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Natural Resource Program Center
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Weather and Climate Inventory
National Park Service
Southern Colorado Plateau Network

Natural Resource Technical Report NPS/SCPN/NRTR—2006/007

ON THE COVER
Grand Canyon National Park

Weather and Climate Inventory
National Park Service
Southern Colorado Plateau Network

Natural Resource Technical Report NPS/SCPN/NRTR—2006/007
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Acronyms

AASC	American Association of State Climatologists
ACIS	Applied Climate Information System
AQ	Utah Division of Air Quality
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
AZMET	The Arizona Meteorological Network
AZRU	Aztec Ruins National Monument
BAND	Bandelier National Monument
BLM	Bureau of Land Management
CACH	Canyon de Chelly National Monument
CASTNet	Clean Air Status and Trends Network
CCRFCD	Clark County (Nevada) Regional Flood Control District
CHCU	Chaco Culture National Historical Park
CLIM-MET	USGS Southwest Climate Impact Meteorological Stations network
CoAgMet	Colorado Agricultural Meteorological Network
COOP	Cooperative Observer Program
CRBFC	Colorado River Basin Forecast Center
CRN	Climate Reference Network
CWOP	Citizen Weather Observer Program
DFIR	Double-Fence Intercomparison Reference
DST	daylight savings time
ELMA	El Malpais National Monument
ELMO	El Morro National Monument
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FIPS	Federal Information Processing Standards
GLCA	Glen Canyon National Recreation Area
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GPMP	Gaseous Pollutant Monitoring Program
GPS	Global Positioning System
GPS-MET	NOAA ground-based GPS meteorology
GRCA	Grand Canyon National Park
GSE	Grant Staircase - Escalante National Monument network
HUTR	Hubbell Trading Post National Historic Site
I&M	NPS Inventory and Monitoring Program
IMPROVE	Interagency Monitoring of Protected Visual Environments
LANL	Los Alamos National Laboratory
LEO	Low Earth Orbit
LST	local standard time
MEVE	Mesa Verde National Park
NADP	National Atmospheric Deposition Program
NAVA	Navajo National Monument

NCDC	National Climatic Data Center
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRCS-SC	Natural Resources Conservation Service snowcourse network
NWS	National Weather Service
PEFO	Petrified Forest National Park
PETR	Petroglyph National Monument
POMS	Portable Ozone Monitoring Network
PRISM	Parameter Regression on Independent Slopes Model
RABR	Rainbow Bridge National Monument
RAWS	Remote Automated Weather Station network
RCC	regional climate center
SAO	NWS/FAA Surface Airways Observation Network
SAPU	Salinas Pueblo Missions National Monument
SCPN	Southern Colorado Plateau Inventory and Monitoring Network
SOD	Summary of the Day
SUCR	Sunset Crater Volcano National Monument
Surfrad	Surface Radiation Budget Network
SNOTEL	Snowfall Telemetry Network
SNOWNET	USDA/USFS Avalanche Network
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
WACA	Walnut Canyon National Monument
WBAN	Weather Bureau Army Navy
WMO	World Meteorological Organization
WRCC	Western Regional Climate Center
WUPA	Wupatki National Monument
WX4U	Weather For You
YUHO	Yucca House National Monument

Executive Summary

Climate drives many of the environmental processes in the Southern Colorado Plateau Inventory and Monitoring Network (SCPN). Climate variations are responsible for short and long-term changes in ecosystem fluxes of energy and matter and they have profound effects on underlying geomorphic and biogeochemical processes. Future changes in climate will, in turn, have tremendous impacts on these processes. Monitoring climate facilitates interpretation of other vital sign measurements. Efforts to manage various native plant and animal species in the SCPN, and the control of invasive species, are very sensitive to both short-term and long-term climate variations. The region covered by the SCPN is influenced by drought and other interannual climate variations such as the El Niño Southern Oscillation (ENSO) and variations in the strength of the summer monsoon. The responses of the SCPN landscape to these climate variations highlight the region's sensitivity to possible future climate changes. Climate changes could also adversely affect the important cultural resources protected by SCPN park units. For these reasons, climate was identified as a high-priority vital sign for SCPN and climate is one of the 12 basic inventories to be completed for all Inventory and Monitoring Parks.

Because of the importance of climate to almost every aspect of both ecology and park management, this project was initiated to inventory past and present climate monitoring efforts. The primary objective of climate and weather monitoring for the SCPN is to provide monthly and annual summaries of climate data, including precipitation and temperature, and determine long-term trends in seasonal and annual patterns of climate parameters and soil moisture. This project was initiated to inventory past and present climate monitoring efforts. In this report, we provide the following information:

- Overview of broad-scale climatic factors and zones important to SCPN park units.
- Inventory of weather and climate station locations in and near SCPN park units relevant to the National Park Service (NPS) I&M Program.
- Results of an inventory of metadata on each weather station, including affiliations for weather-monitoring networks, types of measurements recorded at these stations, and information about the actual measurements (length of record, etc.).
- Initial evaluation of the adequacy of coverage for existing weather stations and recommendations for improvements in monitoring weather and climate.

The climate backdrop of the SCPN is complex. Spatial climate variability within SCPN is heavily influenced by topography. Mean annual temperatures range from under 5°C on the north rim of Grand Canyon National Park (GRCA) to almost 20°C along the Colorado River. Some places along the Colorado River in GRCA and Glen Canyon National Recreation Area (GLCA) can see summertime maximum temperatures approach 50°C. Precipitation is generally proportional to elevation. Mean annual precipitation ranges from just under 150 mm along the Colorado River in GLCA and GRCA, to over 700 mm along the north rim of GRCA. The portions of SCPN that are strongly influenced by the southwestern monsoon have a summer peak in precipitation. However, summer precipitation maxima are not as evident in the northern portions of SCPN and at higher elevations in SCPN. Winter precipitation in the SCPN is very sensitive to ENSO. Positive

ENSO (El Niño) conditions generally lead to wetter conditions in the SCPN. Recent droughts have stressed native vegetation and water resources in the SCPN, increasing the region's vulnerability to wildfires and invasions of alien plant species.

This report builds on the substantial information that has already been compiled by the SCPN network regarding past and present weather and climate monitoring efforts in the SCPN. Through a search of national databases and inquiries to NPS and other government staff, we identified 55 weather and climate stations within the park units of the SCPN. Some of the national-scale weather and climate station networks that are represented within the SCPN park units are:

- National Weather Service Cooperative Observer Program (34 stations),
- Remote Automated Weather Station network (RAWS; 5 stations),
- Surface Airways Observation Network (3 stations),
- Climate Reference Network (1 station), and
- Clean Air Status and Trends Network (3 stations).

Some of the park units within the SCPN are well sampled by weather and climate stations that are either inside park unit boundaries or are near the park units. These include most of the SCPN park units in New Mexico and southwestern Colorado. Bandelier National Monument (BAND), in particular, has a dense coverage of weather/climate stations. However, the park units in northeastern Arizona and northwestern New Mexico have relatively sparse weather/climate station coverage, particularly for automated stations. Exploring partnerships to expand the RAWS network in this region could be very useful for the SCPN.

Besides the manual station at Phantom Ranch, we have not identified any stations on the canyon floor at GRCA. Installing an automated station along the canyon floor, such as a RAWS station, would provide near-real-time conditions from the canyon floor, assist in flash-flood monitoring efforts in the canyon, and facilitate investigations of climate gradients between the canyon rim and floor.

We recommend the continued operation of those stations inside SCPN park units that have long-term climate records. Some records exceed 100 years in length. The lands administered by the NPS are intended to be protected from development and other land use changes that could adversely affect the natural environment. Therefore, long-term climate records from weather/climate stations located in such areas are particularly valuable for describing natural climate characteristics and should be preserved whenever possible.

Acknowledgements

This work was supported and completed under Task Agreement H8R07010001 with the Great Basin Cooperative Ecosystem Studies Unit. We would like to acknowledge very helpful assistance from various National Park Service personnel associated with the Southern Colorado Plateau Inventory and Monitoring Network. Particular thanks are extended to Marguerite Hendrie, Chris Lauver, John Gross, and Margaret Beer. Grant Kelly, Heather Angeloff, and Greg McCurdy, all with the Western Regional Climate Center, provided valuable assistance. Seth Gutman with the National Oceanic and Atmospheric Administration Earth Systems Research Laboratory provided valuable input on the GPS-MET station network. Portions of the work were supported by the Western Regional Climate Center under the auspices of the National Oceanic and Atmospheric Administration.

1.0. Introduction

Weather and climate are key drivers of Colorado Plateau ecosystems. Global- and regional-scale climate variations will have a tremendous impact on natural systems (Chapin et al. 1996; Schlesinger 1997; Jacobson et al. 2000; Bonan 2002). Long-term patterns in temperature and precipitation provide first-order constraints on potential ecosystem structure and function (Whitford 2002). Secondary constraints are realized from the intensity and duration of individual weather events, and additionally, from seasonality and interannual climate variability. These constraints influence the fundamental properties of ecological systems, which in turn influence the life-history strategies supported by a climatic regime (Neilson 1987). Winter precipitation is particularly important with respect to soil moisture conditions and vegetation establishment, survival, and vulnerability to fire. In semiarid landscapes, the composition and structure of plant communities depends largely on the amount and spatial distribution of soil moisture (Breshears and Barnes 1999). Measuring soil moisture in association with integrated upland monitoring sites will provide a critical link between broader climate monitoring and local vegetation patterns.

Trends in ecosystem condition are influenced by a variety of climate factors. It is important to understand the role of climate variability and extremes in driving ecosystem processes (Thomas et al. 2005). Given the importance of climate, it is one of 12 basic inventories to be completed by the National Park Service (NPS) Inventory and Monitoring Program (I&M) network (I&M 2006). As primary environmental drivers for the other vital signs, weather and climate patterns present various practical and management consequences and implications for the NPS (Oakley et al. 2003). Most park units observe weather and climate elements as part of their overall mission. The lands under NPS stewardship provide many excellent locations for monitoring climatic conditions.

It is essential that park units within the Southern Colorado Plateau Inventory and Monitoring Network (SCPN) have an effective climate-monitoring system in place to track climate changes and to aid in management decisions relating to these changes. The primary objective for climate- and weather-monitoring in the SCPN is to provide monthly and annual summaries of climate data, including precipitation and temperature, and determine long-term trends in seasonal and annual patterns of climate parameters and soil moisture (Thomas et al. 2005).

The purpose of this report is to determine the current status of weather and climate monitoring in the SCPN (Figure 1.1; Table 1.1). In this report, we provide the following informational elements:

- Overview of broad-scale climatic factors and zones important to SCPN park units.
- Inventory of locations for all weather stations in and near SCPN park units that are relevant to the NPS I&M networks.
- Results of metadata inventory for each station, including weather-monitoring network affiliations, types of recorded measurements, and information about actual measurements (length of record, etc.).
- Initial evaluation of the adequacy of coverage for existing weather stations and recommendations for improvements in monitoring weather and climate.

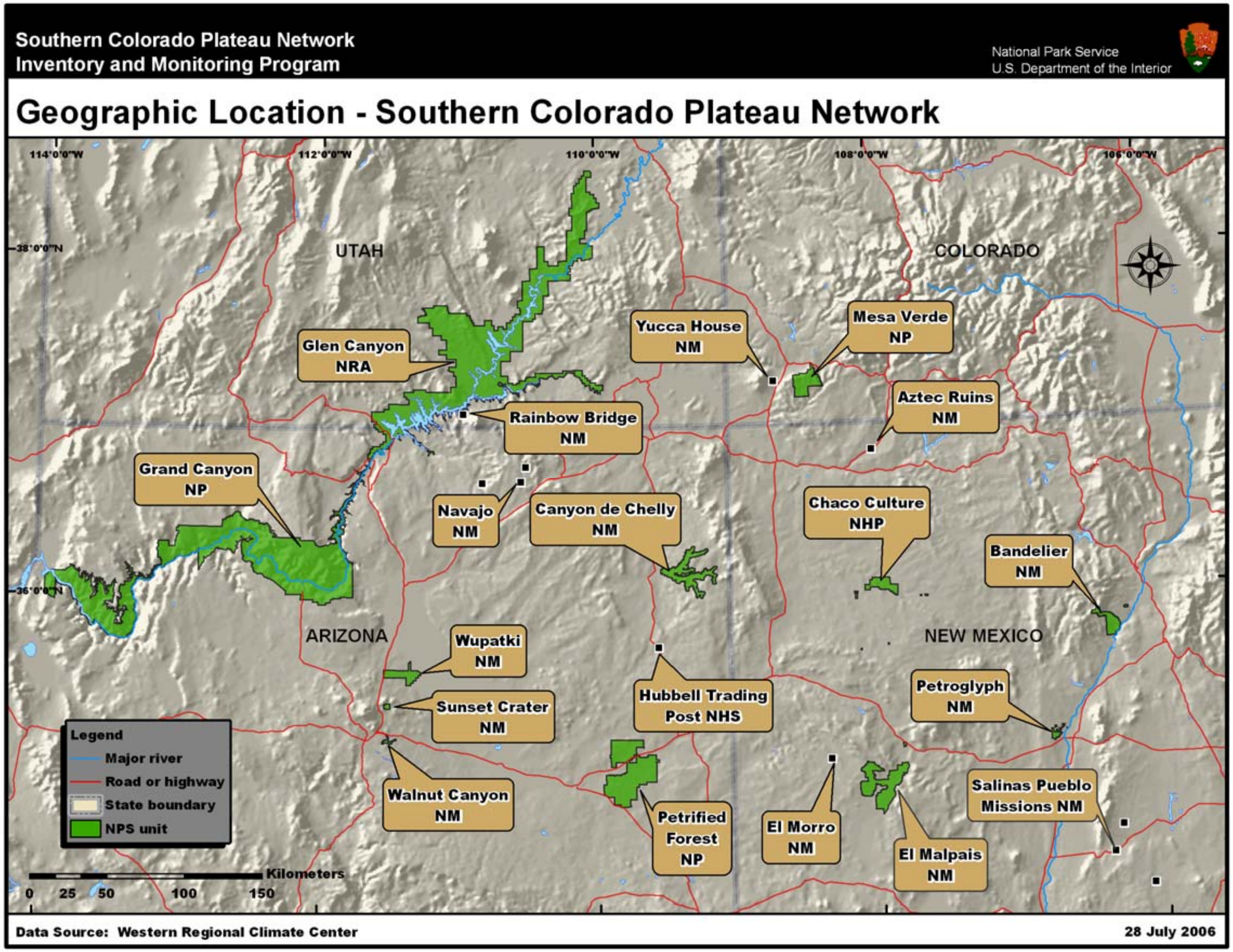


Figure 1.1. Map of the Southern Colorado Plateau Network.

Table 1.1. Park units in the SCPN.

