5.5 CURRENT CONFIGURATION OF US CLIMATE REFERENCE NETWORK STATIONS

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1. INTRODUCTION

NOAA is beginning deployment of its new national U.S. Climate Reference Network (USCRN). The USCRN goal is to reduce unexplained variance in the U.S. long term near-surface air temperature and precipitation trends. This network will provide the United States with a climate observing network that meets national and global commitments to monitor and document climate change. The USCRN program will deploy no fewer than 100 operational sites in the continental United States through FY 2005. One purpose of the USCRN project is to ensure that future trends in primary measurements at specific locations can be monitored without the need for uncertain adjustments and corrections to the data. Primary measurements at each site will include near-surface air temperature and precipitation, supplemented with other variables such as wind speed, solar radiation, and ground surface (skin) temperature. The fully deployed network will provide adequate spatial coverage to monitor the national scale decadal-to-centennial surface air temperature and precipitation trends across the United States. The USCRN vision is to establish and operate a network which 50 years from now will answer the question: *How has the climate of the United States changed over the past 50 years?* To achieve that vision, the program will adhere to the Ten Climate Monitoring Principles defined by Karl *et al.* (1995).

This paper describes the current equipment configuration of the USCRN stations.

2. SYSTEM ARCHITECTURE

The USCRN architecture is modular, so that additional sensors or newer sensor replacements can be added easily. Commercial components are used throughout, sometimes with minor modifications to better meet USCRN's prescribed requirements of accuracy, precision, and reliability. The system has been designed for unattended continuous operation in remote locations with minimal maintenance. It has been designed to operate completely from 12 VDC deep-cycle batteries. Currently most sites use AC power to keep the batteries charged, but at a few locations solar panels are used. The reliability and feasibility of wind power charging is presently being explored. If charging power fails, the system will continue to operate normally for 5 to 6 days. A commercial data logger capable of expansion with a multiplexer is used so that the instrument suite can be expanded in the future if necessary. Instruments were selected that need no external translators, so as to reduce system complexity, calibration drift, and power consumption. The design operating environment is quite broad, ranging between –60C and +60C, with winds up to 50m/s, and rain up to 30mm/min. However the precipitation gauge is expected to operate normally only over the range –25C to +60C.

Because the near-surface air temperature and precipitation are key parameters, the USCRN design philosophy requires triply redundant sensors for these variables. Air temperature accuracy is required to be within ±0.3C over the range –50C to +50C, and within ±0.6C over the ranges –60C to –50C and +50C to +60C, with a resolution of 0.1C for 5 min averages. Precipitation, the other key variable, is required to be accurate to ±0.25mm or ±2% of the reported value, whichever is greater, with a resolution of 0.25mm. The supporting variables have more relaxed measurement accuracy requirements: Wind speed at the height of the temperature measurement is required to be ±1m/s or ±2% of the measured value, whichever is greater. Global incoming solar radiation is required to be within ±70W/m^2 with a minimum resolution of 10W/m^2. The ground surface ("skin") IR temperature is required to be within ±0.5C, with a minimum resolution of 0.1C.

The system also monitors a number of self-health variables such as battery voltage and aspirator fan rpm to assist with remote rapid diagnosis of problems so that repairs can be accomplished quickly.

Data normally are transmitted via the NOAA GOES satellite Data Collection System (DCS) to Wallops Island, Virginia. The data are then sent to the National Climatic Data Center in Asheville, North Carolina via the Internet and the commercial satellite system DOMSAT. In the event of data transmission failure, the individual stations automatically try to catch up when satellite communications are restored. However the data logger also retains all data in memory for up to 5 months, and the data can be extracted during a site visit using a notebook computer or PDA. All reportable data are required to be delivered hourly to NCDC by normal transmission with a minimum communications availability of 95%. Data recovered manually from the data logger using a PC or PDA must be delivered to the NCDC within 30 days after the end of an observing month with a minimum availability of 97%. In practice, over the six month period April through September

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2003, availability of data received at NCDC within the hour was nearly 99%.

3. CURRENT CONFIGURATION

The current configuration utilizes a Campbell Scientific model 23X data logger. A number of these data loggers were purchased with extended temperature certification by the manufacturer and additional memory (4x standard), and these units are reserved for use in extreme environments where extended power outages might occur. As noted above, internal memory is adequate for at least 5 months of data storage; the extended memory units can hold much more data. A Seimac model HDRGOES radio transmitter is used for communication with the GOES satellites via a yagi antenna. The data logger and transmitter are housed in a white-painted fiberglass-reinforced plastic enclosure equipped with a small heater to keep the data logger and transmitter internal temperatures above –40C.

