J2.1 AN OVERVIEW OF THE U.S. CLIMATE REFERENCE NETWORK (USCRN) SYSTEM

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1. INTRODUCTION

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 data have been collected and normalized to extend the instrumental climate record to remote regions and back in time to provide information on climate change at millennial and longer time scales.

The USCRN fulfills this need for obtaining long-term sustainable and robust climate observations that are necessary to document long-term climate change trends for the Nation. The USCRN concept was developed at the end of the 1990s and began being implemented around 2001. A continuous improvement program for USCRN was begun in Fiscal Year (FY) 2008 with the completion in FY 2011 of the installation of new soil moisture, soil temperature, and relative humidity sensors at all USCRN stations in the conterminous United States (CONUS).

This paper documents the progress made by the USCRN Program towards providing the vital surface climate data and information necessary to aid in characterizing national trends in climate.

2. SYSTEM DESCRIPTION AND BACKGROUND

The USCRN is a network of 114 stations in the CONUS developed, deployed, managed, and maintained by the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC), in partnership with NOAA's Atmospheric Turbulence and Diffusion Division (ATDD), for the express purpose of detecting the national signal of climate change. Experimental stations have been located in Alaska since 2002 and Hawaii since 2005, providing network experience in polar and tropical regions. Deployment of a complete 29 station USCRN network in Alaska began in 2009, and is expected to be completed by 2018.

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The primary question that the USCRN was designed to answer involves determining how the climate of the nation has changed over the past 50 years? These stations were designed with climate science in mind. Three independent measurements of temperature and precipitation are made at each station, insuring continuity of record and maintenance of well-calibrated and highly accurate observations.

The stations are placed in pristine environments expected to be free of development for many decades. Stations are monitored and maintained to high standards, and are calibrated on an annual basis. In addition to temperature and precipitation, these stations also measure solar radiation, surface skin temperature, and surface winds, and are being expanded to include triplicate measurements of soil moisture and soil temperature at five depths, as well as atmospheric relative humidity.

The USCRN provides the United States with a reference network that contributes to an International climate observing network under the auspices of the Global Climate Observing System (GCOS). The goal of the program is to create and maintain a sustainable, high-quality climate observation network that will be able to answer critical questions about how the climate (specifically air temperature, precipitation, soil moisture and temperature) of our Nation is changing with the highest degree of scientific confidence. The installation of soil moisture and temperature, and relative humidity sensors were completed at the set of 114 stations as of August 10, 2011, and this will be expanded into Alaska beginning in the summer of 2012.

In 2011, following a year-long evaluation and data quality test period, NCDC formally commissioned two additional USCRN stations in Alaska at Red Dog Mine and Kenai bringing the total number of commissioned stations in Alaska up to four. These two new stations (in addition to two stations commissioned in 2010 - Port Alsworth (in Lake Clark NP) and Sand Point (at USGS Shunagin Magnetic Observatory - represent the first four of the 29 planned USCRN stations in Alaska covering this expansive and ecologically diverse state by 2018. NCDC began the installation procedures and follow-on evaluation and data quality testing at two new USCRN sites at Gustavus and Tok (near Tetlin National Wildlife Refuge), which are slated for commissioning in the September 2012 timeframe. The site survey process continued in the summer of 2011 in preparation for selecting up to three additional USCRN sites for installation in 2012.

The most rapid changes in climate are occurring in high-latitude areas of the Northern Hemisphere, and this is especially evident in Alaska. The deployment of these USCRN stations will greatly enhance NOAA's ability to monitor the changing climate of Alaska, to better understand the pace and character of climate change in the state, and improve the Nation's ability to plan for and respond to these changes. For more information on USCRN please refer to the program web site at http://www.ncdc.noaa.gov/crn/