Acronym	Name
AZRU	Aztec Ruins National Monument
BAND	Bandelier National Monument
CACH	Canyon de Chelly National Monument
CHCU	Chaco Culture National Historical Park
ELMA	El Malpais National Monument
ELMO	El Morro National Monument
GLCA	Glen Canyon National Recreation Area
GRCA	Grand Canyon National Park
HUTR	Hubbell Trading Post National Historic Site
MEVE	Mesa Verde National Park
NAVA	Navajo National Monument
PEFO	Petrified Forest National Park
PETR	Petroglyph National Monument
RABR	Rainbow Bridge National Monument
SAPU	Salinas Pueblo Missions National Monument
SUCR	Sunset Crater Volcano National Monument
WACA	Walnut Canyon National Monument
WUPA	Wupatki National Monument
YUHO	Yucca House National Monument

1.1. Network Terminology

Before proceeding, it is important to stress that this report discusses the idea of "networks" in two different ways. Modifiers are used to distinguish between NPS I&M networks and weather/climate station networks. See Appendix B for a full definition of these terms.

1.1.1. Weather/Climate Station Networks

Most weather and climate measurements are made not from isolated stations but from stations that are part of a network operating in support of a particular mission. The limiting case is a network of one station, where measurements are made by an interested observer or group. Larger networks usually have more and better inventory data and station-tracking procedures. Some national weather/climate networks are associated with the National Oceanic and Atmospheric Administration (NOAA), including the National Weather Service (NWS) Cooperative Observer Program (COOP). Other national networks include the interagency Remote Automated Weather Station network (RAWS) and the U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS) Snowfall Telemetry (SNOTEL) and snowcourse networks. Usually a single agency, but sometimes a consortium of interested parties, will jointly support a particular weather/climate network.

1.1.2. NPS I&M Networks

Within the NPS, the system for monitoring various attributes in the participating park units (about 270–280 in total) is divided into 32 NPS I&M networks. These networks are collections of park units grouped together around a common theme, typically geographical.

1.2. Weather versus Climate Definitions

It is also important to distinguish whether the primary use of a given station is for weather purposes or for climate purposes. Weather station networks are intended for near-real-time usage, where the precise circumstances of a set of measurements are typically less important. In these cases, changes in exposure or other attributes over time are not as critical. Climate networks, however, are intended for long-term tracking of atmospheric conditions. Siting and exposure are critical factors for climate networks, and it is vitally important that the observational circumstances remain essentially unchanged over the duration of the station record. Some climate networks can be considered hybrids of weather/climate networks. These hybrid climate networks can supply information on a short-term "weather" time scale and a longer-term "climate" time scale.

In this report, "weather" generally refers to current (or near-real-time) atmospheric conditions, while "climate" is defined as the complete ensemble of statistical descriptors for temporal and spatial properties of atmospheric behavior (see Appendix B). Climate and weather phenomena shade gradually into each other and are ultimately inseparable.

1.3. Purpose of Measurements

Climate inventory and monitoring activities should be based on a set of guiding fundamental principles. The starting point in evaluating weather/climate monitoring programs begins with asking the following question:

- What is the purpose of weather and climate measurements?

Evaluation of past, present, or planned weather/climate monitoring activities must be based on the answer to this question. Within the context of the NPS, the following services constitute the main purposes for recording weather and climate observations:

- Provide measurements for real-time operational needs and early warnings of potential hazards (landslides, mudflows, washouts, fallen trees, plowing activities, fire conditions, aircraft and watercraft conditions, road conditions, rescue conditions, fog, restoration and remediation activities, etc.).
- Provide visitor education and aid interpretation of expected and actual conditions for visitors to use while in the park and for deciding if and when to visit the park.
- Establish engineering and design criteria for structures, roads, culverts, etc., for human comfort, safety, and economic needs.
- Monitor climate consistently over the long-term to detect changes in environmental drivers affecting ecosystems, including both gradual and sudden events.

- Provide retrospective data to understand *a posteriori* changes in flora and fauna.
- Document for posterity the physical conditions in and near the park units, including mean, extreme, and variable measurements (in time and space) for all applications.

The last three items in the preceding list are pertinent primarily to the NPS I&M networks; however, all items are important to NPS operations and management. Most of the needs in this list overlap heavily. It is often impractical to operate separate climate measuring systems that also cannot be used to meet ordinary weather needs, where there is greater emphasis on timeliness and reliability.

1.4. Design of Climate-Monitoring Programs

Determining the purposes for collecting measurements in a given weather/climate monitoring program will guide the process of identifying weather/climate stations suitable for the monitoring program. The context for making these decisions is provided in Chapter 2 where background on the SCPN climate is presented. However, this process is only one step in evaluating and designing a climate-monitoring program. This process includes the following additional steps:

- Define park and network-specific monitoring needs and objectives.
- Identify locations and data repositories of existing and historic stations.
- Acquire existing data when necessary or practical.
- Evaluate the quality of existing data.
- Evaluate the adequacy of coverage of existing stations.
- Develop a protocol for monitoring the weather and climate, including the following:
    - Standardized summaries and reports of weather/climate data.
    - Data management (quality assurance and quality control, archiving, data access, etc.).
- Develop and implement a plan for installing or modifying stations, as necessary.

Throughout the design process, there are various factors that require consideration in evaluating weather and climate measurements. Many of these factors have been summarized by Dr. Tom Karl, director of the NOAA National Climatic Data Center (NCDC), and widely distributed as the “Ten Principles for Climate Monitoring” (Karl et al. 1996; NRC 2001). These principles are presented in Appendix A, and the guidelines are embodied in many of the comments made throughout this report. The most critical factors are presented here. In addition, an overview of requirements necessary to operate a climate network is provided in Appendix C, with further discussion in Appendix E.

1.4.1. Need for Consistency

A principal goal in climate monitoring is to detect and characterize slow and sudden changes in climate through time. This is of less concern for day-to-day weather changes, but it is of paramount importance for climate variability and change. There are many ways whereby changes in techniques for making measurements, changes in instruments or their exposures, or seemingly innocuous changes in site characteristics can lead to apparent changes in climate. Safeguards must be in place to avoid these false sources of temporal “climate” variability if we are to draw correct inferences about climate behavior through time from archived measurements.

For climate monitoring, consistency through time is vital, counting at least as important as absolute accuracy. Sensors record only what is occurring at the sensor—this is all they can detect. It is the responsibility of station or station network managers to ensure that observations are representative of the spatial and temporal climate scales that we wish to record.

1.4.2. Metadata

Changes in instruments, site characteristics, and observing methodologies can lead to apparent changes in climate through time. It is therefore vital to document all factors that can bear on the interpretation of climate measurements and to update the information repeatedly through time. This information ("metadata," data about data) has its own history and set of quality-control issues that parallel those of the actual data. There is no single standard for the content of climate metadata, but a simple rule suffices:

- Observers should record all information that could be needed in the future to interpret observations correctly without benefit of the observers' personal recollections.

Such documentation includes notes, drawings, site forms, and photos, which can be of inestimable value if taken in the correct manner. That stated, it is not always clear to the metadata provider *what is important* for posterity and *what will be important* in the future. It is almost impossible to "over-document" a station. Station documentation is underappreciated greatly and seldom thorough enough (especially for climate purposes). Insufficient attention to this issue often lowers the present and especially future value of otherwise useful data.

The convention followed throughout climatology is to refer to metadata as information about the measurement process, station circumstances, and data. The term "data" is reserved solely for the actual weather and climate records obtained from sensors.

1.4.3. Maintenance

Inattention to maintenance is the greatest source of failure in weather/climate stations and networks. Problems begin to occur as soon as sites are deployed. A regular visit schedule must be implemented, where sites, settings (e.g., vegetation), sensors, communications, and data flow are checked routinely (once or twice a year at a minimum) and updated as necessary. Parts must be changed out for periodic recalibration or replacement. With adequate maintenance, the entire instrument suite should be replaced or completely refurbished about once every five to seven years.

Simple preventative maintenance is effective but requires much planning and skilled technical staff. Changes in technology and products require retraining and continual re-education. Travel, logistics, scheduling, and seasonal access restrictions can consume major amounts of time and budget but are absolutely necessary. Without such attention, data gradually become less credible and then often are misused or not used at all.

1.4.4. Automated versus Manual Stations

Historic stations often have depended on manual observations and many continue to operate in this mode. Manual observations frequently produce excellent data sets. Sensors and data are simple and intuitive, well tested, and relatively cheap. Manual stations have much to offer in certain circumstances and can be a source of both primary and backup data. However, methodical consistency for manual measurements is a constant challenge, especially with a mobile work force. Operating manual stations takes time and needs to be done on a regular schedule, though sometimes the routine is welcome.

Nearly all newer stations are automated. Automated stations provide better time resolution, increased (though imperfect) reliability, greater capacity for data storage, and improved accessibility to large amounts of data. The purchase cost for automated stations is higher than for manual stations. A common expectation and serious misconception is that an automated station can be deployed and left to operate on its own. In reality, automation does not eliminate the need for people but rather changes the type of person that is needed. Skilled technical personnel are needed and must be readily available, especially if live communications exist and data gaps are not wanted. Site visits are needed at least annually and spare parts must be maintained. Typical annual costs for sensors and maintenance are $1500–2500 per station.

1.4.5. Communications

With manual stations, the observer is responsible for recording and transmitting station data. Data from automated stations, however, can be transmitted quickly for access by research and operations personnel, which is a highly preferable situation. A comparison of communication systems for automated and manual stations shows that automated stations generally require additional equipment, more power, higher transmission costs, attention to sources of disruption or garbling, and backup procedures (e.g. manual downloads from data loggers).

Automated stations are capable of functioning normally without communication and retaining many months of data. At such sites, however, alerts about station problems are not possible, large gaps can accrue when accessible stations quit, and the constituencies needed to support such stations are smaller and less vocal. Two-way communications permit full recovery from disruptions, ability to reprogram data loggers remotely, and better opportunities for diagnostics and troubleshooting. In virtually all cases, two-way communications are much preferred to all other communication methods. However, two-way communications require considerations of cost, signal access, transmission rates, interference, and methods for keeping sensor and communication power loops separate. Two-way communications are frequently impossible (no service) or impractical, expensive, or power consumptive. Two-way methods (cellular, land line, radio, Internet) require smaller up-front costs as compared to other methods of communication and have variable recurrent costs, starting at zero. Satellite links work everywhere (except when blocked by trees or cliffs) and are quite reliable but are one-way and relatively slow, allow no re-transmissions, and require high up-front costs ($3000–4000) but no recurrent costs. Communications technology is changing constantly and requires vigilant attention by maintenance personnel.

1.4.6. Quality Assurance and Quality Control

Quality control and quality assurance are issues at every step through the entire sequence of sensing, communication, storage, retrieval, and display of environmental data. Quality assurance is an umbrella concept that covers all data collection and processing (start-to-finish) and ensures that credible information is available to the end user. Quality control has a more limited scope and is defined by the International Standards Organization as "the operational techniques and activities that are used to satisfy quality requirements." The central problem can be better appreciated if we approach quality control in the following way.

- Quality control is the evaluation, assessment, and rehabilitation of imperfect data by utilizing other imperfect data.

The quality of the data only decreases with time once the observation is made. The best and most effective quality control, therefore, consists in making high-quality measurements from the start and then successfully transmitting the measurements to an ingest process and storage site. Once the data are received from a monitoring station, a series of checks with increasing complexity can be applied, ranging from single-element checks (self-consistency) to multiple-element checks (inter-sensor consistency) to multiple-station/single-element checks (inter-station consistency). Suitable ancillary data (battery voltages, data ranges for all measurements, etc.) can prove extremely useful in diagnosing problems.

There is rarely a single technique in quality control procedures that will work satisfactorily for all situations. These procedures must be tailored to individual station circumstances, data access and storage methods, and climate regimes.

The fundamental issue in quality control centers on the tradeoff between falsely rejecting good data (Type I error) and falsely accepting bad data (Type II error). We cannot reduce the incidence of one type of error without increasing the incidence of the other type. In weather and climate data assessments, Type I errors are deemed far less desirable than Type II errors.

Not all observations are equal in importance. Quality-control procedures are likely to have the greatest difficulty evaluating the most extreme observations, where independent information usually must be sought and incorporated. Quality-control procedures involving more than one station usually involve a great deal of infrastructure with its own (imperfect) error-detection methods, which must be in place before a single value can be evaluated.

1.4.7. Standards

Although there is near-universal recognition of the value of systematic weather and climate measurements, these measurements will have little value unless they conform to accepted standards. There is not a single source for standards for collecting weather and climate data nor a single standard that meets all needs. Measurement standards have been developed by the American Association of State Climatologists (AASC 1985), U.S. Environmental Protection Agency (EPA 1987), World Meteorological Organization (WMO 1983; 2005), Finklin and

Fischer (1990), National Wildfire Coordinating Group (2004), and the RAWS program (Bureau of Land Management [BLM] 1997). Variations to these measurement standards also have been offered by instrument makers (e.g., Tanner 1990).

1.4.8. Who Makes the Measurements?

The lands under NPS stewardship provide many excellent locations to host the monitoring of climate by the NPS or other collaborators. Most park units historically have observed weather/climate elements as part of their overall mission. Many of these measurements come from station networks managed by other agencies, with observations taken or overseen by NPS personnel, in some cases, or by collaborators from the other agencies. National Park Service units that are small, lack sufficient resources, or lack sites presenting adequate exposure may benefit by utilizing weather/climate measurements collected from nearly stations.

2.0. Climate Background

Ecosystem processes in arid environments such as those in the SCPN are strongly governed by climate characteristics (Comstock and Ehleringer 1992; Bailey 1995; Bailey 1998; Thomas et al. 2005). It is therefore essential to understand the climate characteristics of the SCPN. These characteristics are discussed in this chapter.

2.1. Climate and the SCPN Environment

The Colorado Plateau region is arid and is characterized by periods of drought and irregular precipitation, relatively warm to hot growing seasons, and long winters with sustained periods of freezing temperatures (Hunt 1967). These climate variations, along with historical fire patterns, have influenced disturbance rates and patterns in the SCPN and thus play a major role in the development of vegetation communities in this area (Van Devender and Spaulding 1979; Thomas et al. 2005). The Colorado Plateau has a significant number of endemic plant species, partly due to its unique past and present climate characteristics (Welsh 1978). These biotic communities are adversely affected by the spread of invasive species such as cheatgrass (*Bromus tectorum;* Mack 1981; Billings 1990) and saltcedar (*Tamarix;* Shafroth et al. 2005). Drought conditions can increase insect and pathogen infestation rates (Swetnam and Baisan 1994; Floyd et al. 2000), and increase the susceptibility of sites to exotic-plant invasion. Extreme drought conditions in recent years have had adverse impacts on the SCPN region’s vegetation characteristics and hydrology.

