest of RCRN data from the stations in Colorado, Utah, New Mexico and Arizona on June 1, 2014. This required a coordinated modification of ISIS records and modifications to CRN software to stop ingesting observations from the decommissioned stations after the decommissioning date. The historical data for these stations remains available online. This change does not affect any station in the Climate Reference Network.

SMART: The Station Monitoring and Reporting Tool (SMART) continued to provide ATDD engineers and quality control technicians with hourly reports on the status of USCRN stations. In FY14 attention primarily focused on ensuring optimum functionality of the system. A report was added to the SMART system to provide engineers with a new notification threshold for the 1000 mm capacity gauges. Notification is now provided when the gauges reach 250 mm from the top. The previous threshold was set at 150 mm as is the case for the more widely used 600 mm capacity gauges. Another enhancement involved the addition of a new process that checks the status of SMART and restarts the system if necessary. This helps ensure a quick return to service if the SMART system stops due to a server or system problem.

Support to the User Community: The USCRN program assisted several users with tailored data collections and analyses in FY14. Examples include the following:

- Updated existing code to retrieve CRN solar radiation data for Dr. David Brooks (Institute for Earth Science Research and Education http://www.instesre.org/) and wrote additional software to extract flag information for each variable.
- Completed a data request for Dr. Claude Duchon (University of Oklahoma) for 5-min Geonor and tipping bucket precipitation values summed to daily for the POR for three Oklahoma CRN stations. Compared differences between newly calculated Geonor daily summed values and the daily01 product values.

Supported ATDD and CICS scientists by extracting and preparing CRN data for analyses. This included 5-minute soil temperature, soil moisture, air temperature, precipitation, and other elements.

USCRN Science and Development Activities

New Products for Users

Climate monitoring and assessment: A new tool for USCRN users called the Energy Product has been designed to compile daily statistics that are most relevant to home heating and cooling energy use, and also correlated with other types of energy use. For each station, the daily maximum and minimum temperatures and the solar radiation receipt are repeated from the normal Daily01 product. The remaining 16 variables include new calculations and compilations not available elsewhere in the USCRN Web site, including the maximum one-hour heat index daily and its time of occurrence. A cluster of heating variables follows, with 65°F threshold daily heating degree days and degree hours, and summations of the amount of time during the day that temperatures were less than the four thresholds: 65, 50, 32, and 20°F. The cooling cluster focuses on measures related to cooling buildings, including 65°F threshold daily cooling degree days, cooling degree hours for thresholds 65, 74, and 80°F, and summations of the amount of time during the day that temperatures were greater than four thresholds: 65, 85, 90, and 95°F. The chosen variables and thresholds are derived from sources in the U.S. energy industry. The Energy Product was the first USCRN user product approved by NCEI's Science Council, and the prototype was completed during FY 2014. The final version of the data product will be released as a Quality Controlled Dataset early in FY 2015 at the USCRN Web link: http://www.ncdc.noaa.gov/crn/qcdatasets.html.

Monthly national anomaly maps: In conjunction with the Climate Monitoring Branch, a set of temperature and precipitation anomaly maps featuring USCRN station observations has been approved by the National Climatic Data Center Services Council for appearance in the NCEI State of the Climate Web pages. Data file structures have been developed and estimated normals are in place for existing CMB software to generate station-based anomaly maps. The actual mapping work is progressing into FY 2015, and will be available in the first quarter.

National frost depth maps: Soil temperature data were used to identify the lowest layer of frost penetration at the USCRN stations in the conterminous U.S. This effort was an extension of previous work by Ronnie Leeper to map USCRN data for public presentation. The mapping tool for the public to see current observations is located at: http://www.cicsnc.org/pub/CRNSpatial/. The link to the live frost depth map is under the Derived Products link. A map of frost depth from winter FY 2014 is shown in Figure 3.

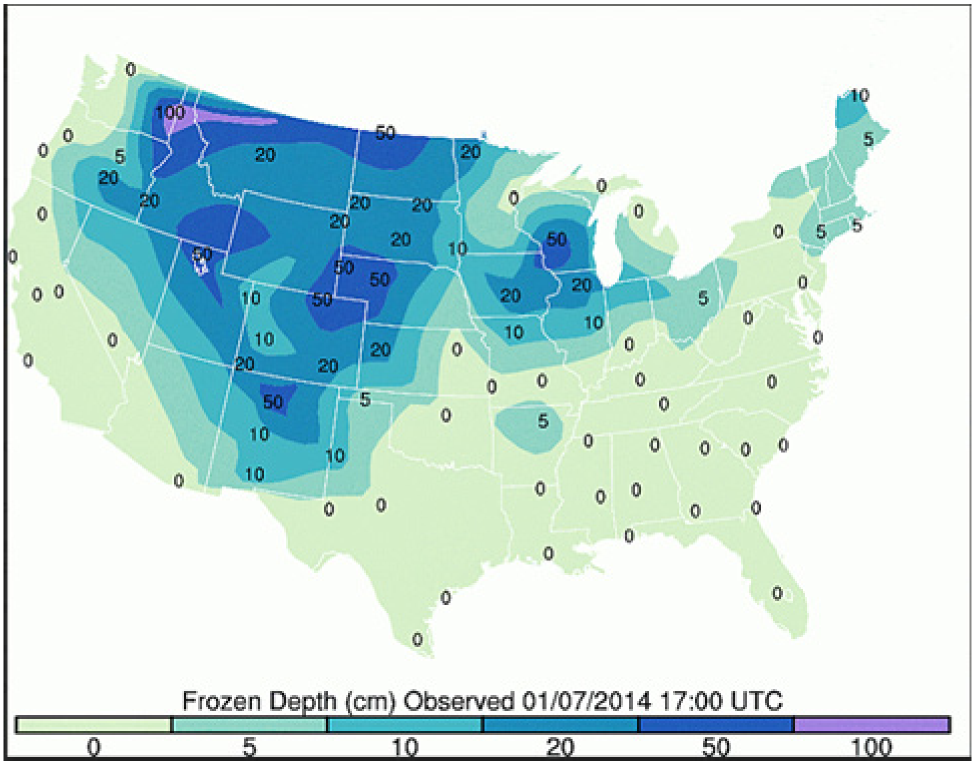


Figure 3. Map of frost (subfreezing) depth penetration in the conterminous U.S. on 7 January 2014. Note that several stations near the Great Lakes do not have frozen soil due to early and heavy snow cover insulating the ground from cold air.

Soil Moisture and Soil Temperature Research

Several projects were undertaken utilizing soil moisture and temperature observations of the USCRN. The most important of these projects was an effort to utilize the national scope of soil moisture and precipitation observations to characterize the 2012 Central U.S. Drought, which cost the U.S. tens of billions of dollars in crop losses and other impacts. The 2012 drought signature was detected nationally at all observational depths (5, 10, 20, 50, and 100 cm). Although 2013 precipitation reached levels similar to 2011, the national summer soil moisture signal at 50cm and 100cm depths did not reach pre-drought levels (Figure 4). The analyses reported in this study demonstrate how the USCRN can be used to monitor national soil moisture conditions relevant to the assessment of drought, and provide a standard set of soil moisture measurements to compare to other regional, state, and local networks.

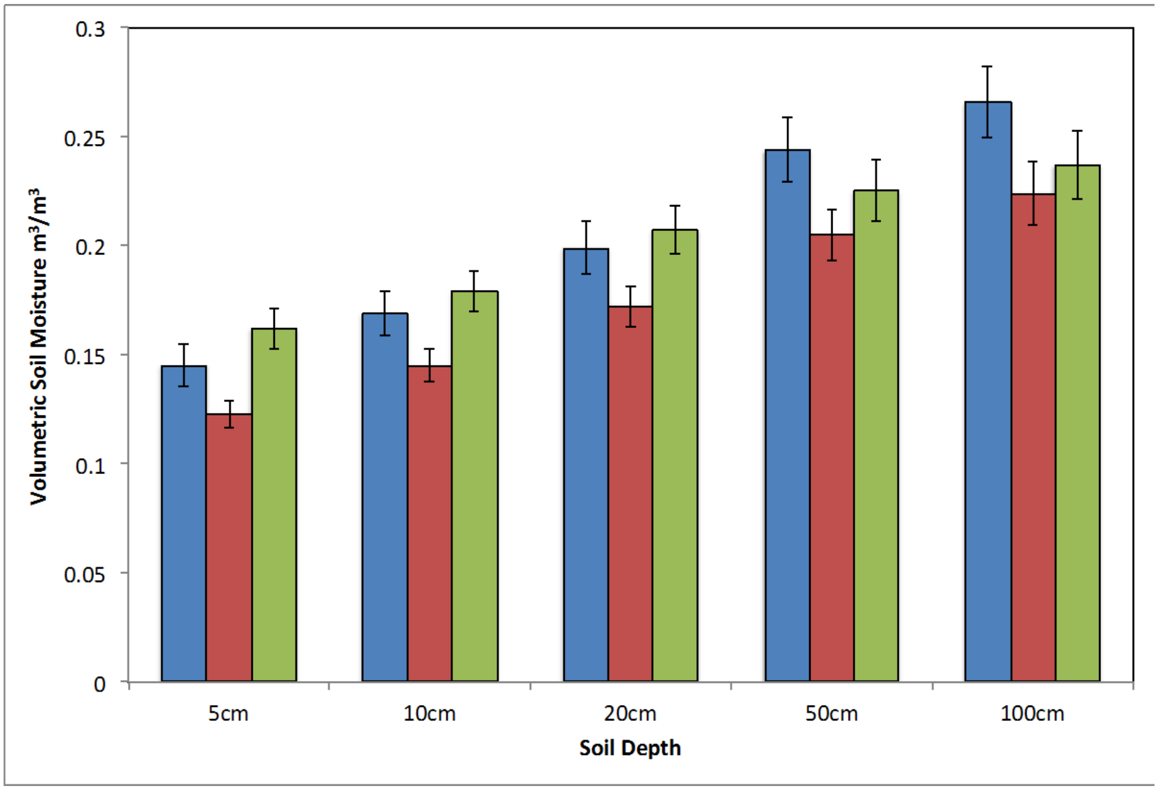


Figure 4. Soil moisture averages and standard error for summer months of 2011, 2012, and 2013 for each depth recorded by USCRN.