The system is powered by two to four lead-acid deep-cycle storage batteries, depending on anticipated local temperatures and heating requirements. If AC power is available to charge the batteries, a Statpower model TrueCharge10 charger is used. A TrippLite model Isotel 4 Ultra surge protector strip is used to protect against power spikes on the AC line. If solar power is used for charging, two to four Siemens SM110 110W solar panels are used with a Morningstar model Prostar 30A regulator. The batteries and charger/ regulator are housed in a separate white-painted environmental enclosure. For operator safety, this is the only point where AC power (if used) is present.

The current primary sensors suite includes three fully independent Thermometrics Corp. platinum resistance thermometers (PRTs), each in its own independent fan-aspirated solar radiation shield (Met-One model 076B, with a Pabst model 4212/12H 12 VDC-operated fan with tachometer output, and gold-plated power and tachometer connector pins for improved corrosion resistance). Each PRT is individually calibrated, so the three temperature readings are normally extremely close to each other; sensor failures are consequently easy to detect. The speed of each fan is monitored.

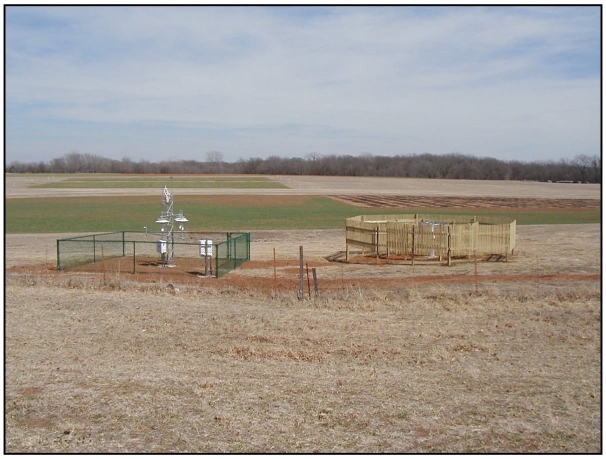
Precipitation is measured using a Geonor model T-200B weighing-type gauge using three separate vibrating-wire load sensors. The load sensors are fitted with a NOAA-designed collar to prevent wire breakage in any sensor from overloading the remaining sensors. Problems with individual sensors are again easy to detect. The Geonor gauge is fitted with a NOAA-designed "smart" collector heater and thermistor, so heat is applied only when the collector is between –5C and +5C. An Eco-Harmony model TB-3 tipping bucket precipitation gauge is installed as a backup; it has a factory-supplied smart heater. The precipitation gauges are surrounded by an Alter-type "swinging leaf" wind shield; this shield was custom manufactured from stainless steel to prevent corrosion in harsh environments. A so-called small double fence intercomparison reference shield (SDFIR; see Wade and Cole, 2001) surrounds the Alter shield to further improve the "catch" under windy conditions, particularly for solid precipitation. The precipitation gauges are mounted on heavy walled aluminum pipe set in a 40cm (newer installations use 46cm) diameter concrete pedestal to resist wind-induced vibration. The Alter shield is set so its upper edge is 5cm above the gauge inlets, the inner SDFIR fence upper edge is 10cm above the gauge inlets, and the SDFIR outer fence is 20 cm above the inlets. A laser leveling device is used in the field to align the shields relative to the gauges.

The supporting sensors are located at the same height as the temperature sensors, 1.5m AGL, per WMO recommended standards for climate monitoring. The currently deployed supporting sensors include a Met-One model 014A rotating cup anemometer for wind speed, a Kipp and Zonen SP Lite silicon pyranometer for total incoming solar radiation, and a Precision Infrared Thermocouple Transducer model IRTS-P IR temperature sensor for determining ground surface (skin) temperature.

All of the non-precipitation instruments are mounted on heavy walled aluminum pipe booms extending about 1.2 m from the sides of a 3m tall Climatronics model C-33HD aluminum tower bottom section with a B-18 base. The tower bottom section was used to allow for the future possibility of adding additional instruments at greater heights above ground (e.g., the 10m WMO standard), and is set into a sturdy and deep concrete base adequate to withstand the wind loads anticipated for a full 10m tower. All mounting and locking hardware is stainless steel or aluminum for long-term corrosion resistance.