Ecosystem structure in the SCPN is also strongly influenced by evapotranspiration rates, which are high in arid climates (Hunt 1967). This is due in part to nearly vertical noontime solar rays during the summer, clear skies, and dry, thin air because of high elevation (Durrenberger 1972). Local precipitation and temperature patterns will dictate soil-water availability. Available soil moisture greatly influences ecosystem responses in arid regions such as SCPN (Thomas et al. 2005). Systems at higher elevations have cooler summer temperatures and are less sensitive to precipitation intensity and duration. Since the Colorado Plateau is a cool desert, winter precipitation typically occurs in the form of snow, even at the lower elevations. Gradual snowmelt from winter precipitation provides deeper infiltration into the soil (West 1988), and largely contributes to available soil water in the SCPN.

The Colorado Plateau is a cool desert. Some of the wintertime precipitation in the SCPN comes in the form of snow, falling at higher elevations. Snowmelt in the spring is a primary source of groundwater recharge and available soil water in the SCPN (West 1988). Winter precipitation is driven largely by orographic processes (West 1988). The Sierra Nevada and the Cascades on the U.S. West Coast, along with the mountain ranges in the Great Basin, intercept much of the winter moisture that comes into the SCPN primarily from the west. Northern portions of the SCPN in particular lie in a cumulative rain shadow from these mountain ranges. Higher altitudes within SCPN are more exposed to this winter moisture and thus tend to have higher mean annual precipitation totals.

Southern monsoonal storms are an important source of summer precipitation in the SCPN (Thomas et al. 2005). The Colorado Plateau is divided roughly into two climatic regions by a broad, northeastward-trending boundary which extends diagonally from northwestern Arizona to north central Colorado (Mitchell 1976; Petersen 1994). This broad boundary coincides with the mean northwestern extent of summer precipitation associated with monsoonal circulation patterns. Approximately two-thirds of the Plateau, (including SCPN park units), lies southeast of this climatic boundary. The magnitude of the summer precipitation maximum generally weakens from southeast to northwest, and the northwestern one-third of the Plateau is dominated by winter precipitation. Occasional variations in the boundary between these two climatic regions may contribute to high inter-seasonal and inter-annual variability in precipitation in the SCPN region (Ehleringer et al. 2000). From November to March, the dominant weather patterns on the southern Plateau include precipitation from Pacific region storms. Early winter months (December and January) tend to experience spatially-heterogeneous precipitation strongly influenced by elevation, while trends in late winter (February and March) show an overall increase in precipitation on the Plateau. By May, drier conditions again prevail and last until late June when monsoonal circulation begins to gain strength (Mock 1996). Wet summer monsoons (characterized by longer periods of heavy rainfall) tend to follow winters characterized by dry conditions, and vice versa (Higgins et al. 1998).

The El Niño Southern Oscillation (ENSO) occurs in a 4-7 year or multidecadal cycle and affects precipitation and climate on the southern Plateau (Wang 1995; Wang and Ropelewski 1995; Trenberth 1997; Mantua and Hare 2002). Positive ENSO phases (El Niño events) tend to bring wet winters and increased stream flow to the SCPN area through southerly displacement of storm tracks. El Niño events usually increase the variability of precipitation in the warm season and the frequency of precipitation in the cool-season (Trenberth 1997). The number of storms and flood events are significantly greater in El Niño events (Cayan and Webb 1992; Hereford and Webb 1992; Higgins et al. 1998). These storm events can greatly affect surface erosion, soil moisture, perennial stream flow, and groundwater recharge (Hereford et al. 2002). Negative ENSO phases (La Niña events) are typified by normal to relatively low warm-season precipitation and drier than normal winters (Hereford et al. 2002). At irregular intervals (about every 3 years), usually between mid-August and October, a major tropical storm moves up the Colorado River Valley from off the Baja peninsula. These events are of considerable biological significance as they can produce high levels of precipitation from September to October, corresponding to the period when warm-season grasses tend to disperse seed (Thomas et al. 2005).

Global-scale climatic changes are likely to have significant impacts on the landscape of the SCPN. Past climatic changes in the SCPN have influenced the region's ecosystems and consequently patterns of human habitation in the region (Van Devender and Spaulding 1979; Spaulding and Graumlich 1986; Thomas et al. 2005). Responses of ecosystems to global warming have been postulated, and likely will vary among systems (Shaver et al. 2000). Warming trends may decrease primary production in arid systems such as the SCPN, where temperatures already correspond to peak production. Interactions among processes also may constrain realized change in system structure. In dryland systems, increased evapotranspiration may effectively offset temperature-driven increases in plant production (Saleska et al. 1999). Given the influence of the monsoonal boundary, the effects of changes in circulation patterns and precipitation due to global climatic change may be seen relatively early in the SCPN compared to other regions (Ehleringer et al. 2000). The influences of climate change in the arid American Southwest are not limited to ecological impacts. Future climate changes could also adversely affect the region's widespread cultural resources, including the archaelogical ruins and artifacts displayed at several SCPN parks.

Understanding the role of climate as a forcing agent for other vital signs is therefore critical to SCPN monitoring. Observed changes in vital signs may be in response to multiple factors, such as anthropogenic stressors or variation in climatic conditions. Discerning reasons for observed changes that are responsive to mitigation measures (e.g., soil erosion vs. climate-driven change) will ensure effective management recommendations. Furthermore, untangling the effects of intrinsic climatic variation and climatic change will provide useful insights into regional trends in environmental change.

2.2. Spatial Variability

The overall climate characteristics of the SCPN are influenced by regional topography (Thomas et al. 2005). While climate patterns on the Colorado Plateau are heterogeneous (Mock 1996), general patterns can be identified for the SCPN: 1) precipitation decreases from high elevations to low elevations; and 2) summer precipitation decreases from the southeast to the northwest (Thomas et al. 2005). Mean annual precipitation is highest in the mountains of southwestern Colorado and northern New Mexico and the Mogollon Rim in Arizona. Annual precipitation totals approach 1000 mm in some of these locations (Figure 2.1). Much lower totals are characteristic of the surrounding basins. The driest conditions occur along the Colorado River Valley and in Arizona in those areas immediately downwind of the San Francisco Peaks and northern Mogollon Rim. Mean annual precipitation totals in these regions average under 150 mm. Mean annual precipitation for the park units in SCPN varies from under 150 mm to over 700 mm. (Figure 2.1).

Precipitation during the summer months (Figure 2.2) is characterized primarily by convective thunderstorms, especially in the higher elevations of the SCPN. Many of these summertime thunderstorms are associated with the southwestern monsoon (Higgins et al. 1998). As previously discussed, the northern boundary of the southwestern monsoon tends to run through the Colorado Plateau. The portions of SCPN that are strongly influenced by the southwestern monsoon have a summer peak in precipitation. This pattern can be clearly seen, for example, for climate stations at Chaco Culture National Historical Park (CHCU) and Walnut Canyon National Monument (WACA; Figure 2.3). However, summer precipitation maxima are not as evident in the northern portions of SCPN and at higher elevations in SCPN, as the monthly precipitation pattern for Mesa Verde National Park shows (MEVE; Figure 2.4).

Grand Canyon National Park (GRCA) contains the greatest spatial variability in precipitation among all the SCPN park units. Mean annual precipitation ranges from under 150 mm at the Colorado River to over 700 mm along portions of the canyon rim (Figure 2.5). This gradient is most severe across the eastern half of GRCA, where canyon rim elevations are the greatest. Much of the precipitation that reaches the canyon rim tends to evaporate before it can reach the canyon floor. Precipitation in GRCA during the winter months is associated with storms from the Pacific Ocean while summer precipitation is often associated with monsoonal thunderstorms.

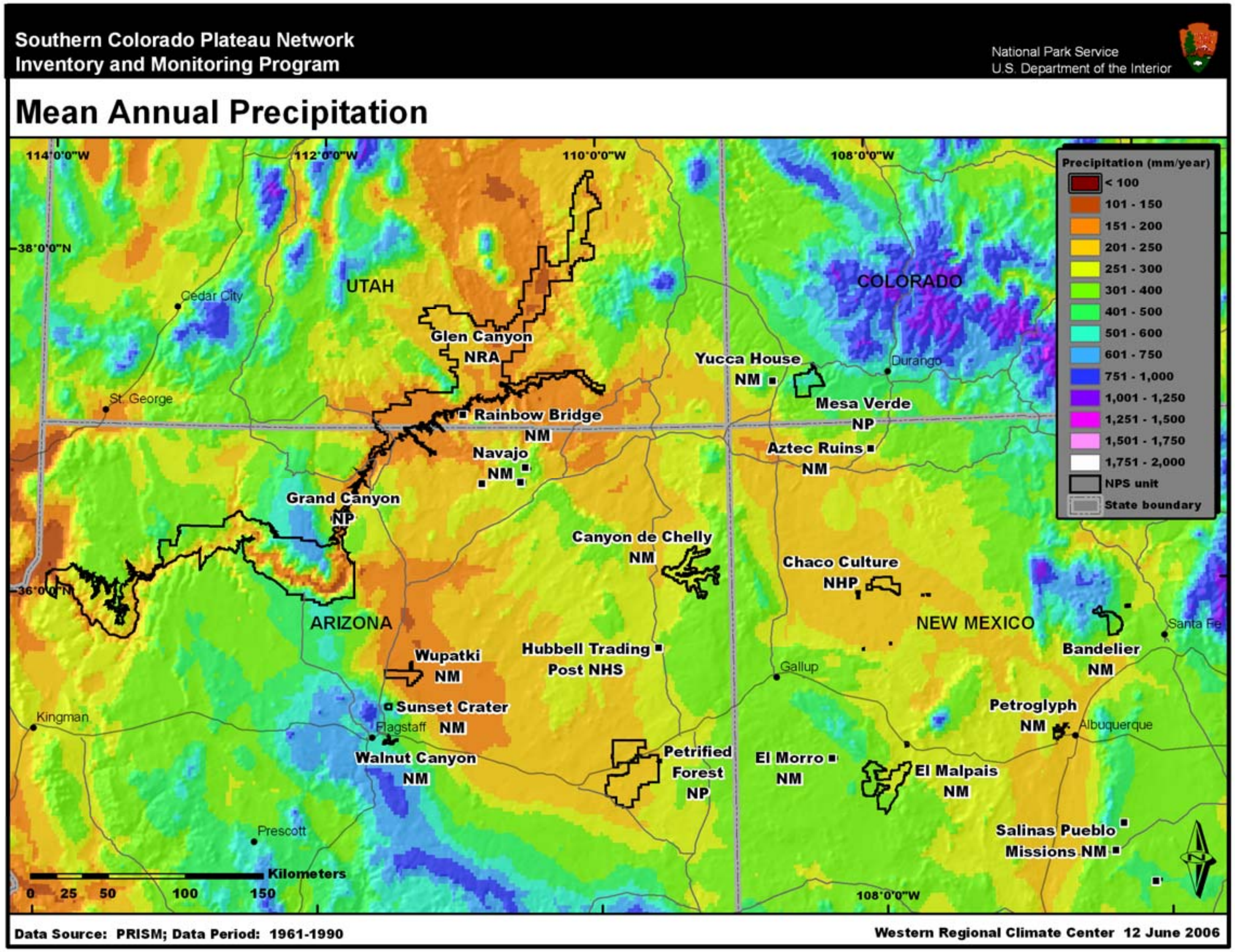


Figure 2.1. Mean annual precipitation, 1961-1990, for the SCPN.

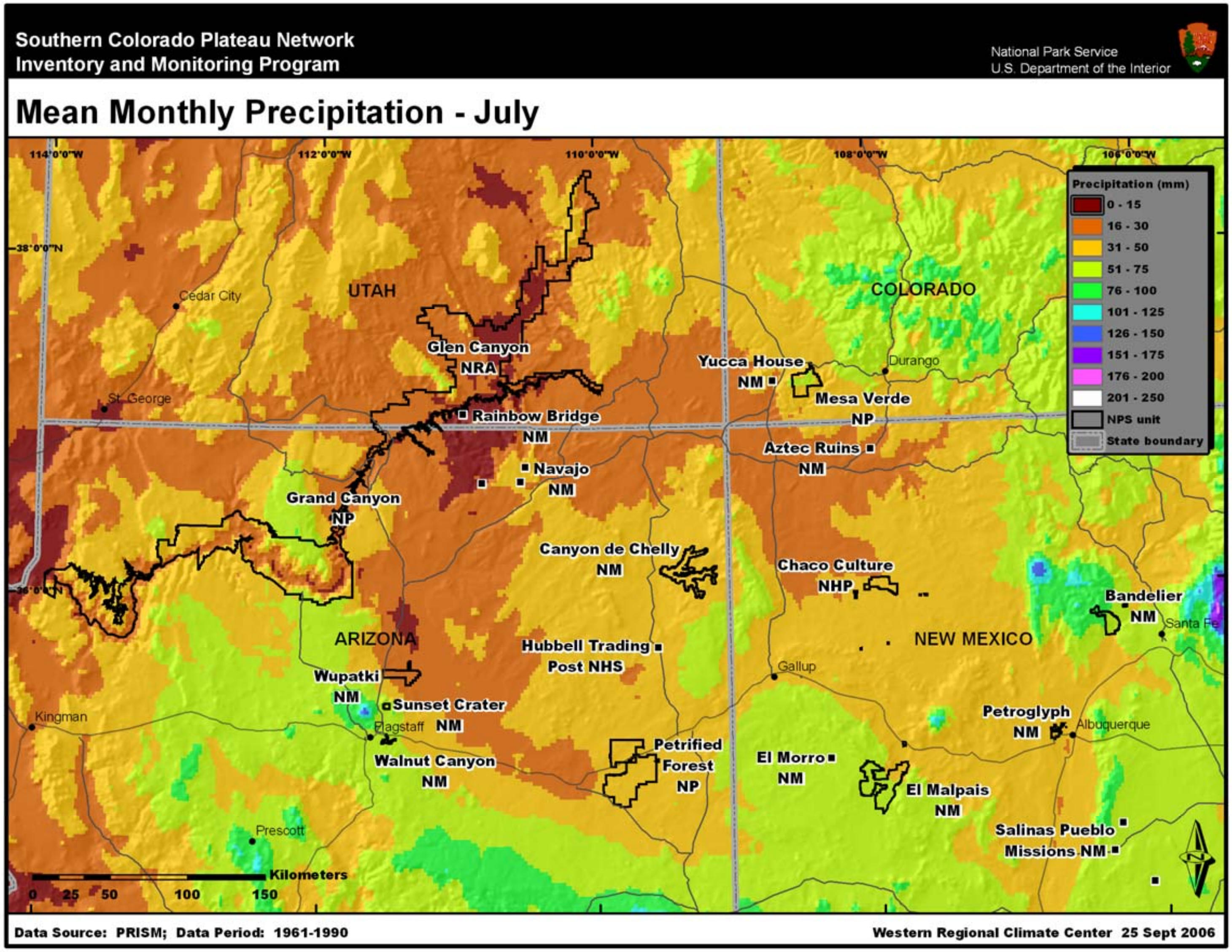
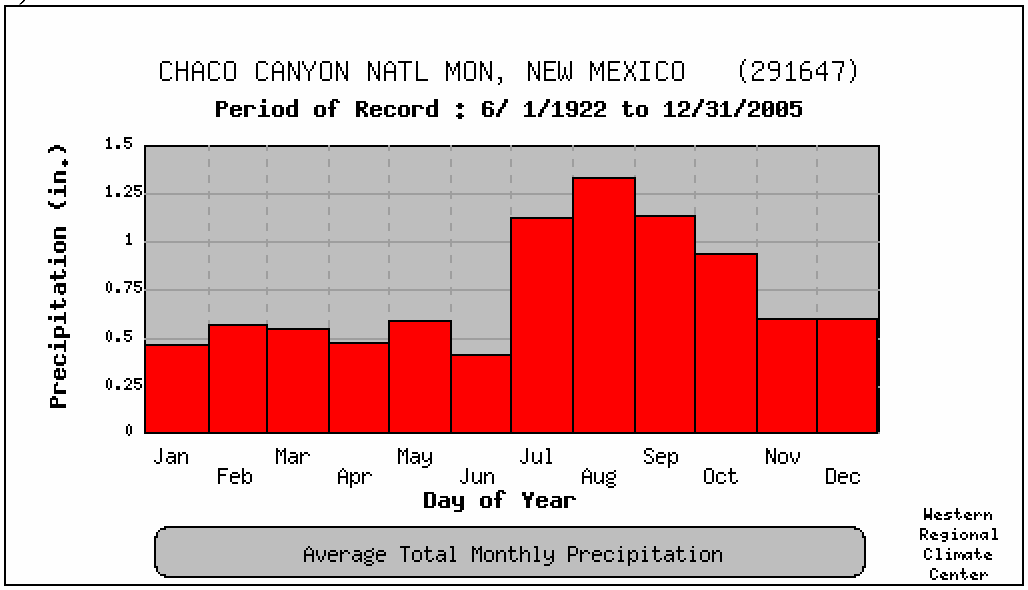