Bell, Jesse E., Rocky Bilotta, Scott Embler, Ronald D. Leeper, Michael A. Palecki, and Tim Wilson, 2015. Evaluation of two drought events in the United States with a newly established national soil monitoring network. Submitted to Vadose Zone Journal.

The team is also looking at the new soil moisture dataset in a more in depth manner, studying the lead and lag relationships between atmospheric climate variables and soil moisture, and the subsequent relationship to drought status in the U.S. Drought Monitor (USDM). A longer standing set of soil moisture stations, the U.S. Department of Agriculture Soil Climate Analysis Network (USDA SCAN) is also utilized in this study to increase spatial coverage and take advantage of longer datasets to examine soil moisture departures from normal. This research project is continuing into FY 2015, but has already shown some interesting relationships. For example, soil moisture changes seem to lead drought recovery changes in the USDM by 4-5 weeks (Figure 5), perhaps indicating a need to reconsider definitions of drought at least at agricultural time scales.

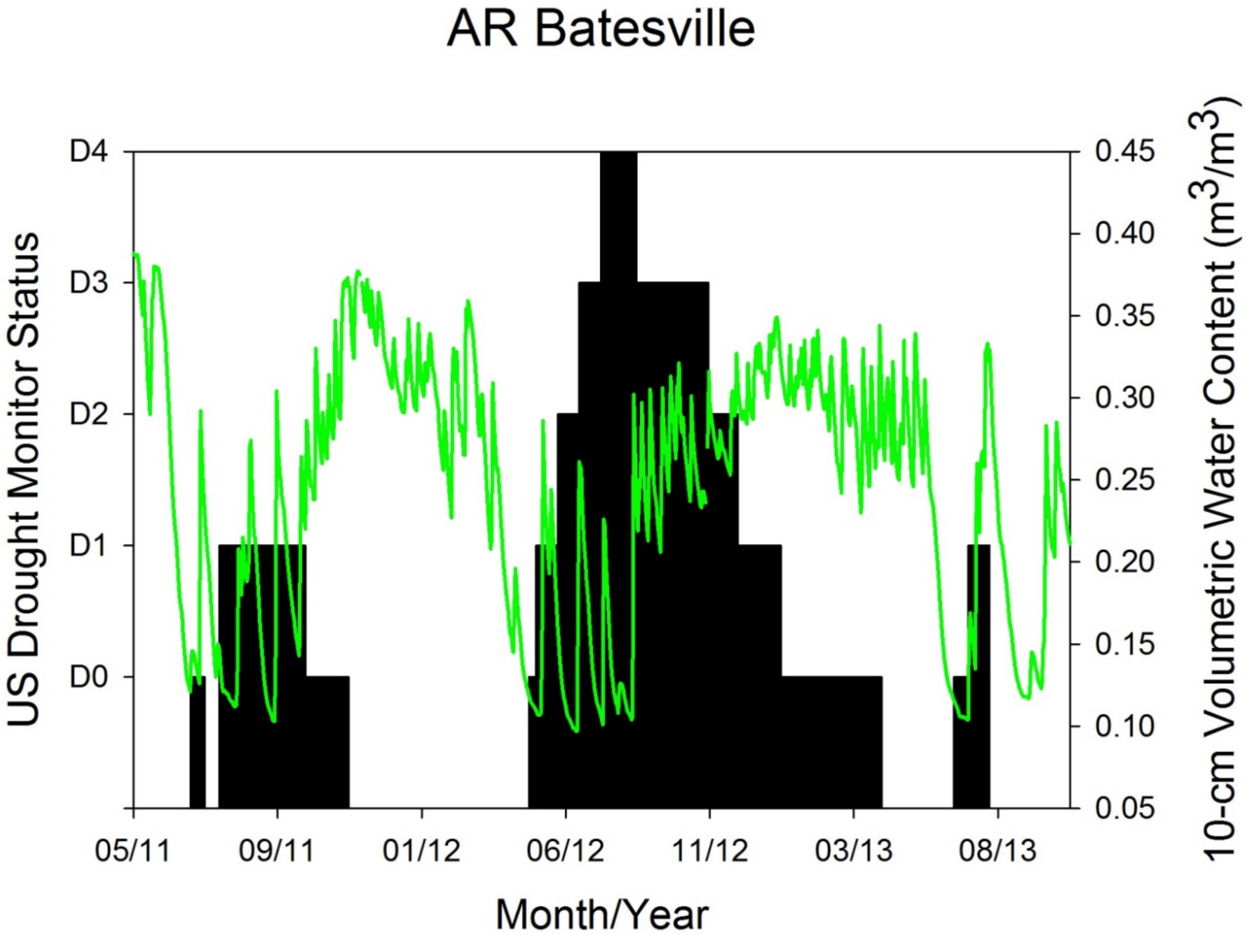


Figure 5. 10-cm soil moisture at Batesville, AR, USCRN station plotted against the local U.S. Drought Monitor status. USDM follows shallow soil moisture initially, but then lags behind soil moisture recovery considerably.

Palecki, M.A., J. Bell, R. Leeper, and R. Bilotta, 2014. U.S. Climate Reference Network Triplicate Soil Moisture Measurements: What We Have Learned So Far. Keynote Speaker at the Third In-Situ and Remote Soil Moisture Sensing Technology Conference: Challenges and Opportunities in A Changing World, March 12-14, 2014, Houston, Texas.

The soil moisture representativeness study continues into its second year, with data collection at Crossville, TN, ending at the end of FY 2014, and the data collection at Millbrook, NY, reaching completion earlier in the year. The variation of 5 cm soil moisture across the 9 km x 9 km area around Millbrook was quite impressive (Figure 6), ranging from desert dry to swampy wet simultaneously, depending on the drainage characteristics of the soil. Agreement across the area was much better after rain, and the overall area average related with a high degree of agreement to the simple USCRN station mean (Figure 7a and 7b), with an $r^2 = 0.776$.

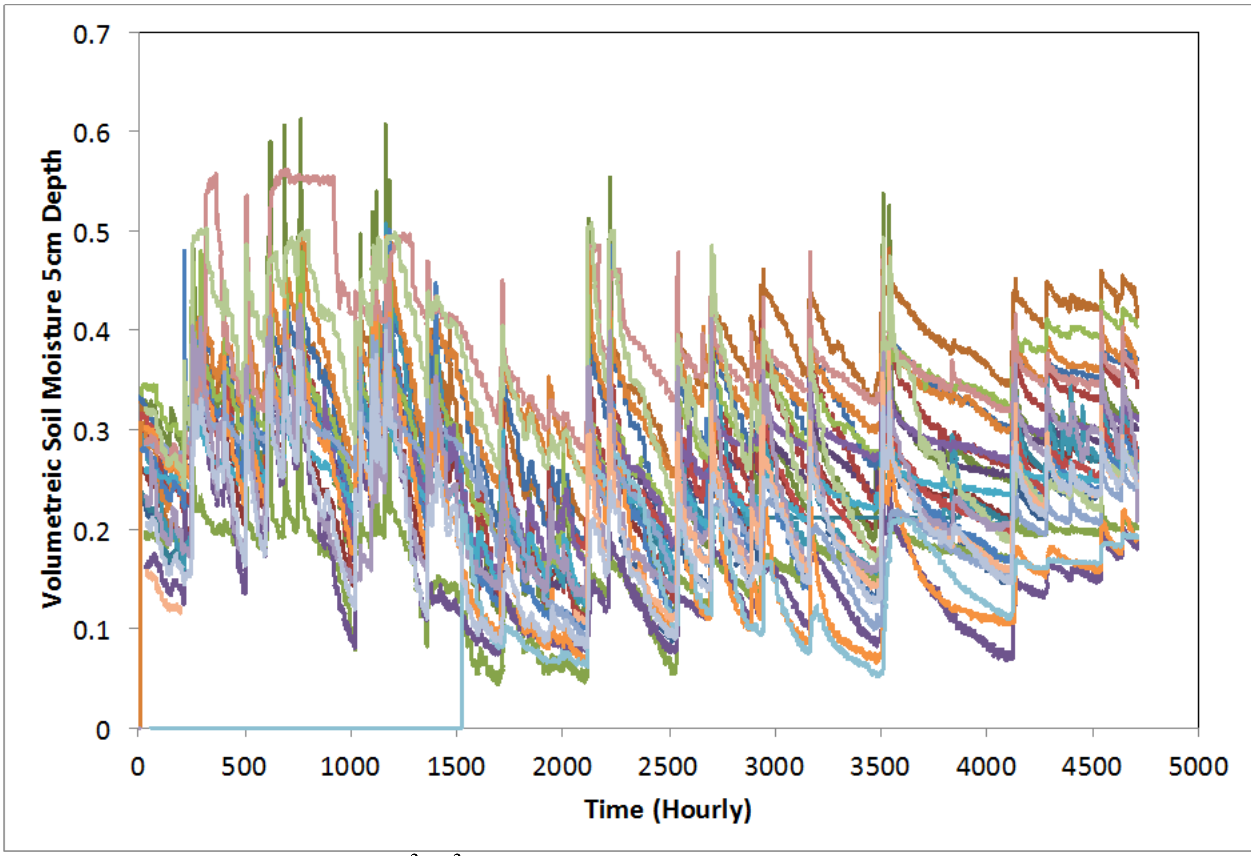
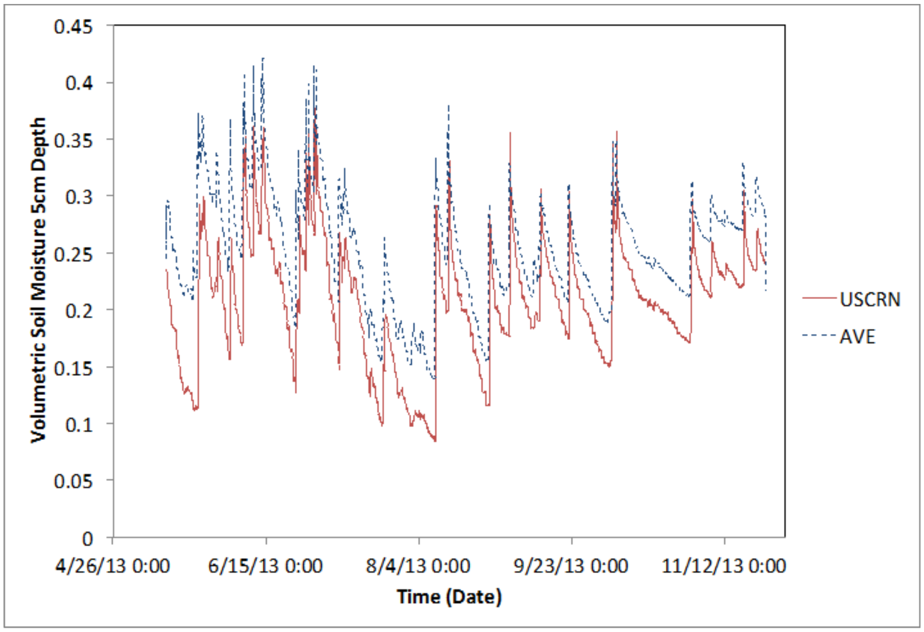