3. USCRN SCIENCE AND RESEARCH

With the commissioning of 114 USCRN sites in the CONUS, there is now a large enough set of observations to allow useful and insightful climate analyses to be performed. In 2010, a paper was published (Menne et al., 2010) using USCRN temperature observations to confirm the reliability of national temperature time series derived from homogenized cooperative observer network data. A subsequent paper was published (Palecki and Groisman, 2011) documenting the utility of using USCRN technology for high-elevation climate networks. Early in FY 2011, two research associates were hired through the NCDC associated Cooperative Institute for Climate and Satellites, North Carolina (CICS-NC), to perform science analysis to support the network and increase our knowledge of climate change and variation in the United States. They have led a substantial science effort to improve the USCRN precipitation algorithm and soil moisture quality control, and also embarked on intercomparisons between USCRN observations and those of other networks. An increasing number of users/collaborators are using the USCRN data for various science applications. As the years go by and more data are gathered, increasing amounts of climate science and applications will be based on the USCRN dataset.

In addition to some bilateral US/Canadian activities, the U.S. GCOS Program has funded some USCRN stations for deployment in various environments on other continents where assistance in modernization is desired. Towards this end, two USCRN-technology stations outside the CONUS were configured to be USGCOS-USCRN test stations (high-elevation and high-precipitation-environment stations). These two stations on Mauna Loa and in Hilo were deployed to two extreme Hawaiian environments as prototypes for possible future deployments in the Andes and in high-precipitation environments.

US-GCOS has worked with the Climate System Research Center at the University of Massachusetts (see http://www.geo.umass.edu/climate/) in helping to install and monitor USCRN-compatible temperature sensor configurations at a station on the Quelccaya Ice Cap in Peru, as well as on Mount Kilimanjaro in Tanzania. About two years of measurements from Quelccaya yielded a sample of 212,000 five-minute observations, during which the two most closely matched platinum resistance thermometers recorded temperatures within 0.1°C 98.4% of the time, and all four thermometers averaged within 0.025°C for the whole period. The USCRN configuration was robust and accurate through extreme conditions at high elevation.

USGCOS-USCRN test stations in Alaska at St. Paul Island and Sitka were instrumental in leading to the development of the Alaska USCRN program. In 2010, the US GCOS program supported the installation of a fully-capable USCRN station at the Russian Federation's Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) Tiksi observatory in the Russian Arctic of Siberia at 72ºN and 128°E. This is the first fully configured USCRN station installed outside of the Americas and illustrates GCOS' support for expanding globally the application of the USCRN approach to climate monitoring and improving climate change detection in the polar region. In 2011, the station in Tiksi became operational and data from that station will become available from the USCRN web site during FY 2012.

The Tiksi USCRN station was installed in August of 2010 and operated over the winter of 2010-2011, however due to a failure in the communications protocols, data was not archived. In late May of 2011, a U.S. - Russian science team arrived on site and started formal data archiving beginning on April 23, 2011. This date is earlier then the arrival of the science team by several weeks due to the fact that the internal data logger had a backwards archive of data. During this spring visit, one of the Geonor precipitation sensors was adjusted to operate properly. The site was primarily installed by the personnel at the Arctic and Antarctic Research Institute (AARI) of St. Petersburg, Russia. AARI is a research laboratory under Roshydromet staff from there made a trip in 2009 to ATDD's Oak Ridge laboratories for USCRN installation training. AARI has also filed and received permission for the USCRN data to legally be transmitted from the Russian Federation, and AARI maintains a Tiksi data center in St Petersburg that acquires the data from Tiksi in near real time (every 4 hours) and then forwards data to the NOAA laboratories in Boulder where they can be found at the following site on-line at the following site at: ftp://ftp.etl.noaa.gov/psd3/arctic/tiksi/CRN/Incoming/.