Figure 2.2. Mean July precipitation, 1961-1990, for the SCPN.

a)



b)

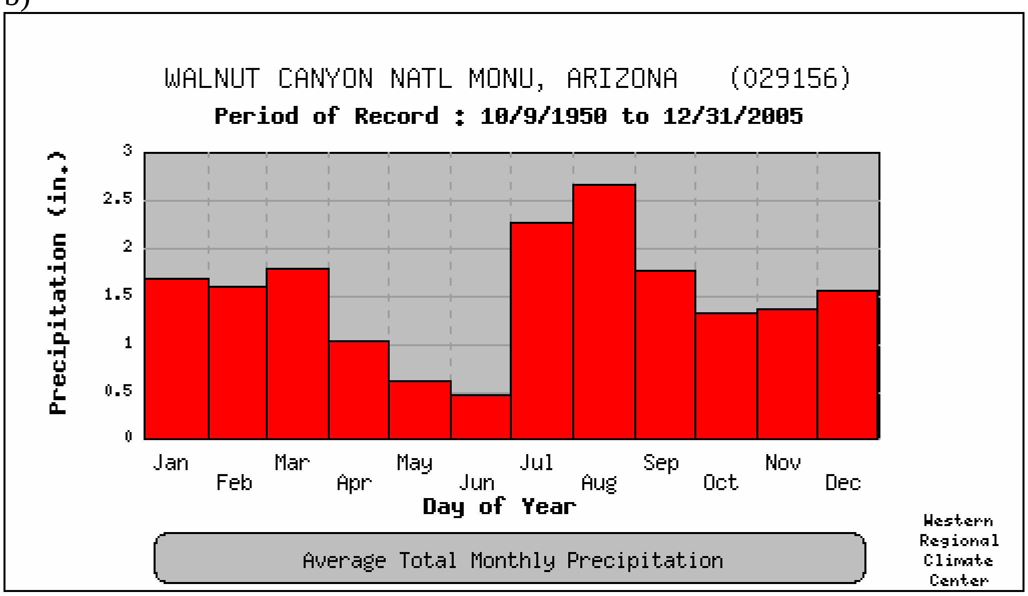


Figure 2.3. Mean monthly precipitation at CHCU and WACA.

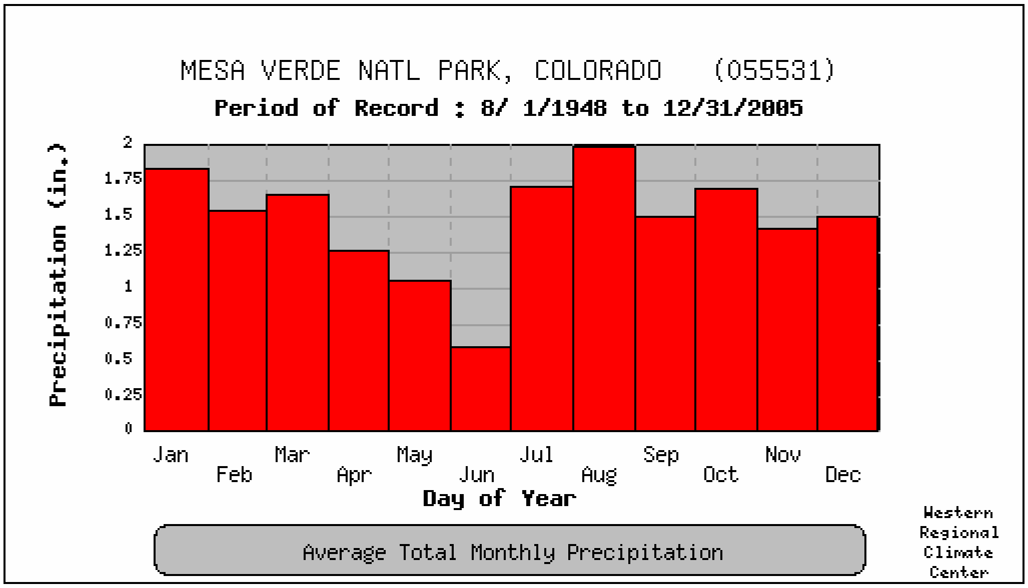


Figure 2.4. Mean monthly precipitation at MEVE.

Mean annual temperatures in the SCPN are strongly influenced by topography (Figure 2.6). The coolest locations of the SCPN are in the higher elevations of southwestern Colorado and northwestern New Mexico. Mean annual temperatures in these regions are generally under 10°C. January minimum temperatures are consistently below -10°C in southwestern Colorado and northwestern New Mexico, yet they often stay above freezing in lower portions of GRCA (Figure 2.7). The warmest conditions are found along the Colorado River Valley, where mean annual temperatures range between 12°C and 17°C (Figure 2.6) and July maximum temperatures often reach 40°C (Figure 2.8).

As with precipitation, GRCA has the greatest variability in temperatures of all the park units in SCPN. Mean annual temperatures can vary by over 15°C between the canyon floor and canyon rim in eastern portions of the park (Figure 2.9). January minimum temperatures regularly fall below -14°C along portions of the northern canyon rim (Figure 2.10). July maximum temperatures (Figure 2.11) typically are around 40°C along the Colorado River and can approach 50°C in especially severe heat waves.

2.3. Temporal Variability

Climate constantly fluctuates, on a variety of temporal scales. Paleoclimatic records (Van Devender and Spaulding 1979; Spaulding and Graumlich 1986) and current instrumental climate records have demonstrated the SCPN's climate variability at multiple time scales (Cayan et al. 1998). Links have been found between Pacific Basin climate indices, such as ENSO and the Pacific Decadal Oscillation (Mantua et al. 1997; Mantua 2000), and precipitation patterns in the western United States (Mock 1996; Cayan et al. 1998). These variations have also been tied to fire activity in the region (Swetnam and Baisan 1994; Floyd et al. 2000). Relative wetness in SCPN has been linked to El Niño events (e.g. Redmond and Koch 1991; Cayan et al. 1998). An example of this was during the winter of 2004-2005. During this El Niño event, portions of the Colorado Plateau received over twice their normal winter precipitation.

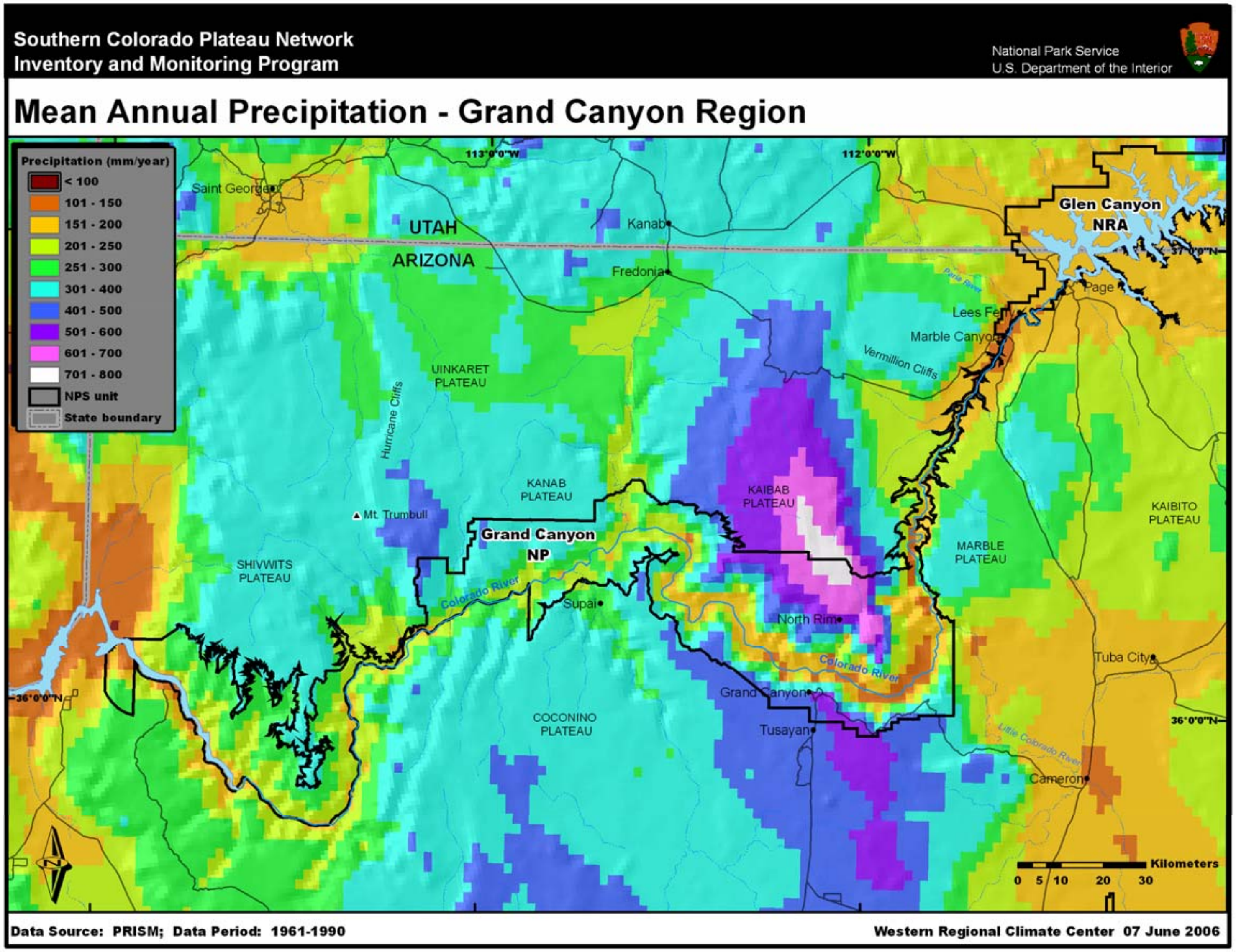


Figure 2.5. Mean annual precipitation, 1961-1990, for GRCA.

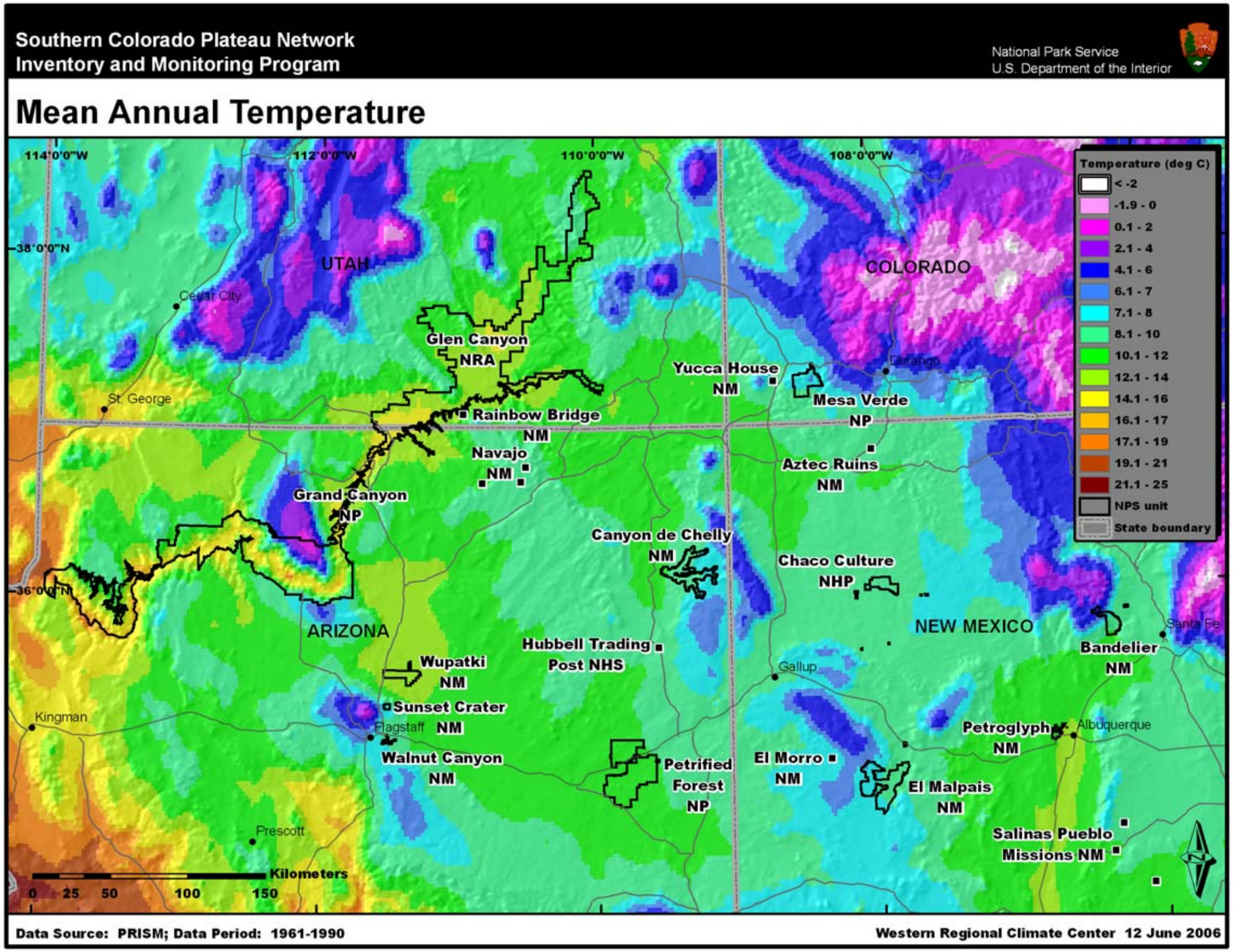


Figure 2.6. Mean annual temperature, 1961-1990, for the SCPN.