Figure 6. 5-cm soil moisture (m^3m^{-3}) measured at 25 locations near the USCRN site in Millbrook, NY, during 2013.



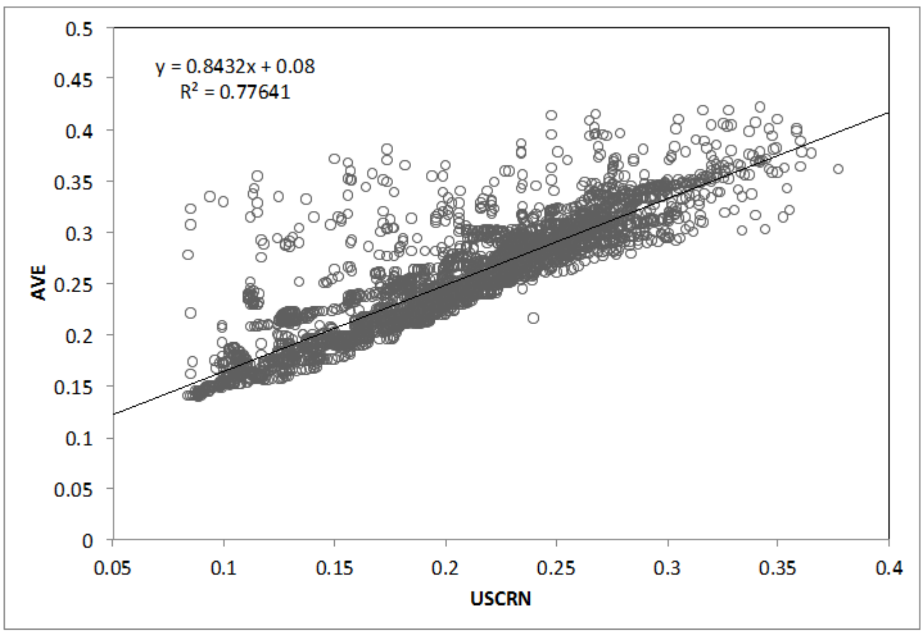


Figure 7. a) 5-cm soil moisture at the Millbrook USCRN site (red) versus the 9 km by 9 km average (blue); b) linear regression between the two shows scaling (non-zero slope) and shifting (+0.08 y-intercept) are both required to calibrate the USCRN station to represent the local area.

These results from Millbrook and a similar set from Crossville will allow for these USCRN stations to be more useful for validation of satellite-based soil moisture estimates from the NASA Soil Moisture Active Passive (SMAP) Mission. USCRN personnel attended to SMAP Calibration/Validation workshop for the 5th year in a row as preparations for launch near completion for a January 2015 launch. In addition to representativeness studies, USCRN Program is working with site hosts at 15 additional stations to collect gravimetric samples of soil to measure soil moisture directly with scales and then relate these standard measurements to the electronically derived measurements of the USCRN stations. It is anticipated that these stations will also be highly useful for SMAP validations over coarse networks, including USCRN.

Finally, a fourth major soil moisture project was started during summer 2014, when a NOAA sponsored Educational Partnership Program scholar, Ms. Chante' Vines, worked with mentors Ronald Leeper and Michael Palecki on a project to compare USCRN soil moisture measurements to those generated by the soil moisture model that is part of the North American Regional Reanalysis (NARR) conducted by National Center for Environmental Prediction. This study showed that there was a very substantial level of agreement regarding summer soil moisture change over time ($r^2 = 0.91$), although there is also a fairly large offset between the two, with USCRN observations being drier by 0.04-0.08 than the NARR model results (Figure 8). This analysis has also been broken down by region and by local pixel or pixels, and will be completed in FY 2015.

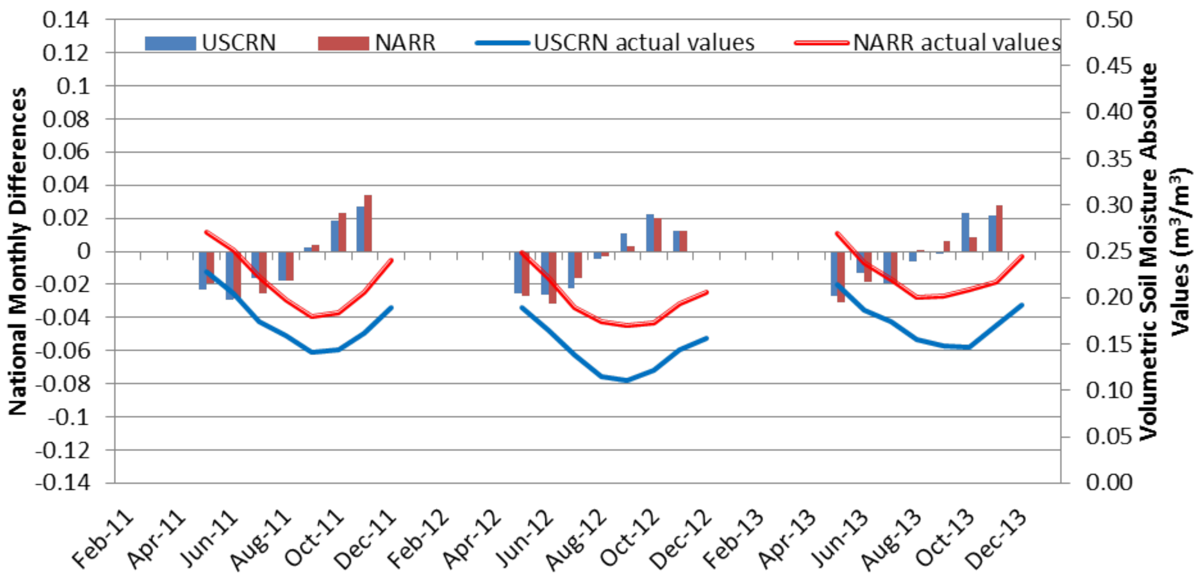


Figure 8. Comparison of USCRN 5-cm soil moisture observations and NARR modelled output, showing very good month-to month change agreement (bars) but also a general offset (lines), with the NARR model output wetter than the USCRN observations.

<u>Precipitation and Air Temperature Research</u>

USCRN – COOP Comparison Study Completed: The general results of comparing Cooperative Observer Program (COOP) climate stations with USCRN were generally as expected for air temperature. Naturally aspirated COOP sensors generally had warmer (0.48°C) daily maximum and cooler (0.36°C) minimum temperatures. However, the specifics from station-to-station varied substantially, especially for minimum temperature. In response to reviewers' comments, the COOP station temperature gauge siting was examined more closely, and several were found to be close to buildings and vegetation, explaining some of the inconsistencies in results. Even more unexpectedly, COOP stations reported more precipitation than USCRN for events surrounded by dry days, about 1.55%. Some of this has been addressed in improving the USCRN precipitation calculation algorithm, but it turns out that much of this is due to precipitation that fell in COOP gauges on previous days and was not reported as multiday precipitation. COOP observer inconsistencies (e.g., multiday observations, time shifts) resulted in many cases with large daily temperature and precipitation differences that were not the result of instrumentation biases. For example, in Figure 9, the COOP minimum temperature reported for December 13 was actually observed on December 14. Many of the largest differences apparent are due to operational issues, rather than instrumentation or siting of stations. The paper is currently being revised.