The precipitation gauge system and shields are located about 15m from the instrument tower. All wiring runs in buried conduit to reduce damage from animals. At some sites a chain-link fence around the instrument tower is used to discourage casual visitors. A door switch is installed on the data logger enclosure to reveal whenever the door is opened for any reason; this also provides a convenient "flag" in the data stream to indicate exactly when site maintenance is under way at any given location.

A typical USCRN station (in Oklahoma) is shown just below. The SDFIR surrounding the rain gauges is to the right of the small tower that holds the other instruments. Two of the three aspirated solar shields for the temperature sensors are visible on the tower. The battery enclosure is visible near the right front corner of the low fence surrounding the instrument tower. The satellite antenna is near the tower top.



4. CALIBRATION METHODS

All sensors are calibrated before installation using NIST-traceable standards. The data loggers are calibrated over their environmental range by their manufacturer using NIST-traceable standards of voltage and frequency. They are then checked at room temperature in a NOAA laboratory using a Krohn-Hite model 511 NIST-traceable precision DC source/ calibrator, an Agilent model 34401A NIST-traceable digital voltmeter, and a Altek model 942 NIST-traceable digital frequency calibrator. Any data logger that is out of specification is returned to the manufacturer.

The PRTs are calibrated over the full –60C to +60C range using a Hart Scientific model 7380 immersion bath, and a NIST-traceable Hart model 5612 Secondary Reference Temperature Standard PRT probe connected to a Hart 1502A controller/digital readout. A Hart model 5901-1241 triple-point cell is available for single-point checks of the secondary standard thermometer. A special silicon-based fluid (Hart Cold Fluid Halocarbon 0.8, model 5019, part number 75350080) is used to span the entire calibration range without having to change the bath fluid. The system is operated completely under program control to step from one calibration point to the next (every 5C) after allowing adequate time for stabilization. Six PRTs are calibrated at once. There are two complete and identical calibration baths, standard thermometers, and controllers in case a problem is suspected with any calibration device.

The Geonor weighing-type gauges are calibrated using precision-machined stainless steel weights that self-center within the collection bucket. This allows calibration in the field as well as in the laboratory. The tipping bucket gauge is calibrated using an Eco-Harmony model FCD field calibration device which drops a precisely metered amount of water into the gauge's collection funnel. This was separately verified by weighing the quantity of water delivered.

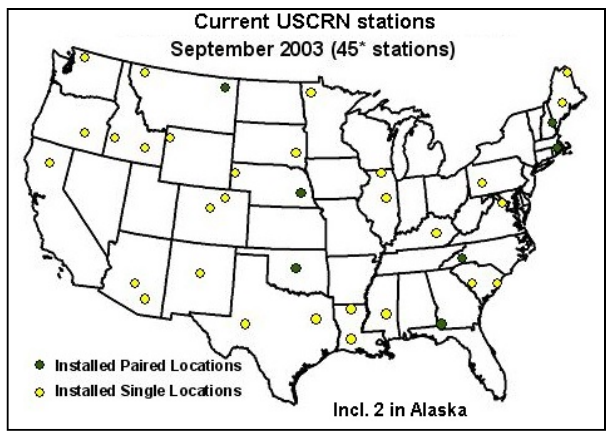
The rotating cup anemometers are calibrated in the NOAA-ATDD 1m x 1m wind tunnel between 0 and 18m/s. A NIST-traceable R. M. Young model 27106D light-chopper propeller anemometer fitted with propeller model 08274 is used as the house standard. The wind tunnel is programmed following ASTM standard D5096-96, to establish a threshold (bearing check; average of 10 trials) for each rotating cup anemometer, as well as an 11 point calibration curve.

The silicon pyranometers are mounted in groups of 16 units in a flat plate holder and set up in an open field with good sky view next to a cluster of three Eppley model PSP Precision Spectral Pyranometers calibrated to World Radiometric Standards. They are exposed to the sky for time periods between a week and a month, depending on sky cover conditions. Calibrations use an ensemble of only clear-sky conditions.

The IR surface temperature sensors are calibrated by their manufacturer, and a Hart Scientific model 9133 blackbody source is used to check that calibration.

5. CURRENT STATION DEPLOYMENT

About 50 stations will be operational by January 2004. The figure below shows the station distribution at the end of FY 2003. Some sites are deployed in pairs located within roughly 50 km of each other, to provide redundancy in case one site is unexpectedly closed over the 50 to 100 year design life of the network. These are shown as black dots.