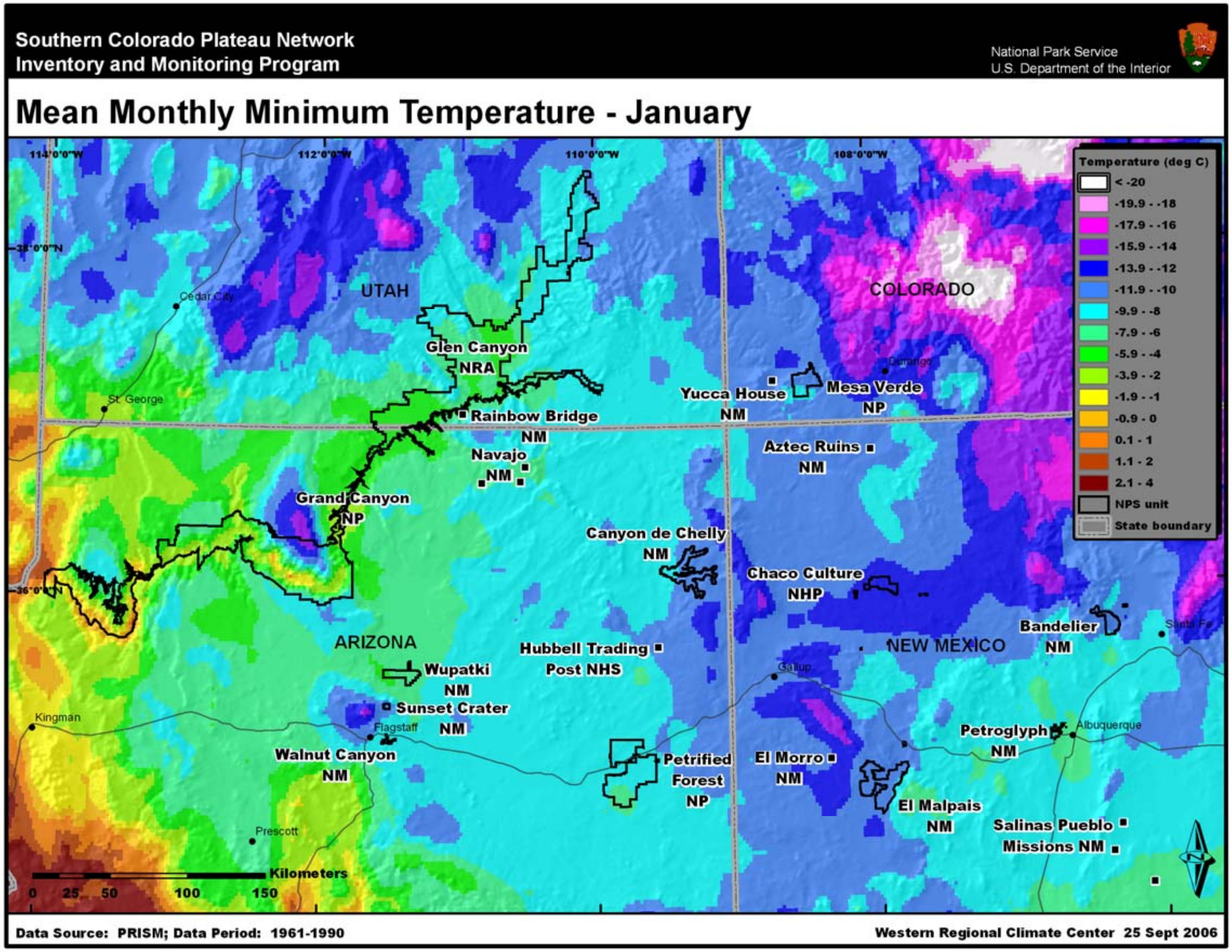


Figure 2.7. Mean January minimum temperature, 1961-1990, for the SCPN.

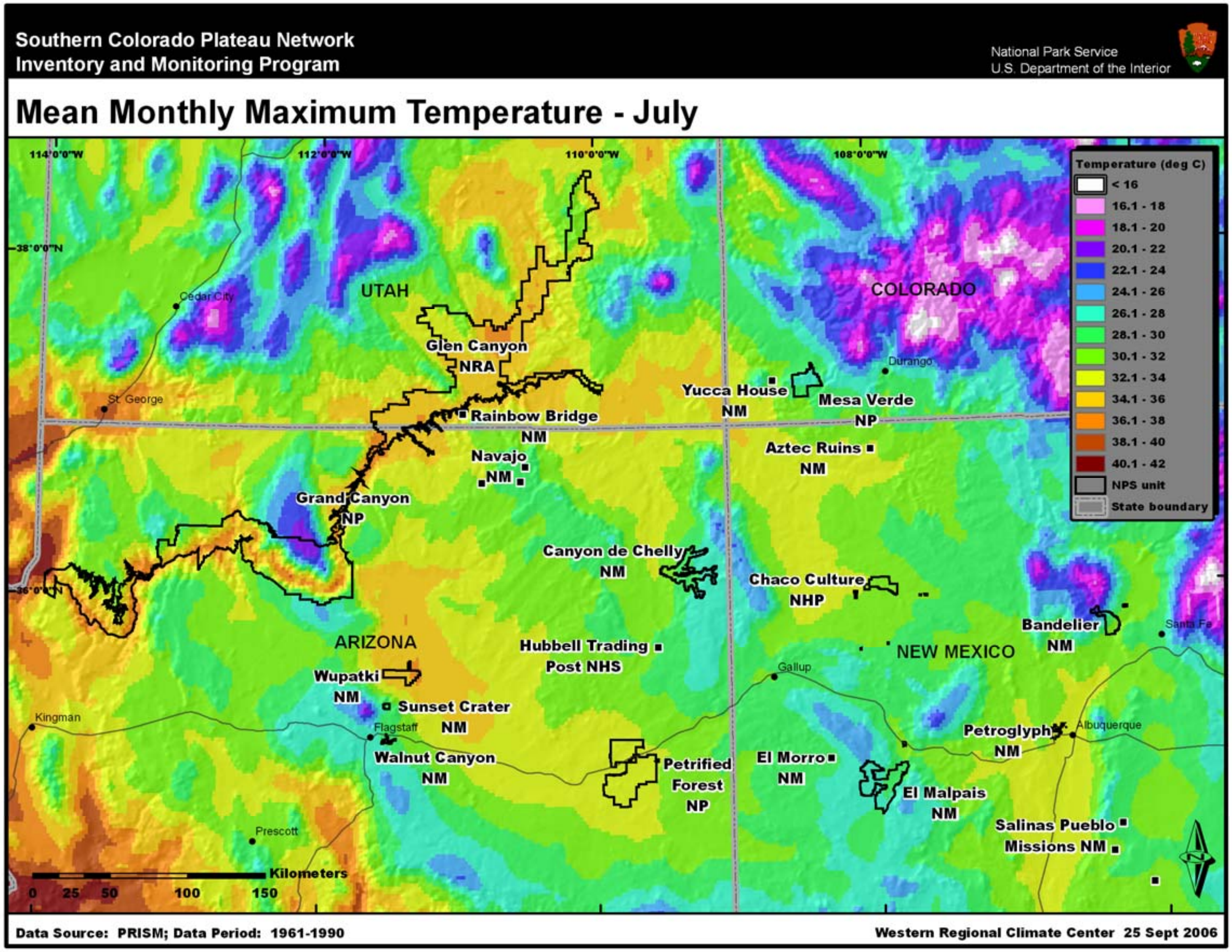


Figure 2.8. Mean July maximum temperature, 1961-1990, for the SCPN.

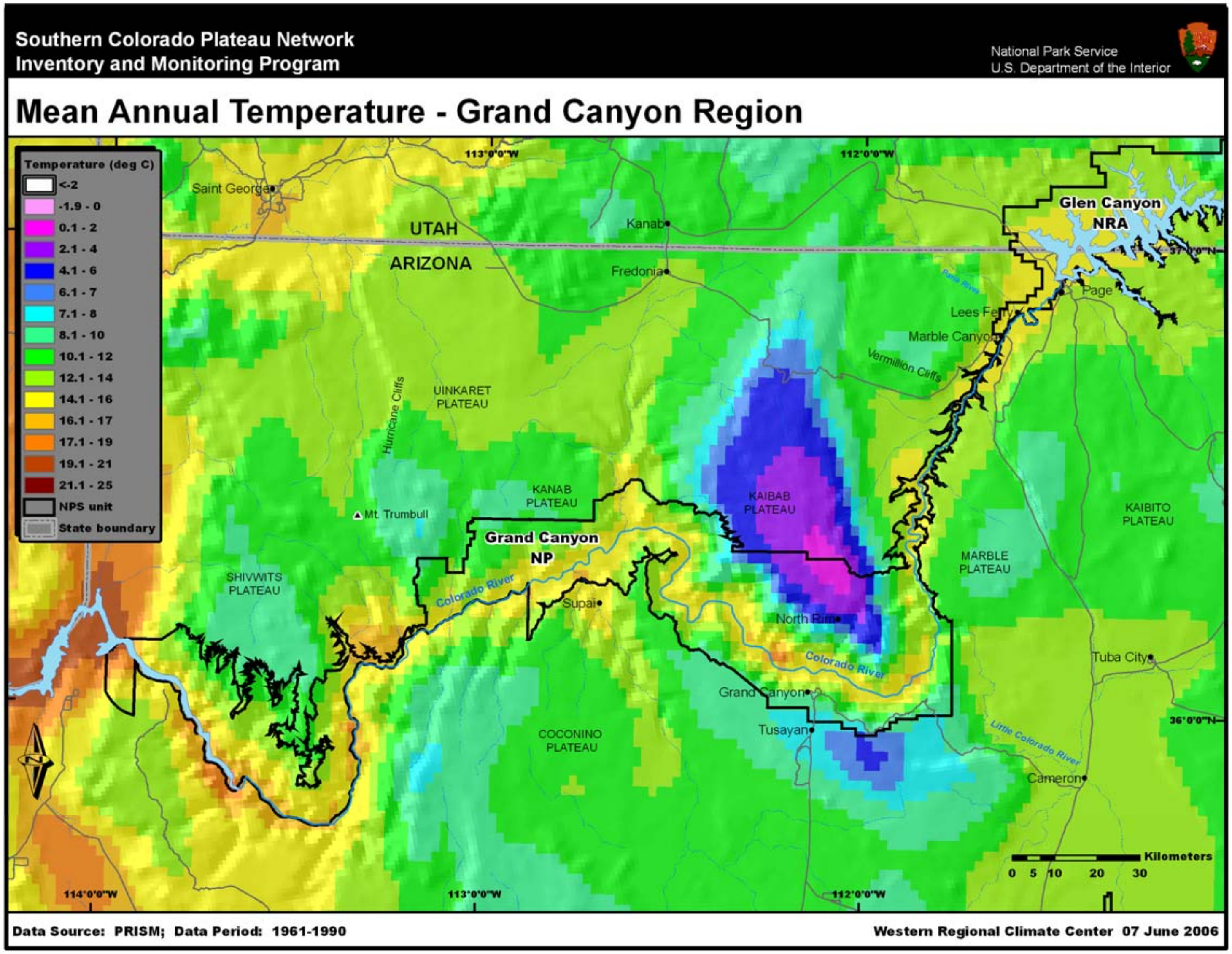


Figure 2.9. Mean annual temperature, 1961-1990, for GRCA.

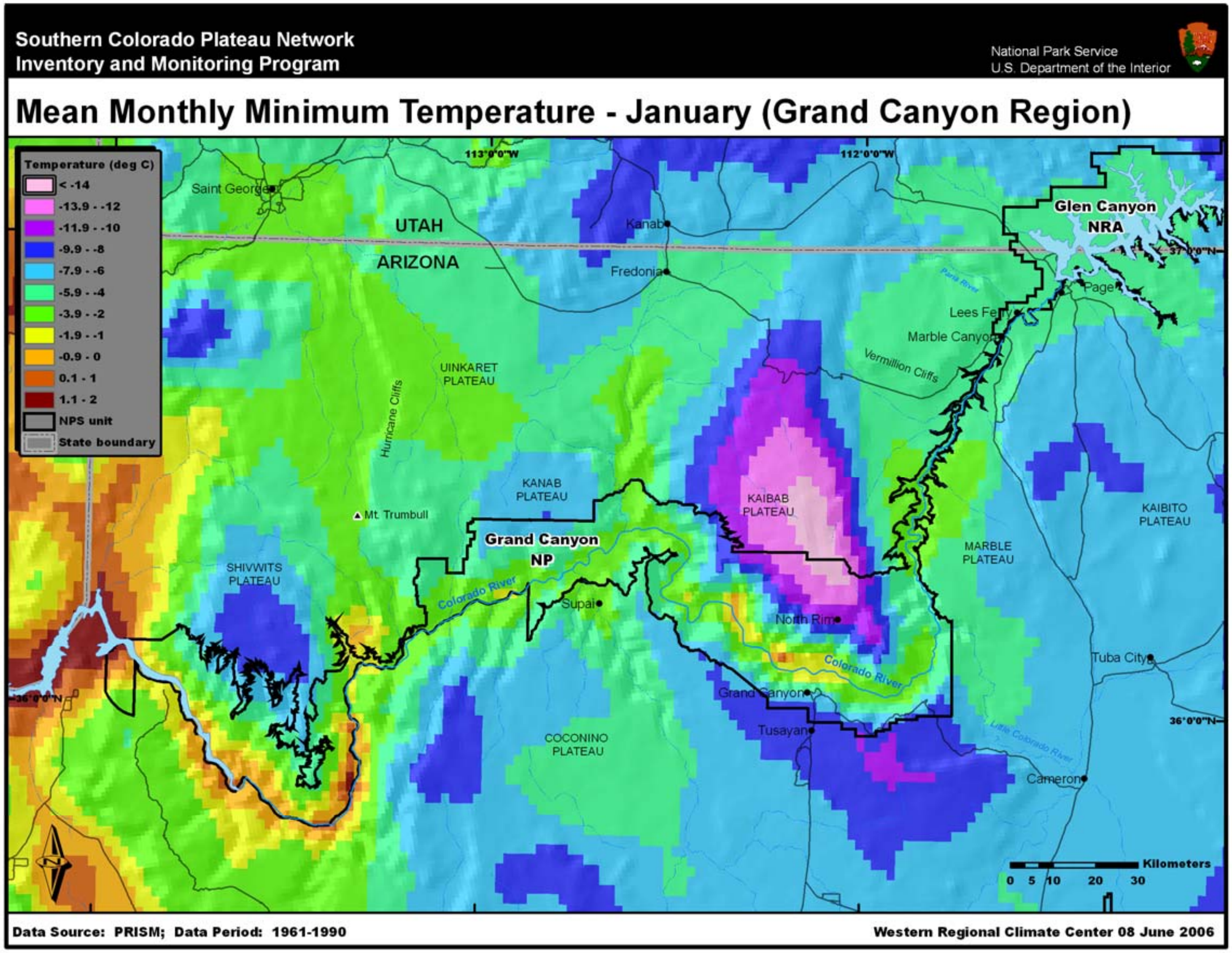


Figure 2.10. Mean January minimum temperature, 1961-1990, for GRCA.