The XV World Meteorological Organization's (WMO) Commission for Instruments and Methods of Observation management meeting in September 2010 approved an international study on solid precipitation that will include snowfall and snow depth measurements in various regions of the world in a multisite experiment. The USCRN precipitation test bed in Marshall, Colorado, will be a lead facility in this intercomparison along with sites from Norway, China, Canada, Japan, Switzerland, Finland and New Zealand. The goals for the intercomparison are to assess the methods of measurement and observation of solid precipitation, snowfall, and snow depth at automatic unattended stations used in cold climates (e.g., polar and alpine), with the following objectives are as follows:

- Definition of an in-situ field reference for measuring solid precipitation using an automatic weighing gauge
- Define, develop and validate a field reference using automatic gauges for each parameter being investigated, which would allow an increased reporting resolution (e.g. 1 hour, 30 minutes, 10 minutes, 1 minute).

- Assessment of Automatic Gauges used in operational applications for the measurement of Solid Precipitation: Provide recommendations of best practices and configurations for the operational gauges, in operational environments.
- Investigate and understand the accuracy and precision of gauges and the ability to accurately report solid precipitation.
- Evaluation of new and emerging technology for the measurement of solid precipitation (e.g. non-catchment), and their potential for use in operational applications. Enable studies on the homogenization of automatic/manual observations: configure and collect during the experiment a comprehensive data set that could be made available for further data mining, for specific applications.

The USCRN, Canadian, and Finland precipitation testbeds in 2012 will establish the field reference for the automated measurement of solid precipitation that will be used by all other participants starting in 2013. This includes the gauge type, the wind shielding around the gauge, and the heater used to inhibit 'capping and dumping' caused by the accumulation of snow in the gauge inlet and on the cover of the gauge, and the measurement resolution. The potential field reference will be compared to the established secondary reference which is the manual Tretyakov gauge inside a Double Fence Intercomparison Reference (DFIR) wind shield.

One of the real benefits of the USCRN program is the extensibility it offers in support of other scientific purposes. For example, detailed knowledge of the spatial and temporal distribution of incoming solar radiation (insolation) at the earth's surface has the potential utility for a wide range of hydrologic and agronomic applications. These include the estimation of regional evapotranspiration and carbon fluxes, management of water supply, and implementation of precision farming practices. Otkin, et al (2005), have for example, used hourly pyranometer from USCRN stations to validate Geostationary Operational Environmental Satellite based insolation data.

A number of other on-going science and technical efforts going on with USCRN can be found in the most recent annual report for 2011 at http://www1.ncdc.noaa.gov/pub/data/uscrn/publications/annual_reports/FY11_USCRN_Annual_Report.pdf.

4. USCRN DATA AND OPERATIONS

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

These issues have been addressed in the design and fielding of the USCRN and the foundation has been established for generating high-confidence climate attributions from this network. With completion of the deployment phase and the collection of more than nine years of data at some stations, meaningful climate insights can begin to be drawn from this network. While a 10-year period-of-record is recommended for conservative applications of USCRN to the study of climate change at the national level, efforts made in FY 2010 and FY2011 to begin to link these new and relatively brief records to longstanding homogenized climate records for purposes of climate monitoring have been made through the generation of estimated normals linking USCRN and USHCN v2 observations, and through the beginning of network intercomparison activities.

USCRN stations are already serving as robust and stable platforms for monitoring extreme events. The inclusion of battery backup and in some cases solar panels has enabled USCRN stations to continue operating during severe weather conditions and other longer lasting catastrophic events.

4.1 Operations During Extreme Conditions Southern Tornado Outbreak – April 2011

The record setting tornado outbreak of April 25-28, 2011, produced its peak damage in Alabama and Tennessee on the 27th. This area includes 4 USCRN stations. No USCRN stations in Alabama lost any data due to local and regional AC power outages due to the battery back-up systems of these stations.

Only the USCRN station in Crossville, TN, lost the ability to transmit briefly, but only one hour of data was lost. This is quite a testament to the engineering of these systems, and the good fortune of the stations not to receive a direct hit from the most powerful tornadoes. Most stations connected to the electrical grid weathered the storms and retained power through working AC service or through battery backup. All the USCRN stations powered by solar panels continued working throughout the time period.