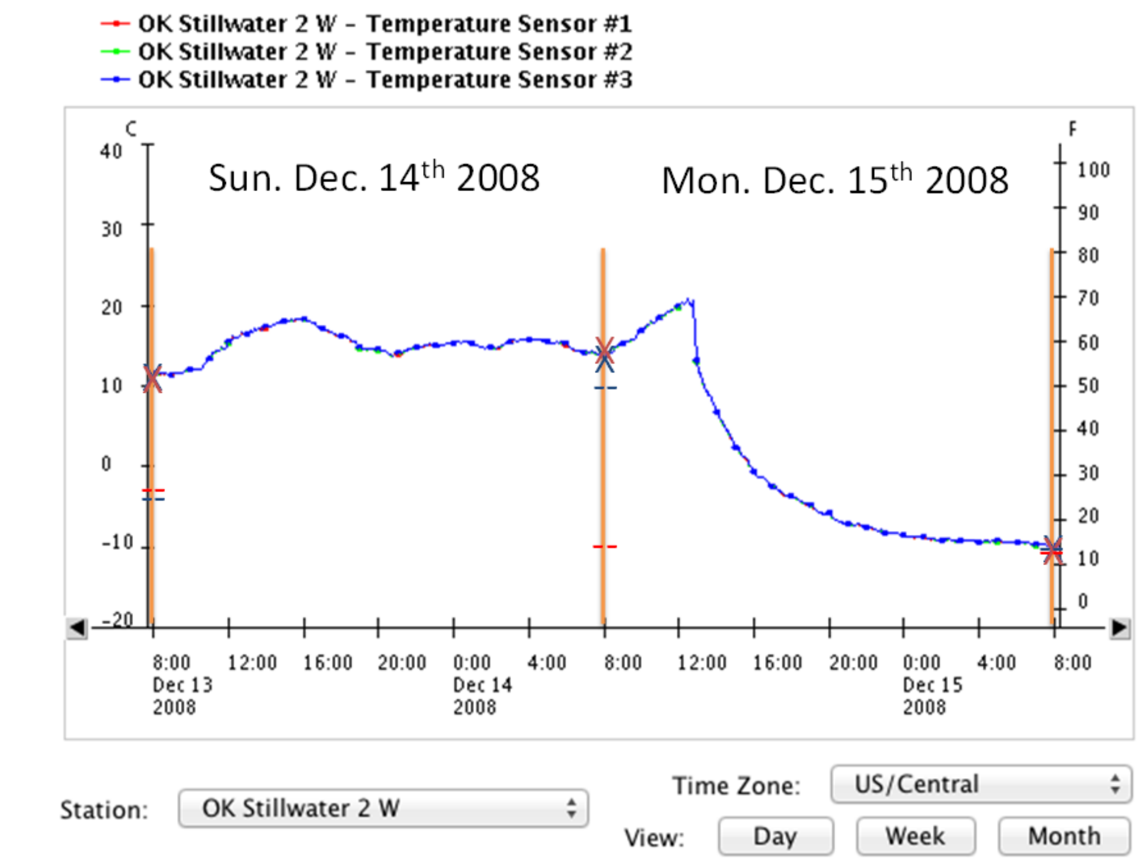
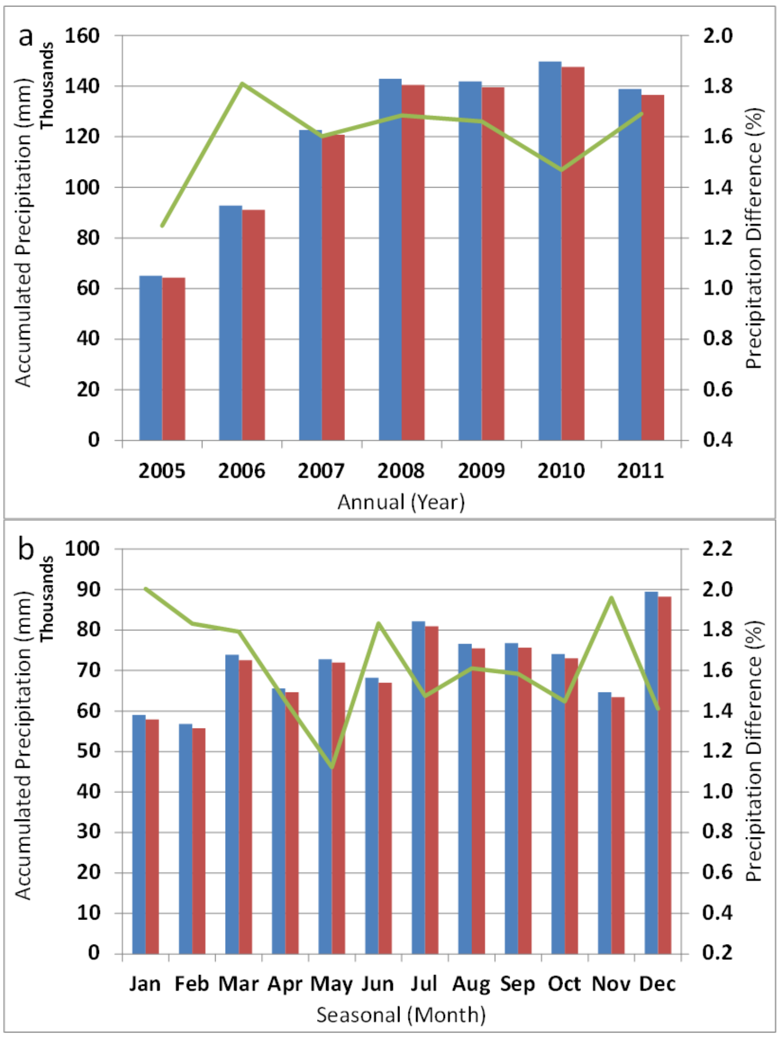


Figure 9. Sub-hourly USCRN redundant temperature observations from December 13th through the 15th with USCRN (blue) and COOP (red) time-of-observation (X) and minimum (--) temperatures at COOP observation time (orange bar).

Leeper, Ronald D., Jared Rennie, and Michael 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. doi: 10.1175/JTECH-D-14-00172.1,* in press.

Precipitation Calculation Algorithm Improvement: Work continued in FY 2014 on efforts to improve the USCRN algorithm for calculating 5-minute precipitation totals using triplicate measurements of depth change in a weighing bucket gauge and a measurement of wetness by a disdrometer. The final algorithm was approved by the USCRN Configuration Control Board as Configuration Change Request #46, and has been briefed to the NCEI Science Council and prepared as a publication submitted to a refereed journal. A network-wide increase in total precipitation of 1.6% occurs in the transition from the current calculation method to the new calculation algorithm (Figure 10), which is also in agreement with the level of difference between bulk precipitation from 12 USCRN stations and their nearby COOP station pairs.

Figure 10. USCRN total precipitation computed from (blue) newCalc and (red) currentCalc with



(green-line) percent differences over (a) annual and (b) monthly time scales.

Leeper, Ronald D., M. A. Palecki, and J. Davis, 2015. USCRN quality assurance methods for weighing bucket precipitation gauges with triplicate depth measurements. *Journal of Atmospheric and Oceanic Technology,* in press.

Gauge Evaporation: A further nuance to calculating precipitation from a weighing bucket gauge with three independent depth measurements is the role of evaporation. Because every weighing gauge has at least a small amount of noise, it is often normal practice to smooth or average gauge data for a period before gauge depth starts to rise, so as to provide a reference level from which to measure depth change and, therefore, precipitation. Two weighing gauges of the type used by USCRN were installed near each other, and one was treated with an evaporative suppressant, and the other not treated. The untreated gauge evaporated on average 0.12 mm hr^{-1} from June to August. However, precipitation underestimates due to evaporation are dependent on the method of calculation, with a longer averaging period for the reference depth in the current Pairwise comparison algorithm causing a negative bias in calculated precipitation (-4.6% bias with respect to control) while a weighted averaging algorithm without smoothing yielded very little bias (Figure 11). An evaporative suppressant makes weighing gauge precipitation estimates much less susceptible to the calculation algorithm and/or noise in the gauge depth measurements.

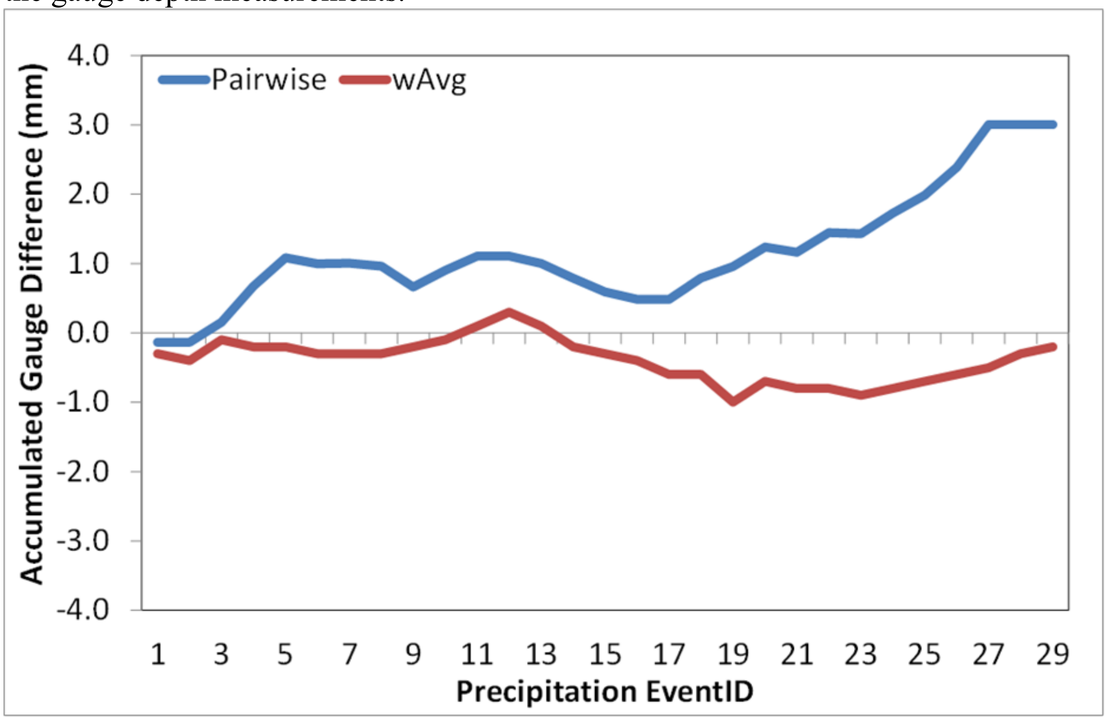


Figure 11. Evaporating gauge and non-evaporating gauge accumulated precipitation event differences between USCRN current Pairwise comparison algorithm (with a 2-hour reference period) and a new weighted averaging algorithm (with a 5-minute reference period) calculation methods. The new approach yielded only very small differences in precipitation between treated and untreated gauges, suggesting that it has a low sensitivity to evaporation.