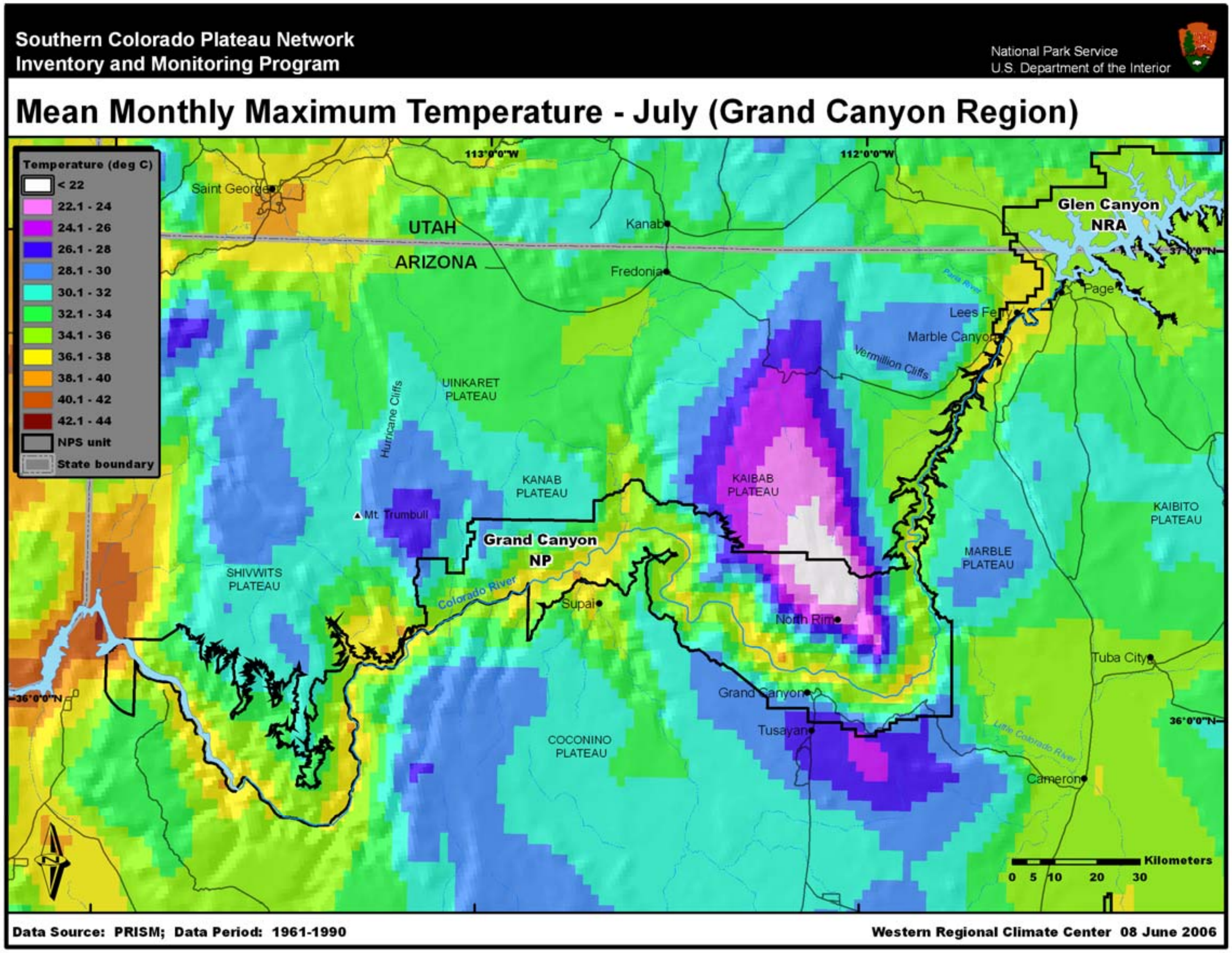


Figure 2.11. Mean July maximum temperature, 1961-1990, for GRCA.

Besides the temporal variations in climate due to the ENSO cycle and occasional tropical systems, longer-term climate trends are also important drivers of the SCPN environment. Temporal variations in mean annual temperature for the Colorado River Basin (Figure 2.12) indicate that temperatures have warmed considerably during the twentieth century. In northwest Arizona (Figure 2.13a), the early twentieth century actually shows a cooling, with a strong warming trend during the remainder of the time period. To the east, in New Mexico, slight warming trends are indicated (Figure 2.13b).

Variations in precipitation for the SCPN (Figure 2.14) generally show that there is no systematic trend. General wetter conditions dominated during the early part of the twentieth century, while drier conditions were prevalent in the 1950s. Generally wetter conditions have prevailed in some portions of SCPN during the latter part of the twentieth century (e.g. Figure 2.9b), although drought conditions in the last 5-10 years have stressed SCPN ecosystems. Some of the interannual and decadal variations in precipitation are likely associated with variations in the Pacific Decadal Oscillation and ENSO.

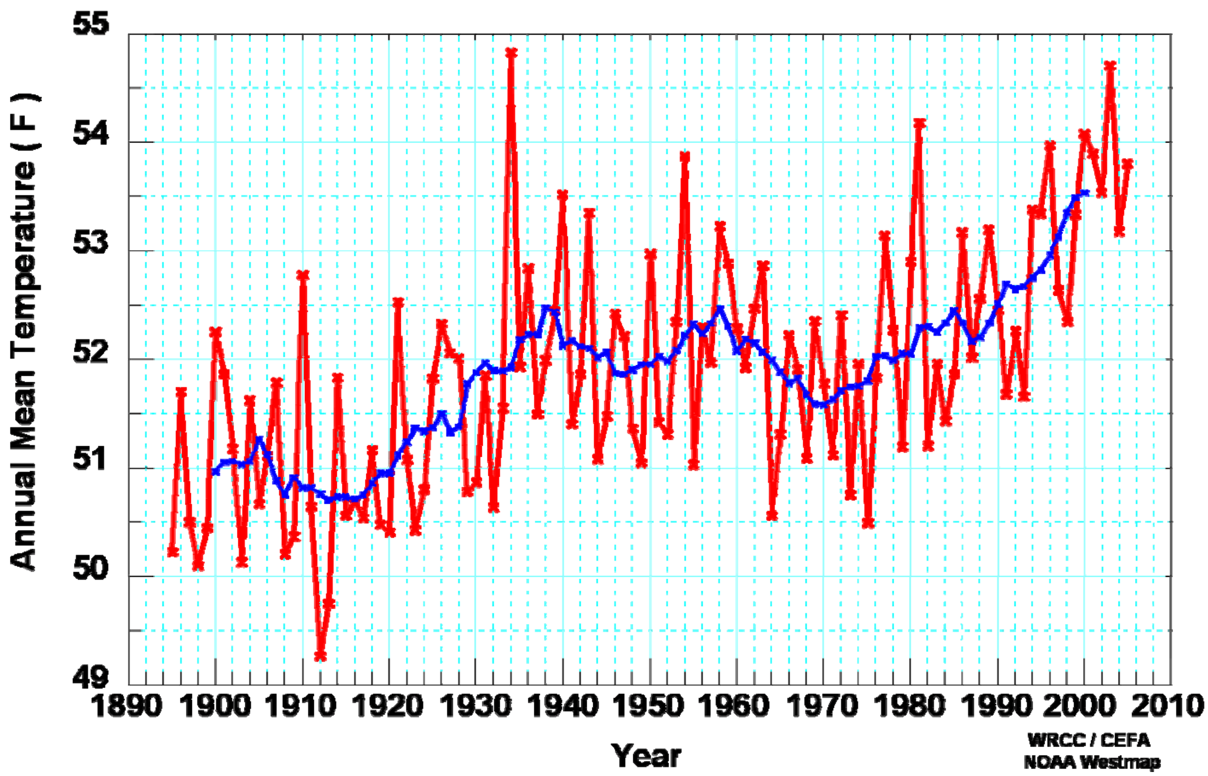
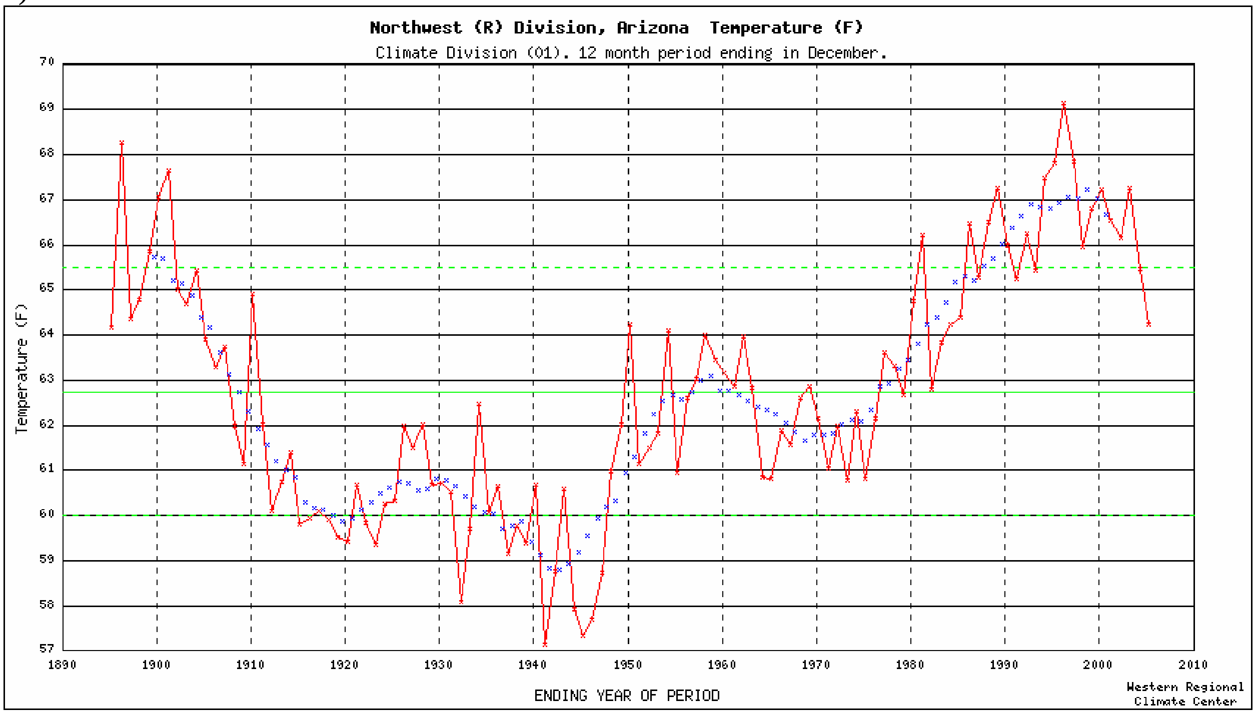


Figure 2.12. Colorado River Basin mean annual temperature trends, 1895-2005. Temperature data are taken from PRISM.

a)



b)