4.2 Operations During Hurricane Irene – Aug-Sep 2011

All the USCRN stations in the path of Irene fared well during the storm. While it appears that the McClellanville, SC, station lost AC power for the period from 4:00 pm local time on August 26 until 11:00 am on August 27, and the Millbrook, NY, station may have lost AC power from 10:00 am to 8:00 pm on August 28, the battery backup system kept both stations transmitting until AC power was restored, and all the data are up to date for the storm period. USCRN stations from Titusville, FL, to Limestone, ME, recorded precipitation and wind impacts from Irene.

The highest USCRN rain totals were 6.61 in (167.9 mm) at Avondale, PA, 6.35 in (161.3 mm) at Millbrook, NY, and 6.21 in (157.8 mm) at Cape Charles, VA, all of which were within the range of nearby NWS precipitation measurements. Cape Charles was also the windiest USCRN site, with a peak 10-second gust of 44.5 mph (19.9 m/s) and peak hourly wind average of 28.7 mph (12.8 m/s). Interestingly, even though this USCRN wind gust measurement was measured at only a height of 5 feet (1.5 meters) above the ground, it was close to nearby peak gusts at Wallops Island (53 mph, 23.7 m/s) and Accomack County Airport (52 mph, 23.2 m/s), which were 3-second gusts measured at the standard level of 32.8 feet (10 meters) above the ground. Also, due to the high winds, the weighing bucket gauge at the station accumulated about 2 inches (50 mm) more precipitation than the co-located tipping bucket gauge.

4.3 Operations During Tropical Storm Lee – Sep 2011

As noted earlier, a particularly dense network of USCRN operational and regional experimental sites is located in Alabama, and these stations observed large amounts of rain from TS Lee. Regional stations in Guntersville and Scottsboro in northeast Alabama received 11.34 inches (288.10 mm) and 10.51 inches (266.9 mm), respectively, while the USCRN site at Gadsden received 9.91 inches (251.7 mm). After drenching the Gulf Coast states, Lee moved northward, where substantial rain amounts were recorded along its path: 6.85 in (173.9 mm) at Avondale, PA; 6.84 in (173.7 mm) at Ithaca, NY; 6.73 in (171.0 mm) at Charlottesville, VA, 5.67 in (144.0 mm) at Elkins, WV, and 5.42 in (137.6 mm) at Millbrook, NY.

Combining the precipitation totals for Irene and Lee, Avondale received 14.69 in (373.2 mm) between August 25 and September 8, Millbrook received 12.40 in (315.0 mm), and Ithaca received 8.52 in (216.3 mm), demarcating the south, east, and north edges of some of the worst flooding in the Mid-Atlantic region in many years. Overall, the USCRN stations performed very well in some very challenging severe weather situations during FY 2011, and this speaks well to its overall engineering design.

5. A VISION FOR USCRN

The USCRN is just beginning its second decade of service in monitoring the nation's climate; now that the installation of all continental sites has been completed, including the soil sensor and relative humidity sensor add-on, the challenge is to assure that we continue to operate the existing sites to the same high-quality climate standards, as we continue to expand the network into Alaska through 2018.

The USCRN is without a doubt the nation's gold standard when it comes to the climate monitoring of surface air temperature and precipitation, as well as for soil moisture and temperature. It is exciting to see that USCRN soil measurements will form part of the calibration and validation of NASA's SMAP mission scheduled for launch in 2014, and therefore, we have to redouble our efforts to ensure that the calibration of our soil data is at the highest level possible. A continuing challenge is to focus attention on creating good and credible science and data products from USCRN data that can address a broad range of data users. For example, as NCDC has worked to produce a new set of 30-year climate normals for the country from 1981-2010, for the first time, USCRN data is now part of this and is providing enhanced information to assist in this effort. While USCRN has operated at most for 10 years at a few sites, the USCRN scientific staff works to use these data to help enhance efforts at characterizing the nation's climate.