Leeper, R.D., and J. Kochendorfer, 2015. Evaporation from weighing precipitation gauges: impacts on automated gauge measurements and quality assurance methods. *Atmospheric Measurement* Techniques, in press..

Air Freezing Index: The air freezing index, or AFI, is a common metric for relating the severity of the winter season at a location to the expected frost depth distribution over time. It is based on a cumulative graphing of degree days above and below freezing (0°C or 32°F) starting on August 1, and is the number represented by the difference in freezing degree days between the highest and lowest local extreme points from the beginning of winter to the depth of winter. The study was conducted predominantly with daily COOP station mean temperatures for thousands of places in the conterminous U.S. USCRN temperature data were gathered over a 5 year period to compare the annual AFI generated by all USCRN stations in each of 9 U.S. climate regions. The USCRN results were used as a reference to confirm the results averaged across the COOP stations in each region. This analysis (Table 3 in Bilotta et al. 2014, not shown) demonstrated very significant correlations and confirmed that the AFI calculations were reliable. The paper showed a strong decrease in both 2-yr and 100-yr return interval annual AFI values in the northern Great Plains from the 1951-1980 period to the current climate normal period, 1981-2010.

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.

Field and Testbed Activities

Continued Intecomparison and Sensor Testing

Air Temperature Bias Experiment: Homogenization of temperature records is required to account for the effects of urban area land surface conditions and changes in sensor technologies. Homogenization is largely based on statistical techniques, however, and may contribute to uncertainty in the measured U.S. surface-temperature record. To provide physically-based error estimates applicable to the U.S. temperature record, an experiment was performed in an urban landscape in Oak Ridge, TN to evaluate the effects of artificial heat sources such as buildings and parking lots on air temperature. Air temperature measurements within a grassy field, located at varying distances from artificial heat sources at the edge of the field, were recorded from Nov 2012 through March 2014 using both the NOAA US Climate Reference Network methodology and the National Weather Service Maximum Minimum Temperature Sensor system. The effects of the roadways and buildings were quantified by comparing the air temperature measured close to the artificial heat sources to the air temperature measured well-within the grassy field, over 200 m downwind of the artificial heat sources. Significant air temperature biases were detected based on both the measurement type and the measurement location.

WMO Solid Precipitation Intercomparison Experiment: In collaboration with other countries participating in the WMO Solid Precipitation Intercomparison Experiment (WMO-SPICE) NOAA/ATDD has contributed significantly to experiment planning, project management, and data analysis methods used in this international comparison of precipitation measurement methods. The goal of the intercomparison is to create a new standard for the automated measurement of solid precipitation and to develop methods to relate current precipitation measurement techniques back to the new standard. NOAA/ATDD has helped quantify the uncertainty in both liquid and solid precipitation measurements and determine the minimum amount of precipitation that can be measured accurately enough to produce reliable relationships between catch efficiency and wind speed. In addition, NOAA/ATDD is leading the effort to accurately determine precipitation type for WMO-SPICE. NOAA/ATDD has also helped define the methods used to analyze existing precipitation datasets.

Comparison of the Belfort and the MetOne Fan-Aspirated Radiation Shields: In order to produce accurate air temperature measurements, air temperature sensors must be shielded from the effects of solar and thermal radiation. Triple-walled fan-aspirated radiation shields provide the best system for accurate air temperature measurements, but a well-designed radiation shield must also minimize the power required by its fans. After intensive testing, the USCRN engineering team selected the MetOne fan-aspirated shield for its accuracy, ease of maintenance, and low-power demand. As part of a Cooperative Research and Design Agreement with Belfort Instruments, we have shared our shield design criteria with them and are testing their newest radiation shield. In a 1.5 yr. long field comparison between the MetOne radiation shield and the Belfort radiation shield in Oak Ridge, TN the Belfort shield performed well, with only small deviations from the MetOne shield of on average 0.04° C, which were well within the design requirements of the USCRN. The deviations were likely due to calibration differences and actual differences in the air temperature around the towers rather than the shielding.

The USCRN Soil Moisture Analysis: Thanks to the remarkable developments in soil-environment monitor technologies site-specific soil moisture sensors, once the prerogative of short-term, specialized, detailed studies, are being widely deployed in routine ground surface climate observations. Increased interests exist for accurate determination of soil moisture to be incorporated as a realistic component in the assessment of regional environmental, weather, climate, and hydrology. Between April 2009 and August 2011, ATDD and NCEI deployed soil moisture and soil temperature sensor probes at the 114 stations in the continental United States. So far the NOAA soil moisture network is the only ground-based network that spans the entire continental U.S. with a distribution of stations in nearly all the many different topographical, vegetation, and climate environments of the country. Therefore, in conjunction with the soil moisture measurements the *in situ* variations of soil are important issues to consider because it is difficult to know ahead of time how soil, vegetation, and land-use factors would influence soil moisture variability. During the soil moisture field installation, soil core samples were collected from the exact depth locations of the soil sensor probes. Analyses of the soil cores were conducted by the National Soil Survey Center (NSSC), Lincoln, Nebraska to determine the soil particle size distribution (PSD), bulk density (BD), soil water content at water potentials of 33 kPa (field capacity, FC) and 1500 kPa (permanent wilting point, PWP). The PSD and BD quantify the bulk soil matrix and the FC and PWP are important variables for calculating the amount of soil water required to support vegetation growing processes. This direct knowledge of soil properties for and among the USCRN sites can ultimately improve our ability to understand and evaluate the soil moisture measurements. Providing site-specific soil data that affect soil moisture would assure the quality of the soil moisture measurements and improve the soil moisture values in determining site-specific soil water budgets to help manage water resources for operations in agriculture and hydrology, as well as improve land surface parameterizations in weather, climate and hydrological predictions.

Monitoring Activity Highlights

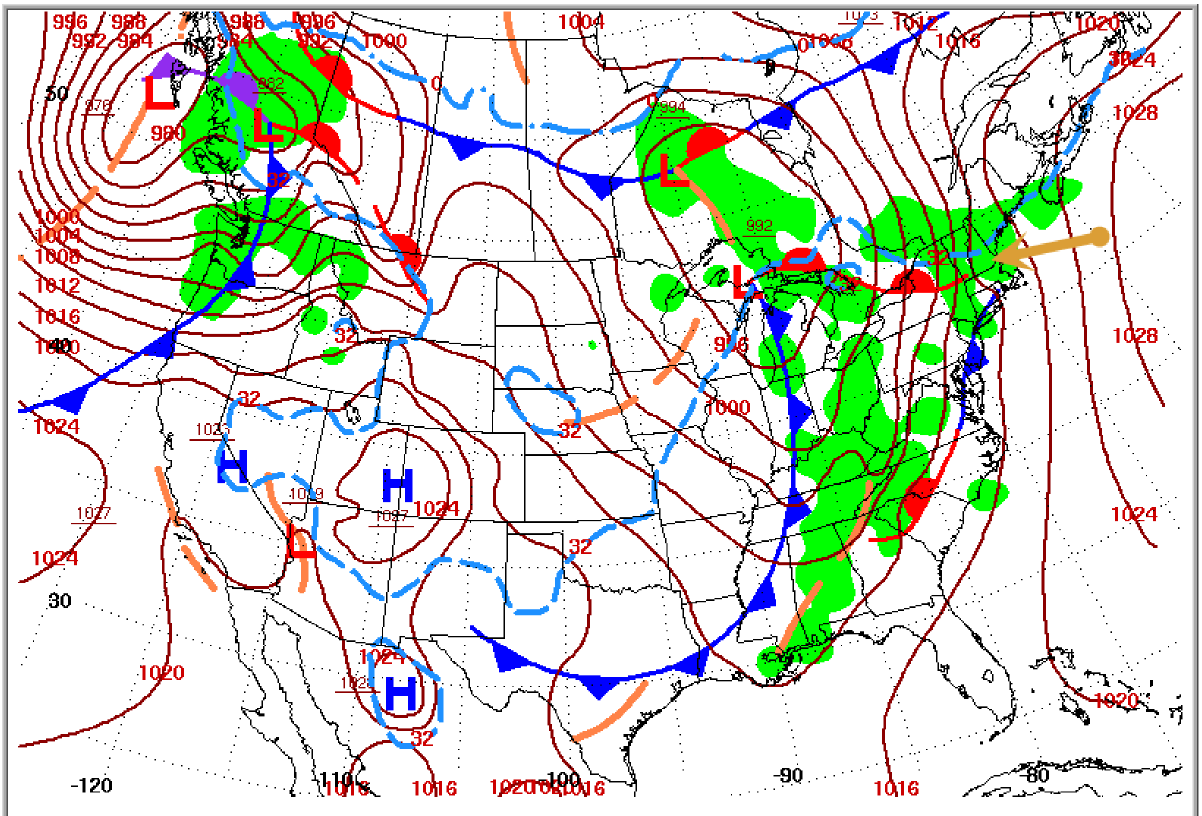
Extreme Temperature Shift in New Hampshire

On January 11, 2014 a warm front moved northward over the paired USCRN sites near Durham, NH (Figure 12). Stations are about 4 miles apart and are located at the point of the yellow arrow.

Daily Weather Maps

; DAY

SATURDAY JANUARY 11, 2014



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

Figure 12. Daily Weather Map for Saturday, January 11, 2014.

As the front passed over the stations, ambient temperatures rose more than 20F/12C (blue line in graph below) in about 30 minutes. Perhaps of greater interest is that both stations remained in the fog throughout the event as is indicated by the consistent 100% relative humidity readings (Figure 13).