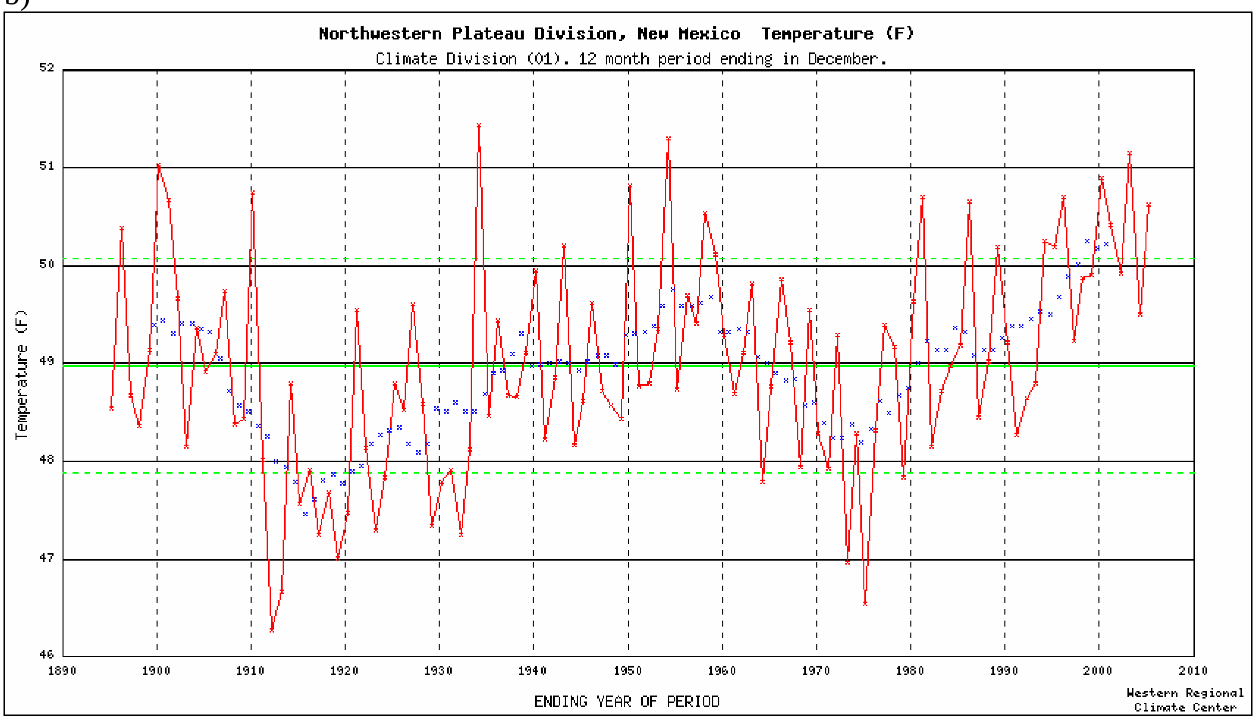
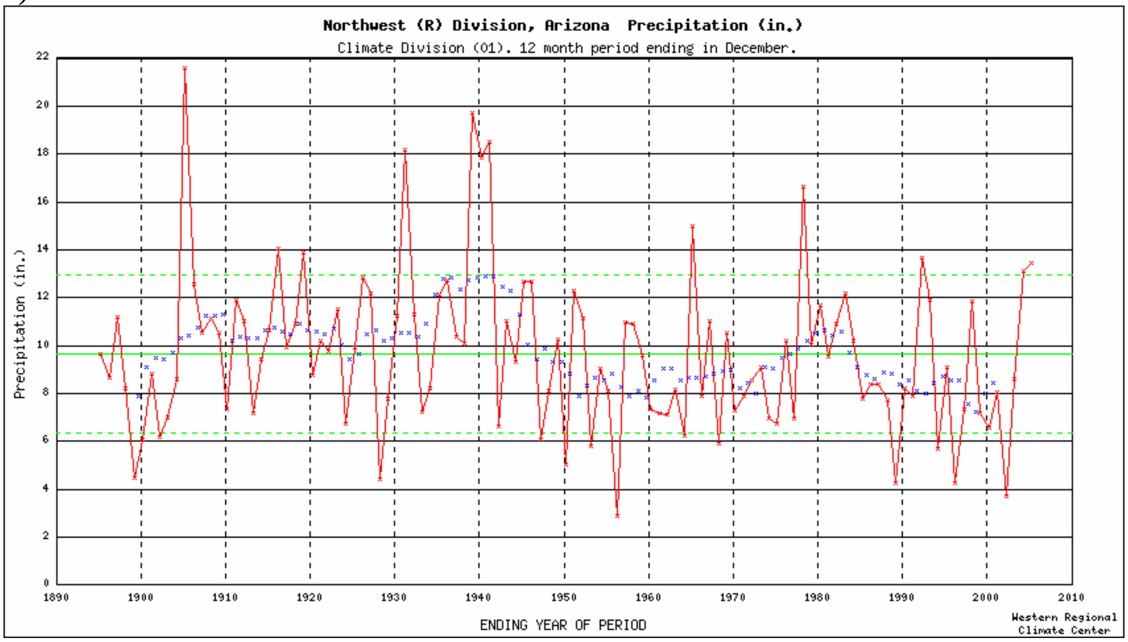


Figure 2.13. Temperature time series, 1895-2005, for northwestern Arizona (a) and for northwestern New Mexico (b). Twelve-month average temperature ending in December (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted line).

a)



b)

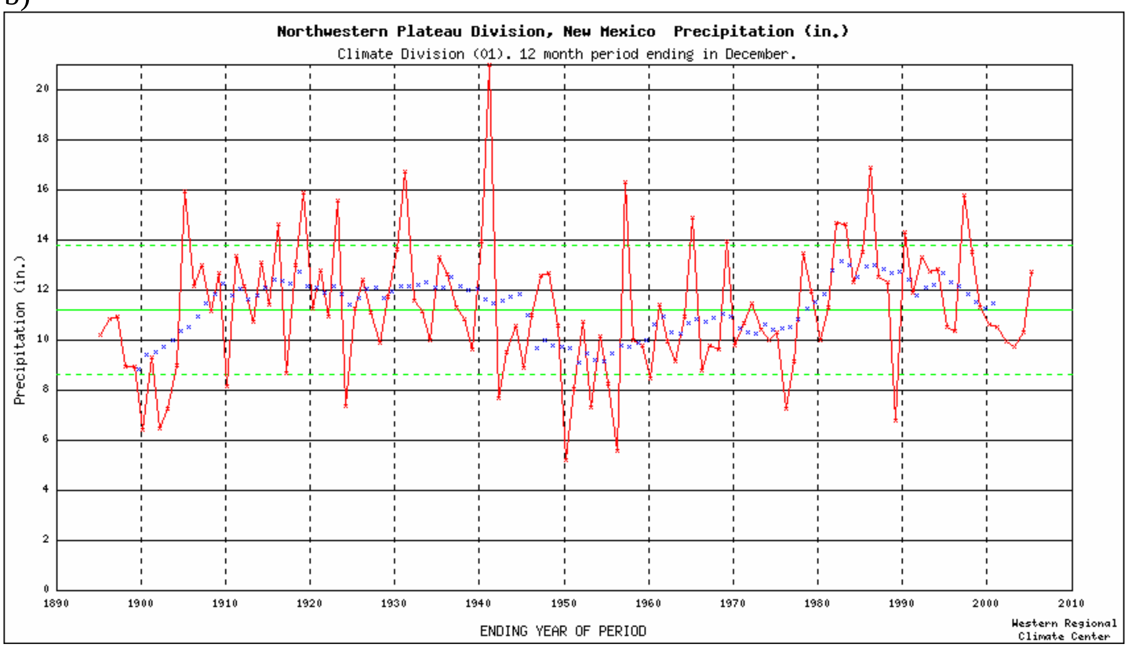


Figure 2.14. Precipitation time series, 1895-2005, for northwestern Arizona (a) and for northwestern New Mexico (b). Twelve-month average precipitation ending in December (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted line).

2.4. Parameter Regression on Independent Slopes Model (PRISM)

The climate maps presented here were generated using the Parameter Regression on Independent Slopes Model (PRISM). This model was developed to address the extreme spatial and elevation gradients exhibited by the climate of the western United States (Daly et al. 1994; 2002; Gibson et al. 2002; Doggett et al. 2004). The maps produced through PRISM have undergone rigorous evaluation across the western United States. Originally, this model was developed to provide climate information at scales matching available land-cover maps to assist in ecologic modeling. Elevation provides the first-order constraint for the mapped climate fields, with orientation (aspect) providing a second-order constraint. The PRISM technique specifically accounts for different time-integrated climate elements whose behavior depends on spatial scale. The model has been enhanced gradually to address inversions, coast/land gradients, and climate patterns in small-scale trapping basins. Monthly climate fields are generated by PRISM to account for seasonal variations in elevation gradients in climate elements. These monthly climate fields then can be combined into seasonal and annual climate fields. Since PRISM maps are grid maps, they do not replicate point values but rather, for a given grid cell, represent the grid-cell average of the climate variable in question at the average elevation for that pixel. The model relies on observed surface and upper-air measurements to estimate spatial climate fields.

3.0. Methods

Having discussed the climatic characteristics of SCPN, we now present the procedures that were used to obtain information for weather/climate stations within SCPN. This information was obtained from various sources, as mentioned in the following paragraphs. Retrieval of station metadata constituted a major component of this work.

3.1. Metadata Retrieval

A key component of station inventories is determining the kinds of observations that have been conducted over time, by whom, and in what manner; when each type of observation began and ended; and whether these observations are still being conducted. Metadata about the observational process generally consist of a series of vignettes that apply to time intervals and, therefore, constitute a *history* rather than a single snapshot. This report has relied on metadata records from three sources: (a) Western Regional Climate Center (WRCC), (b) NPS personnel, and (c) other knowledgeable personnel, such as state climate office staff. Metadata (Table 3.1) have been obtained as completely as possible for weather/climate stations in and near the park units within SCPN. An expanded list of relevant metadata fields for this inventory is provided in Appendix D.

The initial metadata sources for this report were stored at WRCC. This regional climate center acts as a working repository of many western climate records, including the main networks outlined in this section. Live and periodic ingests from all major national and western weather/climate networks are maintained at WRCC. These networks include the COOP network, the Surface Airways Observation Network (SAO) network jointly operated by NOAA and the Federal Aviation Administration (FAA), the NOAA upper-air observation network, NOAA data buoys, the RAWS network, the SNOTEL network, and various smaller networks. The WRCC is expanding its capability to ingest information from other networks as resources permit and usefulness dictates. This center has relied heavily on historic archives (in many cases supplemented with live ingests) to assess the quantity (not necessarily quality) of data available for NPS I&M network applications.

This report has relied primarily on metadata stored in the Applied Climate Information System (ACIS), a joint effort among regional climate centers (RCCs) and other NOAA entities. Metadata for SCPN weather/climate stations identified from the ACIS database are available in file "SCPN_from_ACIS.tar.gz" (see Appendix G). Historic metadata pertaining to major climate- and weather-observing systems in the United States are stored in ACIS where metadata are linked to the observed data. A distributed system, ACIS is synchronized among the RCCs. Mainstream software is utilized, including Postgress, Python™, and Java™ programming languages; CORBA®-compliant network software; and industry-standard, nonproprietary hardware and software. All major national climate and weather networks have been entered into the ACIS database. For this project, the available metadata from many smaller networks also have been entered. Data sets are in the NetCDF (Network Common Data Form) format, but the design allows for integration with legacy systems, including non-NetCDF files (used at WRCC) and additional metadata (added for this project). The ACIS also supports a suite of products to visualize or summarize data from these data sets. National climate-monitoring maps are updated

Table 3.1. Primary metadata fields for weather/climate stations within the SCPN. Explanations are given as appropriate,

Metadata Field	Notes
Station name	Station name associated with network listed in "Climate Network."
Latitude	Numerical value (units: see coordinate units).
Longitude	Numerical value (units: see coordinate units).
Coordinate units	Latitude/longitude (units: decimal degrees, degree-minute-second, etc.).
Datum	Datum used as basis for coordinates: WGS 84, NAD 83, etc.
Elevation	Elevation of station above mean sea level (m).
Slope	Slope of ground surface below station (degrees).
Aspect	Azimuth that ground surface below station faces.
Climate division	NOAA climate division where station is located. Climate divisions are NOAA-specified zones sharing similar climate and hydrology characteristics.
Country	Country where station is located.
State	State where station is located.
County	County where station is located.
Weather/climate network	Primary weather/climate network the station belongs to (RAWS, Clean Air Status and Trends Network [CASTNet], etc.).
NPS unit code	Four-letter code identifying park unit where station resides.
NPS unit name	Full name of park unit.
NPS unit type	National park, national monument, etc.
UTM zone	If UTM is the only coordinate system available.
Location notes	Useful information not already included in "station narrative."
Climate variables	Temperature, precipitation, etc.
Installation date	Date of station installation.
Removal date	Date of station removal.
Station photograph	Digital image of station.
Photograph date	Date photograph was taken.
Photographer	Name of person who took the photograph.
Station narrative	Anything related to general site description; may include site exposure, characteristics of surrounding vegetation, driving directions, etc.
Contact name	Name of the person involved with station operation.
Organization	Group or agency affiliation of contact person.
Contact type	Designation that identifies contact person as the station owner, observer, maintenance person, data manager, etc.
Position/job title	Official position/job title of contact person.
Address	Address of contact person.
E-mail address	E-mail address of contact person.
Phone	Phone number of contact person (and extension if available).
Contact notes	Other information needed to reach contact person.

daily using the ACIS data feed. The developmental phases of ACIS have utilized metadata supplied by the NCDC and NWS with many tens of thousands of entries, screened as well as possible for duplications, mistakes, and omissions.

In addition to obtaining weather/climate station metadata from ACIS, metadata were also obtained from NPS staff at the SCPN office in Flagstaff, Arizona. The metadata provided from the SCPN office are available in the attached files "SCPN_NPS.tar.gz" (Appendix G). Note that there is some overlap between the metadata provided from SCPN and the metadata obtained from ACIS. We have also relied on information supplied at various times in the past by BLM, NPS, NCDC, NWS, and the state climate offices of Colorado and Utah (Table 3.2).

Table 3.2. Additional sources of weather and climate metadata for the SCPN.

Name	Position	Phone Number	Email Address
Robert Gillies	Utah State Climatologist	(435)797-2664	rgillies@nr.usu.edu
Nolan Doesken	Colorado State Climatologist	(970)491-8545	nolan@ccc.atmos.colostate.edu
Byron Peterson	NWS Flagstaff Forecast Office	(928)556-9161	byron.peterson@noaa.gov

Two types of information have been used to complete the climate station inventory for the SCPN.

- Station inventories: Information about operational procedures, latitude/longitude, elevation, measured elements, measurement frequency, sensor types, exposures, ground cover and vegetation, data-processing details, network, purpose, and managing individual or agency, etc.

- Data inventories: Information about measured data values including start and end dates, completeness, properties of data gaps, representation of missing data, flagging systems, how special circumstances are denoted in the data record, etc.

This is not a straightforward process. Extensive searches are typically required to develop historic station and data inventories. Both types of inventories frequently contain information gaps and often rely on tacit and unrealistic assumptions. Sources of information for these inventories frequently are difficult to recover or are undocumented and unreliable. In many cases, the actual weather/climate data available from different sources are not linked directly to metadata records. To the extent that actual data can be acquired (rather than just metadata), it is possible to cross-check these records and perform additional assessments based on the amount and completeness of the data.

Certain types of weather/climate networks that possess any of the following attributes have not been considered for inclusion in the inventory:

- Private networks with proprietary access and/or inability to obtain or provide sufficient metadata.
- Private weather enthusiasts (often with high-quality data) whose metadata are not available and whose data are not readily accessible.
- Unofficial observers supplying data to the NWS (lack of access to current data and historic archives; lack of metadata).
- Networks having no available historic data.
- Networks having poor-quality metadata.

- Networks having poor access to metadata.
- Real-time networks having poor access to real-time data.

Previous inventory efforts at WRCC have shown that for the weather networks identified in the preceding list, in light of the need for quality data to track weather and climate, the resources required and difficulty encountered in obtaining metadata or data are prohibitively large.

3.2. Criteria for Locating Stations

To identify stations for each park unit in SCPN, we first identified the centroid for each park unit. The centroid is defined as the average latitude and longitude of vertices defining the boundary of the park unit. We then calculated the diagonal distance of the park-unit bounding box (a box defined by the maximum and minimum latitude and longitude for the park unit). Next we identified all weather and climate stations, past and present, whose distances from the centroid were less than twice the diagonal distance of the park-unit bounding box. From these stations, we selected only those that were located in SCPN park units or within 40 km of a SCPN park-unit boundary. We selected a 40-km buffer in an attempt to include the airport sites in the communities surrounding the SCPN park units.

The station locator maps presented in Chapter 4 are designed to show clearly the spatial distributions of all major weather/climate station networks in SCPN. We recognize that other mapping formats may be more suitable for other specific needs.