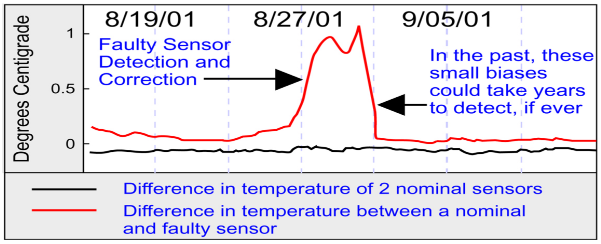


6. CURRENT DATA QUALITY CONTROL AND NETWORK MONITORING

Data are transmitted hourly from each station to either the GOES East or West satellites, and sent via the Internet and DOMSAT from NASA's Wallops Island ground station to NCDC, where an inventory check is performed. The inventory system identifies any missing stations and data, and begins an immediate check of alternate transmission sources from Wallops Island and NOAAPort. A highly automated quality control review process begins immediately. The original data and the processed QC flags are immediately posted on line for Web access. All received data and station history data (metadata) are archived. Automated quality control and Health of the Network monitoring processes alert a maintenance team to ailing sensors or systems. If the data transmission process fails for some reason, the stations will automatically try to catch up when service is restored. If this process does not succeed, the local site contact person is asked to manually retrieve the data and deliver it to the NCDC via the Internet or on a disk.

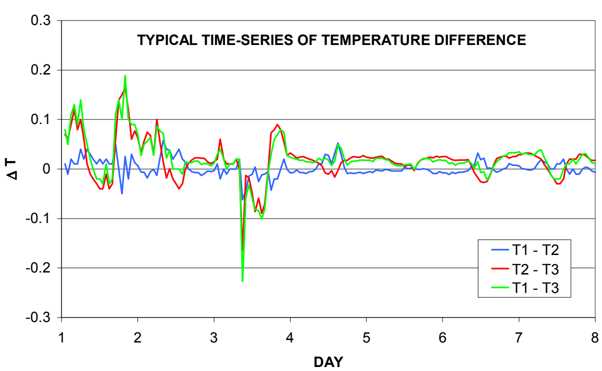
7. DATA EXAMPLE

The figure below shows a real world example of temperature data differences from three probes at one



site. One sensor developed a problem leading to an error of about 1C. Because of the redundant sensors, the close initial calibration of the sensors, and the hourly automated quality control review process, it was immediately clear when this occurred and which sensor was at fault. Repairs were quickly accomplished. In systems with single sensors, this small temperature error would be very difficult or impossible to detect. Such time-dependent biases affect the fidelity of the climate record. In the USCRN these can be detected quickly, and thus reduce uncertainty in the quality of the climate record provided to decision makers.

The following figure shows 8 days of temperature difference data from three normally performing sensors. The temperature differences rarely exceed 0.2C.

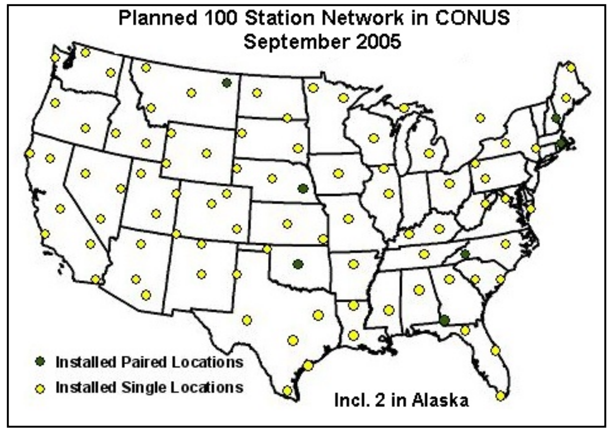


8. SYSTEM METADATA

Complete documentation on each system down to the individual sensor level helps build user confidence in the data. All data and information about the USCRN is accessible through a NCDC-maintained web site, **http://www.ncdc.noaa.gov/crn.html**. The metadata include site photos and panoramas; lists of all instruments by serial number, dates of installation and removal of all instruments; sensor calibration histories; site installation and maintenance histories; procedures for calibration, installation, and maintenance; anomaly tracking; and other details.

9. PLANS FOR NETWORK EXPANSION

The map below shows the anticipated 100 station USCRN network that will be completed by the end of 2005 under present funding levels.



10. ACKNOWLEDGEMENTS

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11. DISCLAIMER

12. REFERENCES

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