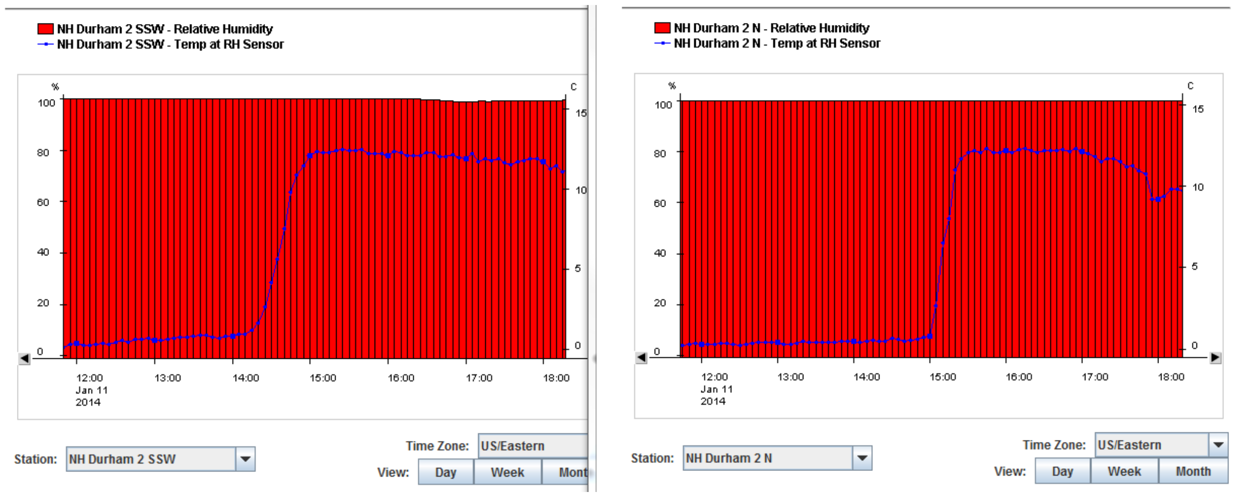
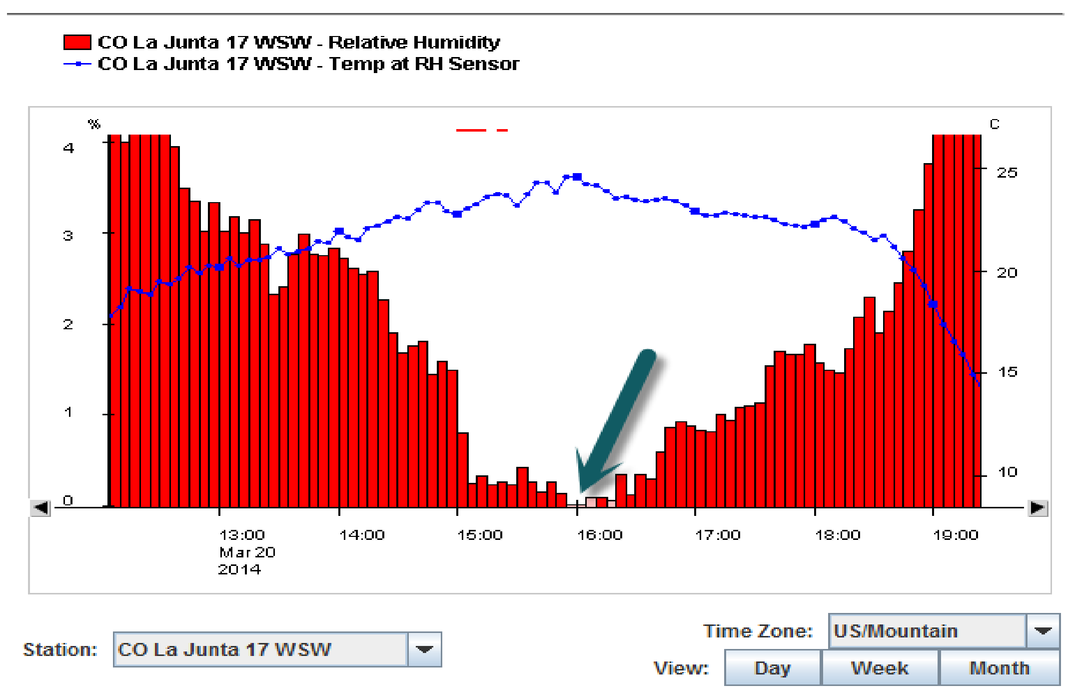


Figure 13. Graphs of ambient air temperature and relative humidity for Durham 2 N and 2 SSW, NH.

Paired Colorado sites confirm validity of apparent anomaly

During several events this Spring the relative humidity sensors at a couple of the USCRN sites reported values of less than 1%. One of those was at La Junta 17 WSW, CO on March 20, 2014 (Figure 14).



Source: National Climatic Data Center/NESDIS/NOAA

Figure 14. Relative humidity graph for CO La Junta 17 WSW.

NWS instrumentation at the La Junta Municipal Airport reported similar values of 2% during the same time. The second occurrence was at the USCRN site 11 miles west of Tucson, AZ on April 20, 2014, and those <1% values were also corroborated by NWS measurements at the Tucson Airport.

Extreme Rainfall Events

Fairhope, AL

The CRN site near Fairhope, AL experienced a series of "training" thunderstorm cells that produced a storm total of 8.25 inches/209.5mm, of which 7.76 inches/197.2mm fell in three hours. The maximum 60 minute total was 3.76 inches/95.5mm (Figure 15). The Fairhope site is represented by the black dot. This was just short of the USCRN record 60 minute rain of 3.77 inches set at Titusville 7 E, FL on July 7, 2006.

Based on NOAA Atlas 14 Point Frequency Estimates, the 3 hour total of 7.76 inches has an expected recurrence interval of 100 years, while the expected recurrence for the 60 minute value of 3.76 inches is only a once in 25 year event.

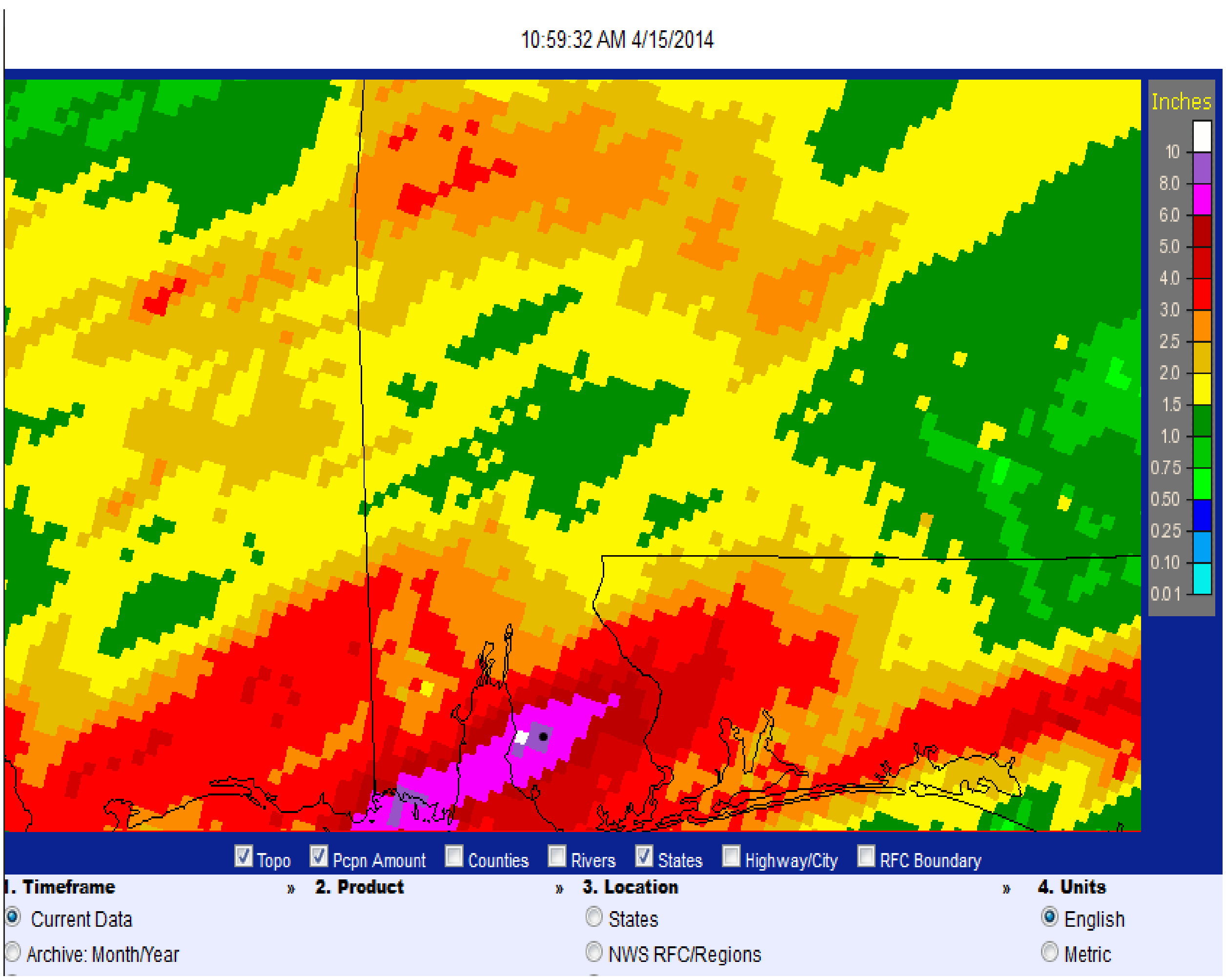


Figure 15. Storm Total Radar Estimated Precipitation from the Mobile, AL NWS Radar

Cape Charles, VA

The Cape Charles 5 ENE, VA USCRN site experienced the remnants of a tornado cell that moved across the Southern portion of Chesapeake Bay on July 24, 2014, killing one and injuring others in a campground about 5 miles WSW of the USCRN station. It was a fast moving storm only lasting about 10 minutes, but in the first 5 minutes 0.95 inches/24.17mm fell, with another 0.68 inches/17.23mm falling in the next 5 minutes, giving a 10 minute total for the storm of 1.63 inches/41.40mm (Figure 16). These values exceed the existing USCRN Network extreme 5 and 10 minute values of 0.88 and 1.50 inches set at the Sundance 8 NNW, WY site on Sept 4, 2013. When comparing these new record values against the NOAA Atlas 14 recurrence interval values, we find that both the values were within the 90% confidence limits of a 1000 year event for this location (Figure 17). USCRN station located at point of orange arrow.