The second decade of USCRN will occur during a time of more constrained resources. However, the primary mission of the Program must remain the ability to maintain stations in peak operating condition, and to encourage site hosts to continue to preserve the stability of the station sites in the face of internal and external pressures to change. It is the stability and quality of measurements that will set the USCRN apart from other observation systems and increase its intrinsic worth to governmental, academic, and private sector users alike. These in situ measurements will become the reference standard for other in situ networks, and for remote sensing systems. Despite resource pressures USCRN must be championed as the best option for understanding surface climate changes and variations as they occur, and its governing principles and techniques need to be promoted internationally. A vision of the future in which this happens sees USCRN-like climate observation systems expanding to all corners of the globe, and in particular to undersampled high-elevation, high-latitude, and tropical climate regimes.

As such, USCRN must continue to make progress both technologically and scientifically. Instruments must continue to undergo intercomparison testing to identify valid replacements for what is currently deployed, and also to identify better and more cost effective methods of climate observing. Quality control research needs to be supported to identify problems and improve our understanding of data deficiencies so that we can properly assess the confidence level of the measurements.

Climate science's use of the data must be greatly expanded as more years of data become available. Reliance on the USCRN for representing the state of the surface climate in the US will expand in FY 2012 with the application of better USCRN normals estimates, and will continue through the next decade. Soil moisture measurements will be blended with soil modeling systems to better use these brief time series to determine if soils are drier or wetter than normal. USCRN will become more connected to an ever increasing set of users, starting with other NOAA offices and branches, such as providing input to NCEP models, satellite validation and algorithm development, and climate models of all types (short term, decadal, century), and ending with many other external and international partners.

The next decade will see USCRN play a larger role in science's ability to better understand the nature of climate change impacting the United States, and modelers will continue to use USCRN data as a key standard for judging the performance of their models over the instrumental period. The USCRN is invaluable to the future of climate science and must continue to make progress and move forward as the gold standard for surface climate observing in the U.S.

6. SUMMARY AND CONCLUSION

In summary, the USCRN is a network of 114 stations in the Continental U.S. developed, deployed, managed, and maintained by NOAA's NCDC. While the network is managed by NCDC, the on-going operation and continuous improvements in the system would not be possible without the work done in partnership with NOAA's ATDD in Oak Ridge, TN.

USCRN was established for the express purpose of detecting the national signal of climate change, and as such began fielding stations beginning in 2001. and the vision of the program is to maintain a sustainable high-quality climate observation network that 50 years from now can with the highest degree of confidence answer the question: How has the climate of the nation changed over the past 50 years? Data from all stations in addition to all system documentation is available from the USCRN website at http://www.ncdc.noaa.gov/crn/.

Another 10 plus stations including experimental stations that have been located in Alaska since 2002 and Hawaii since 2005, providing network experience in polar and tropical regions; furthermore, as part of the most recent International Polar Year and in partnership with Roshydromet a USCRN station was installed in Tiksi in the Russian Arctic to help further advance the need for reference surface climate observations in high latitude regions. Deployment of the full complement of 29 USCRN stations in Alaska began in 2009 and is expected to be completed by 2018.

These stations were designed with climate science in mind. Three independent measurements of temperature and precipitation are made at each station, insuring continuity of record and maintenance of well calibrated and highly accurate observations. The stations are placed in pristine environments expected to be free of development for many decades. Stations are monitored and maintained to high standards, and are calibrated on an annual basis. In addition to measurements of surface temperature and precipitation, these stations also measure solar radiation, surface skin temperature, and surface winds. Since 2009 the network has been augmented by the implementation of triplicate measurements of soil moisture and soil temperature at five depths, as well the installation of atmospheric relative humidity sensors.

The challenge as we enter the second decade of USCRN operations is now to continue the high level of annual maintenance, equipment refresh, robust engineering, and continuous improvements in quality control, quality assurance, and sensor development that will ensure that the USCRN can continue to accurately document climate change on a national scale over the next 50–100 years.

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