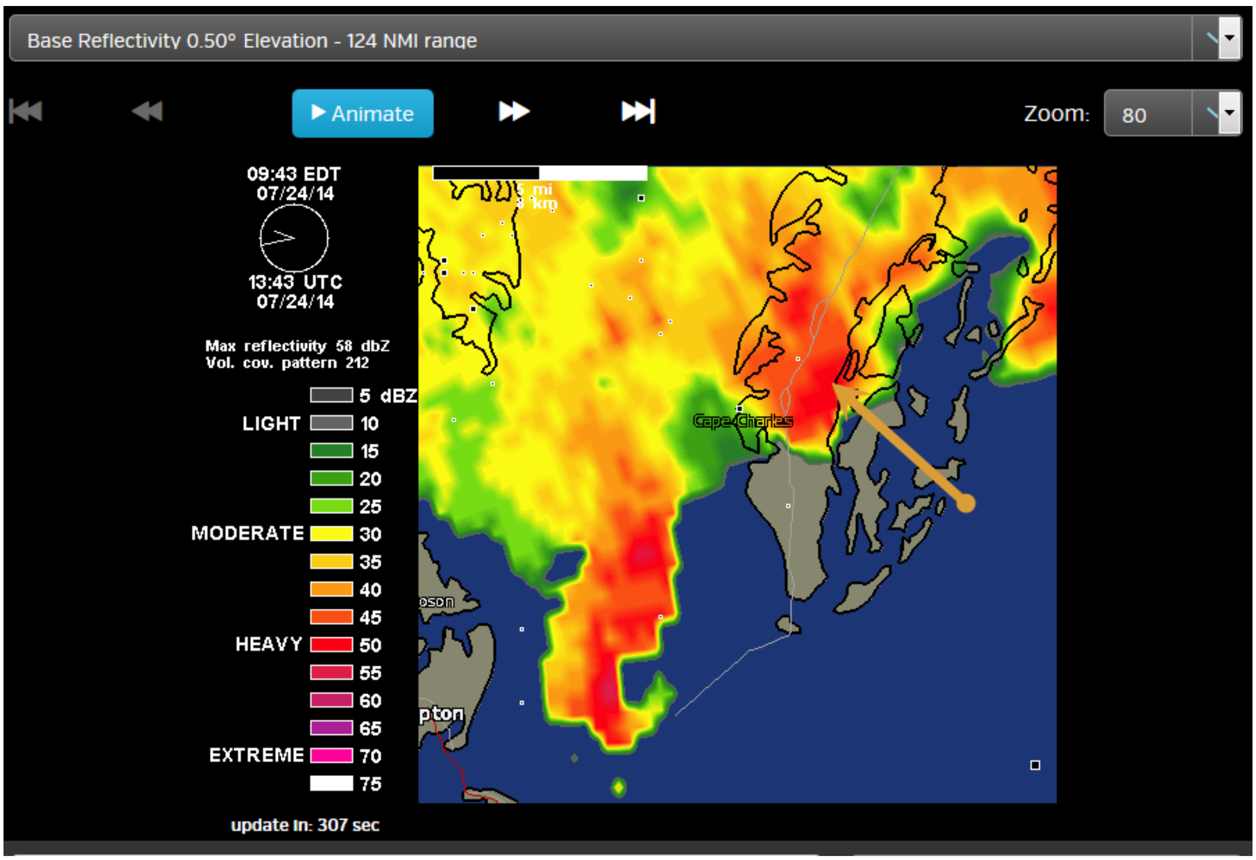
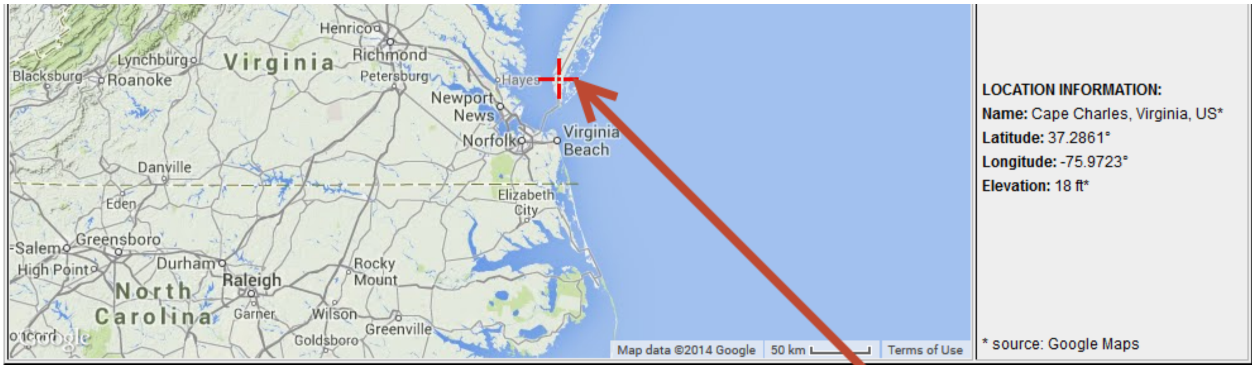


Figure 16. Mid-Morning Radar Image of the Tornado Storm Cell July 24, 2014



POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION

NOAA Atlas 14, Volume 2, Version 3

PF tabular | PF graphical | Supplementary information | Print Page

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.366 (0.331-0.407)	0.423 (0.383-0.467)	0.457 (0.415-0.504)	0.548 (0.496-0.605)	0.617 (0.556-0.680)	0.694 (0.624-0.765)	0.755 (0.676-0.833)	0.814 (0.725-0.896)	0.873 (0.772-0.964)	0.948 (0.833-1.05)
10-min	0.585 (0.528-0.650)	0.677 (0.613-0.747)	0.732 (0.664-0.806)	0.877 (0.793-0.968)	0.984 (0.886-1.08)	1.11 (0.993-1.22)	1.20 (1.07-1.32)	1.29 (1.15-1.42)	1.38 (1.22-1.52)	1.49 (1.31-1.65)

Figure 17. Location Map for the Cape Charles USCRN site, and a Portion of the Point Precipitation (PF) Estimates Page from NOAA Atlas 14.

Only six weeks later a weak low pressure system moved slowly NE from SW Georgia and brought another significant rain event to the same USCRN site at Cape Charles 5 ENE (Figure 18). Station location is at the point of the orange arrow in the Daily Weather Map below. The 28 hour storm total was 9.49 inches/240.9mm of which 8.39 inches/213.1mm fell in 24 hours. As indicated in the precipitation graph below, there was a six hour period with no rain between the more intense portions of the event (Figure 19). Despite that six hour pause the (2 Day) storm total of 9.49 inches and the 24 hour total of 8.39 inches both ranked at a 100 year recurrence interval per NOAA Atlas 14.

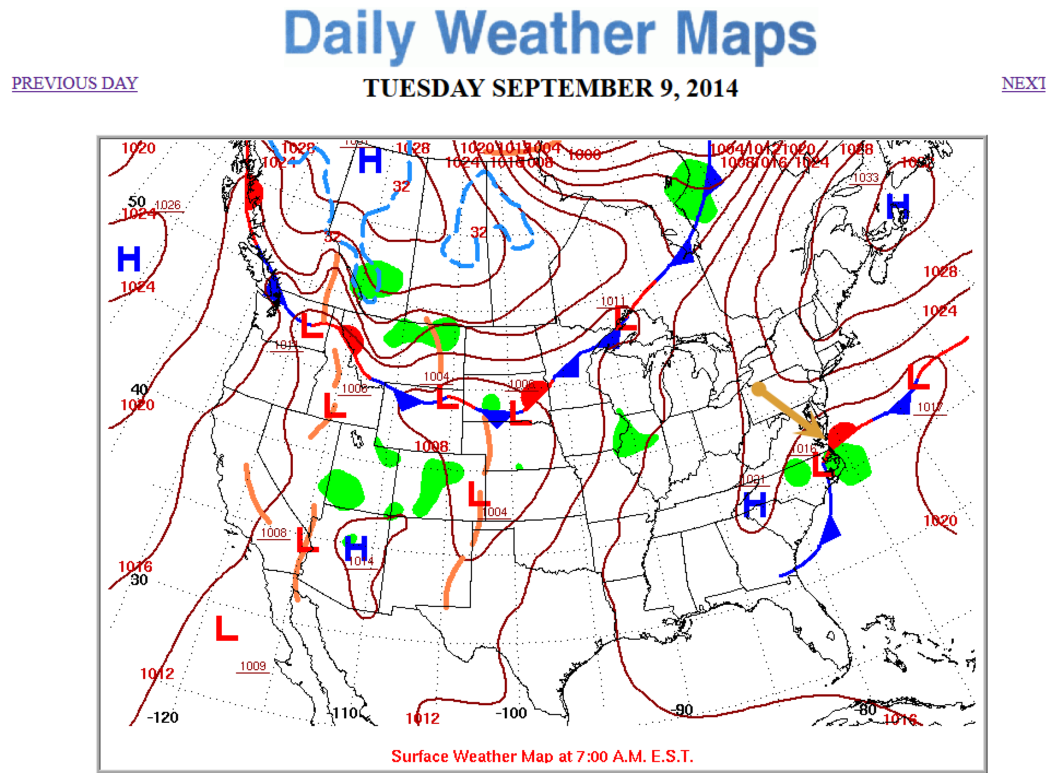


Figure 18. Daily Weather Map for Tuesday, September 9, 2014.

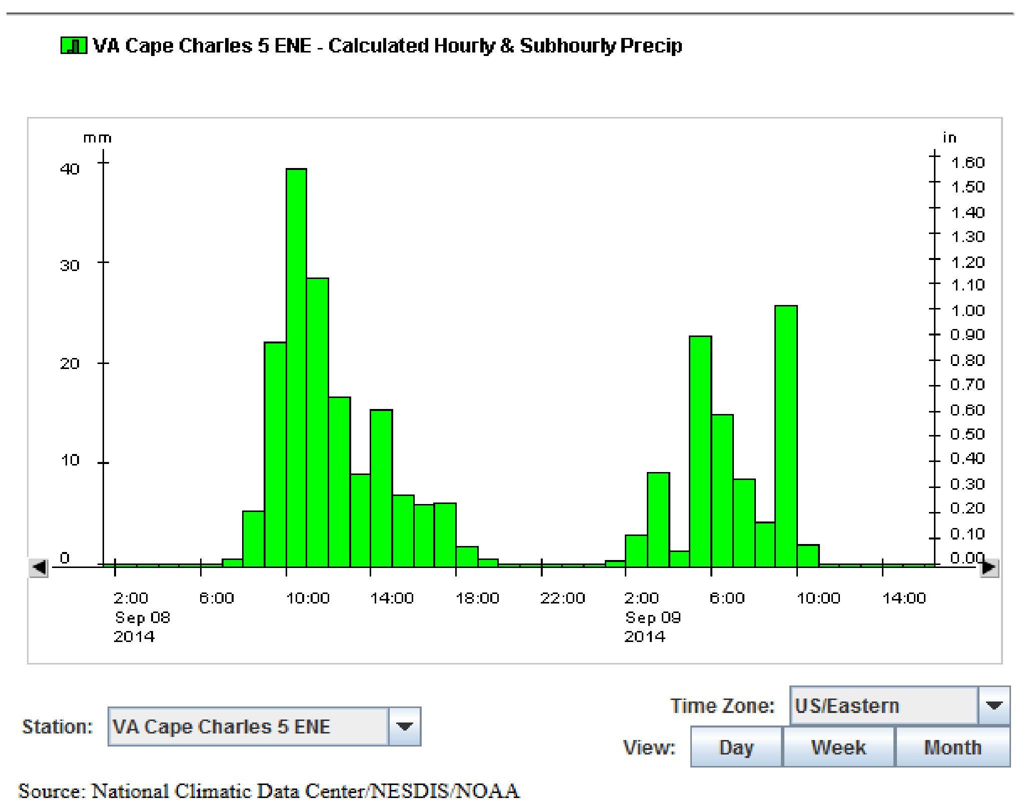


Figure 19. Cape Charles 5 ENE Hourly Precipitation Graph for Sept. 8-9, 2014

Chillicothe, MO

Less than a day later an intense rain event occurred at the USCRN site 22 miles ENE of Chillicothe, MO. Reviewing the color scale on the NWS Radar Estimated Accumulation Map (Figure 20), indicates a radar estimated amount of 8 to 10 inches/203.2-254.0mm. Location of the site is depicted by a black dot on the map. The station recorded a storm total of 9.72 inches/246.7mm in 12 hours (Figure 21). Based on NOAA Atlas 14 this was a once in a 500 year event for this location. The maximum hourly amount was 3.18 inches/80.8mm, but that amount only had an expected recurrence interval of 50 years. Given the fact that the intense rains occurred over a wide area, flooding was also wide spread.

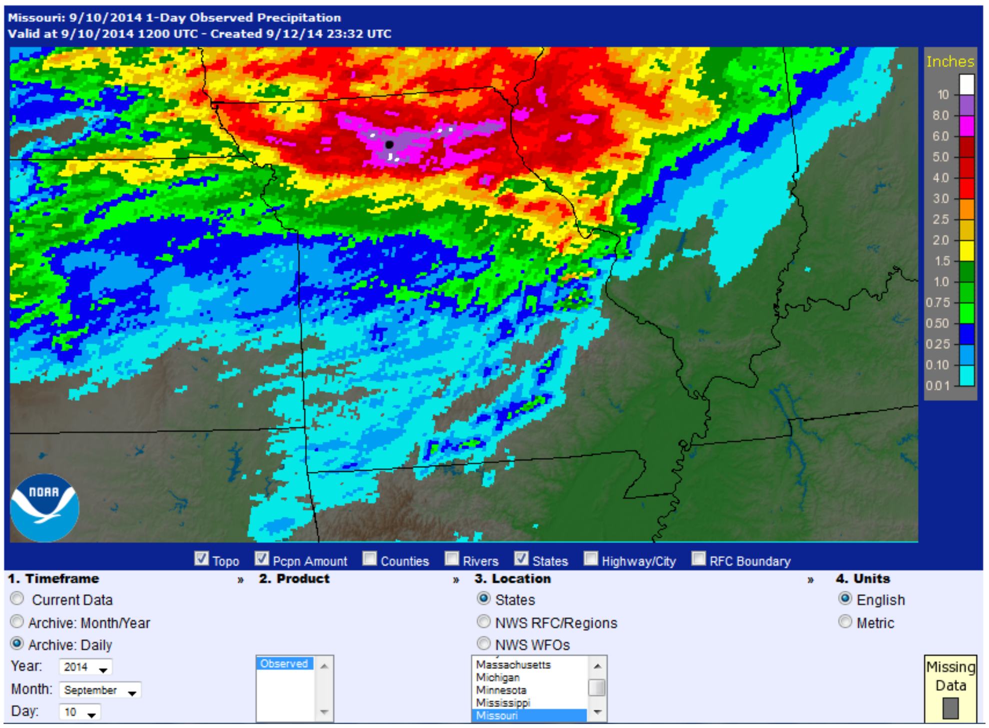
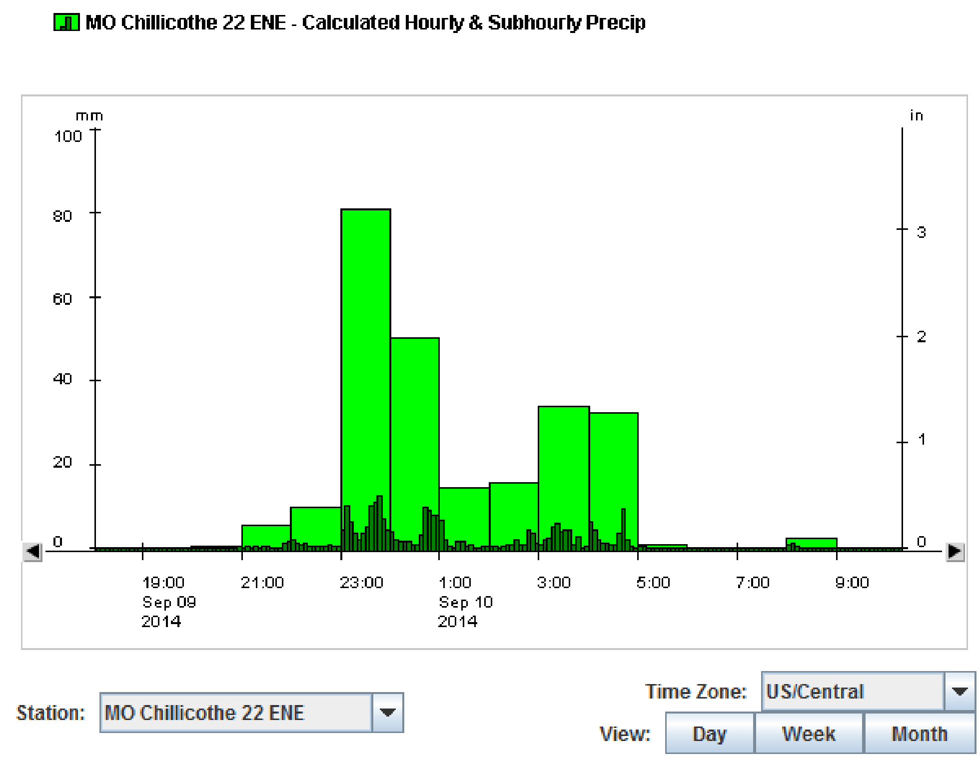


Figure 20. NWS Radar Estimated Storm Total Precipitation Map for Sept 9-10, 2014



Source: National Climatic Data Center/NESDIS/NOAA

Figure 21. Hourly and 5 Minute Precipitation Values from USCRN Site at Chillicothe 22 ENE, MO.

Plans for FY15

A number of long-term science projects described above will reach completion in FY 2015:

- Precipitation algorithm approval is anticipated in FY15, and this will allow for a project to repair precipitation exceptions (poor quality data that passed automated QC), apply the new precipitation calculations, generate new estimated normal, and then create a new precipitation monthly anomaly data set for comparison with GHCN gridded data.
- USCRN-COOP comparison paper will be submitted to a journal.
- USCRN soil temperature and plant green-up paper will be submitted to a journal.

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

- Development of new USCRN air temperature products for energy and agriculture.
- Submission of a paper using USCRN soil moisture data to examine the 2012 drought in the central U.S.
- Further research on soil moisture lead-lag relationships with precipitation, temperature, and SPI/SPEI values.

- Collaborative work on soil moisture calibration, scaling, and representativeness with ATDD.
- Continued efforts to create climate end-products taking advantage of data from the USCRN.

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 Summer 2015
- Two new stations will be deployed in Alaska during the summer 2015 timeframe bringing the total number of stations up to 18 out of an eventual 29.
- 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.