4.0. Station Inventory

An objective of this report is to show the locations of weather/climate stations for the SCPN region in relation to the boundaries of the NPS park units within the SCPN. A station does not have to be within park boundaries to provide useful data and information for a park unit.

4.1. Climate and Weather Networks

Most stations in the SCPN are associated with at least one of 19 weather/climate networks (Table 4.1). Brief descriptions of each weather/climate network are provided below (see Appendix F for greater detail).

Table 4.1. Weather/climate networks represented within the SCPN.

Acronym	Name
AQ	Utah Division of Air Quality
AZMET	The Arizona Meteorological Network
CASTNet	Clean Air Status and Trends Network
CCRFCD	Clark County (Nevada) Regional Flood Control District
COOP	NWS Cooperative Observer Program
CRBFC	Colorado River Basin Forecast Center
CRN	NOAA Climate Reference Network
CWOP	Citizen Weather Observer Program
GPMP	Gaseous Pollutant Monitoring Program
GPS-MET	NOAA ground-based GPS meteorology
GSE	Grand Staircase – Escalante National Monument network
LANL	Los Alamos National Laboratory
NRCS-SC	USDA/NRCS snowcourse network
POMS	Portable Ozone Monitoring System
RAWS	Remote Automated Weather Station network
SAO	NWS/FAA Surface Airways Observation Network
SNOTEL	USDA/NRCS Snowfall Telemetry Network
SNOWNET	USDA/U.S. Forest Service Avalanche Network
WX4U	Weather For You

4.1.1. Utah Division of Air Quality (AQ)

The Utah Division of Air Quality runs weather stations to support their efforts in air quality monitoring for the state of Utah. This network is primarily an air-quality monitoring network managed by the EPA.

4.1.2. The Arizona Meteorological Network (AZMET)

The Arizona Meteorological Network (AZMET) provides near-real-time weather data that is used primarily for agricultural applications in southern and central Arizona. Meteorological elements measured by AZMET include temperature (air and soil), humidity, solar radiation, wind (speed and direction), and precipitation.

4.1.3. Clean Air Status and Trends Network (CASTNet)

This network is primarily an air-quality monitoring network managed by the EPA. Hourly weather and climate elements are measured and include temperature, wind, humidity, solar radiation, soil temperature, and sometimes moisture. These elements are intended to support interpretation of air-quality parameters that also are measured at CASTNet sites. Data records at CASTNet sites are generally one–two decades in length.

4.1.4. Clark County (NV) Regional Flood Control District (CCRFCD)

The Clark County Regional Flood Control District (CCRFCD) was created in 1985. The CCRFCD operates a set of weather stations whose primary purpose is to collect near-real-time precipitation measurements in support of efforts by the CCRFCD to manage and monitor potential flood conditions in the district.

4.1.5. NWS Cooperative Observer Program (COOP)

The COOP network has been a foundation of the U.S. climate program for decades. Manual measurements are made by volunteers and consist of daily maximum and minimum temperatures, observation-time temperature, daily precipitation, daily snowfall, and snow depth. When blended with NWS measurements, the data set is known as SOD, or “Summary of the Day.” The quality of data from COOP sites ranges from excellent to modest.

4.1.6. Colorado River Basin Forecast Center (CRBFC)

The CRBFC network has over 100 weather stations in the Colorado River Basin. The primary purpose of CRBFC stations is to collect meteorological data in support of efforts by the CRBFC to monitor potential flood conditions in the Colorado River Basin.

4.1.7. NOAA Climate Reference Network (CRN)

The CRN is intended as a reference network for the U.S. that meets the requirements of the Global Climate Observing System. Up to 115 CRN sites are planned for installation, but the actual number of installed sites will depend on available funding. Temperature and precipitation are the primary meteorological elements are measured. Wind, solar radiation, and ground surface temperature are also measured. Data from the CRN are intended for use in operational climate-monitoring activities and to place current climate patterns in historic perspective.

4.1.8. Citizen Weather Observer Program (CWOP)

The CWOP network consists primarily of automated weather stations operated by private citizens who have either an Internet connection and/or a wireless Ham radio setup. Data from CWOP stations are specifically intended for use in research, education, and homeland security activities. Although meteorological elements such as temperature, precipitation, and wind are measured at all CWOP stations, station characteristics do vary, including sensor types and site exposure.

4.1.9. NPS Gaseous Pollutant Monitoring Program (GPMP)

The GPMP network measures hourly meteorological data in support of pollutant monitoring activities. Measured elements include temperature, precipitation, humidity, wind, solar radiation, and surface wetness. These data are generally of high quality, with records extending up to 1-2 decades in length.

4.1.10. NOAA Ground-Based GPS Meteorology (GPS-MET)

The GPS-MET network is the first network of its kind dedicated to GPS meteorology (see Duan et al. 1996). GPS meteorology utilizes the radio signals broadcast by the satellite Global Positioning System for atmospheric remote sensing. GPS meteorology applications have evolved along two paths: ground-based (Bevis et al. 1992) and space-based (Yuan et al. 1993). For more information, please see Appendix G. The stations identified in this inventory are all ground-based. The GPS-MET network was developed in response to the need for improved moisture observations to support weather forecasting, climate monitoring, and other research activities. The primary goals of this network are to measure atmospheric water vapor using ground-based GPS receivers, facilitate the operational use of these data, and encourage usage of GPS meteorology for atmospheric research and other applications. GPS-MET is a collaboration between NOAA and several other governmental and university organizations and institutions. Ancillary meteorological observations at GPS-MET stations include temperature, relative humidity, and pressure.

4.1.11. Grand Staircase-Escalante National Monument Network (GSE)

The GSE network is a local network of weather/climate stations whose primary purpose is to provide local meteorological data for Grand Staircase-Escalante National Monument. These stations are primarily located to the west of Glen Canyon National Recreation Area.

4.1.12. Los Alamos National Laboratory (LANL)

The Los Alamos National Laboratory (LANL) operates a set of weather/climate stations whose objective is to provide meteorological observations and climatological information for the Los Alamos area. Measured elements include temperature, precipitation, humidity, pressure, wind speed and direction, and solar radiation. These data are of high quality.

4.1.13. Portable Ozone Monitoring System (POMS)

The POMS network is operated by the NPS Air Resources Division. Sites are intended primarily for summer, short-term (1-5 years) monitoring of near-surface atmospheric ozone levels in remote locations. Measured meteorological elements include temperature, precipitation, wind, relative humidity, and solar radiation.

4.1.14. Remote Automated Weather Station Network (RAWS)

The RAWS network is administered through many natural resource management agencies, particularly the BLM and the Forest Service. Hourly meteorology elements are measured and include temperature, wind, humidity, solar radiation, barometric pressure, fuel temperature, and precipitation (when temperatures are above freezing). The fire community is the primary client for RAWS data. These sites are remote and data typically are transmitted via GOES (Geostationary Operational Environmental Satellite). Some sites operate all winter. Most data records for RAWS sites began during or after the mid-1980s.

4.1.15. NWS/FAA Surface Airways Observation Network (SAO)

These stations are located usually at major airports and military bases. These include Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS) sites. Almost all SAO sites are automated. The hourly data measured at these sites include temperature, precipitation, humidity, wind, pressure, sky cover, ceiling, visibility, and current weather. Most data records begin during or after the 1940s, and these data are generally of excellent quality.

4.1.16. USDA/NRCS Snowfall Telemetry (SNOTEL) Network

The USDA/NRCS maintains a network of automated snow-monitoring stations known as SNOTEL. The network was implemented originally to measure daily precipitation and snow water content. Many modern SNOTEL sites now record hourly data, with some sites now recording temperature and snow depth. Most data records began during or after the mid-1970s.

4.1.17. USDA/NRCS snowcourse Network (NRCS-SC)

The USDA/NRCS maintains another network of snow-monitoring stations in addition to SNOTEL. These sites are known as snowcourses. These are all manual sites, measuring only snow depth and snow water content one–two times per month during the months of January to June. Data records for these snowcourses often extend back to the 1920s or 1930s, and the data are generally of high quality. Many of these sites have been replaced by SNOTEL sites, but several hundred snowcourses are still in operation.

4.1.18. USDA/USFS Avalanche Network (SNOWNET)

The United States Forest Service (USFS) administers a collection of weather stations run by various state- and local-level avalanche centers throughout the western U.S. Measured meteorological elements include temperature, precipitation, wind, and humidity.

4.1.19. Weather For You Network (WX4U)

The WX4U network is a nationwide collection of weather stations run by local observers. Data quality varies with site. Standard meteorological elements are measured and usually include temperature, precipitation, wind, and humidity.

4.1.20. Other Weather/Climate Networks

In addition to the weather/climate networks mentioned above, there are various networks that are operated for specific purposes by specific organizations or governmental agencies or scientific research projects. These networks could be present within SCPN but have not been identified in this report. Some of the commonly used networks include the following:

- NOAA upper-air stations
- Federal and state departments of transportation
- National Science Foundation Long-Term Ecological Research Network
- U.S. Department of Energy Surface Radiation Budget Network (Surfrad)
- Park-specific monitoring networks and stations
- Other research or project networks having many possible owners

There are two weather stations associated with the U.S. Geological Survey (USGS) Southwest Climate Impact Meteorological Stations network (CLIM-MET) in Canyonlands National Park and may be relevant for GLCA weather and climate monitoring activities. Weather stations associated with the CLIM-MET network are operated under the American Drylands Project. This project investigates the connection between climate properties and geologic processes in the southwestern U.S. Climate data from this project are being input into regional climate models that simulate future climatic conditions for the region.

We are aware of weather and climate stations near the SCPN park units in southwestern Colorado that are associated with CoAgMet (Colorado Agricultural Meteorological Network). The CoAgMet network is a weather monitoring network originally started in the early 1990s by the Agricultural Research Service branch of the USDA and the Plant Pathology extension service at Colorado State University. Data are managed by the Colorado Climate Center. Measured elements include temperature, precipitation, wind, relative humidity, solar radiation, and soil temperature.

In addition to the above networks, we have identified local NPS weather stations as well as stations in the Interagency Monitoring of Protected Visual Environments (IMPROVE) and National Atmospheric Deposition Program (NADP) networks. Data access for these stations could not be verified at the time of this report and are therefore listed in Appendix H. We anticipate that any stations identified from these networks will be added to the final versions of the metadatabase files accompanying this report.

4.2. Station Locations

The weather/climate networks we have identified in SCPN (discussed in Section 4.1) have up to several dozen stations in each park unit (Table 4.2). Most of these stations are COOP stations.

Lists of stations have been compiled for the SCPN (Table 4.2). A station does not have to be within the boundaries to provide useful data and information regarding the park unit in question. Some might be physically *within* the administrative or political boundaries, whereas others might be just outside, or even some distance away, but would be *nearby* in behavior and representativeness. What constitutes "useful" and "representative" are questions whose answers vary according to application, type of element, period of record, procedural or methodological observation conventions, and the like.

4.2.1. Greater Four Corners Region

There is one climate station inside the boundaries of Canyon de Chelly National Monument (CACH; Table 4.3). This site (Canyon de Chelly) is an active COOP station which is located at the west entrance of CACH (Figure 4.1) and has been operating since 1908. Data, however, are only readily available since 1970. The station with next longest period of record is Lukachukai, an active COOP station that is outside of CACH and has been operating since 1914. Unfortunately, data from Lukachukai are not consistently reliable. The closest automated sites for CACH are two RAWS stations (Piney Hill, Washington Pass) that are located about 30 km south and east of CACH. These RAWS stations have been in operation since 2003. Several NRCS-SC stations are currently monitoring seasonal snow conditions in the mountains that are located 20-30 km east of CACH along the Arizona/New Mexico border.

Glen Canyon National Recreation Area (GLCA) and Grand Canyon National Park (GRCA) are the two largest parks in the SCPN in terms of areal extent. They also have the most weather/climate stations located within their park boundaries, of any of the park units in the SCPN (Table 4.2). There are 12 active and historical sites in GLCA (Table 4.3). Seven of these stations are COOP stations. The COOP station with the longest period of record for GLCA is Lees Ferry, which has been active since 1916. The data record at Lees Ferry is mostly complete, but has a significant five-year gap from 1938-1943 and subsequent occasional gaps lasting up to several months. The latest multi-month data gaps occurred in May-June of 1991, September 1991, and March of 1995. Five automated weather observations provide near-real-time data inside GLCA (Table 4.3). Two of these stations are SAO stations at and around Bullfrog Basin. The CRBFC, GSE, and SNOWNET networks also have one automated station each in GLCA. The Bullfrog Basin SAO sites provide the longest data records of the automated stations in GLCA. Outside of GLCA, a couple COOP stations provide lengthy data records that start in the early 1900s (Table 4.3). The COOP station "Bluff" has been active since 1911, with a data record that is quite complete and of high quality. The COOP station "Escalante" has been active since 1901. There are several active RAWS stations within 40 km of the park boundaries of GLCA (Figure 4.1; Table 4.3). Most of these RAWS stations have been in operation since the

Table 4.2. Number of stations near (in) SCPN park units. Numbers are listed by park unit and weather/climate network.

Network	AZRU	BAND	CACH	CHCU	ELMA	ELMO	GLCA	GRCA	HUTR	MEVE
AQ	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)
AZMET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
CASTNet	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(1)	**0**(0)	**1**(1)
CCRFCD	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(0)	**0**(0)	**0**(0)
COOP	**12**(1)	**39**(0)	**13**(1)	**29**(1)	**42**(1)	**35**(1)	**45**(11)	**39**(8)	**15**(0)	**6**(1)
CRBFC	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(1)	**1**(0)	**0**(0)	**2**(1)
CRN	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(1)
CWOP	**0**(0)	**2**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(0)	**2**(0)	**0**(0)	**1**(0)
GPMP	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(1)	**1**(0)	**1**(1)
GPS-MET	**1**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
GSE	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**14**(1)	**2**(0)	**0**(0)	**0**(0)
LANL	**0**(0)	**6**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
NRCS-SC	**0**(0)	**3**(0)	**9**(0)	**4**(0)	**6**(0)	**6**(0)	**0**(0)	**2**(2)	**2**(0)	**2**(0)
POMS	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(1)	**0**(0)	**0**(0)
RAWS	**2**(0)	**13**(0)	**2**(0)	**2**(0)	**8**(1)	**8**(0)	**9**(0)	**21**(2)	**1**(0)	**4**(2)
SAO	**2**(0)	**2**(0)	**0**(0)	**1**(0)	**3**(0)	**1**(0)	**5**(2)	**4**(1)	**0**(0)	**1**(0)
SNOTEL	**0**(0)	**3**(0)	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(0)
SNOWNET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**0**(0)
WX4U	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(0)	**0**(0)	**0**(0)
Other	**0**(0)	**2**(0)	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**0**(0)	**1**(0)	**1**(0)	**0**(0)
Total	**17**(1)	**72**(0)	**24**(1)	**38**(1)	**44**(2)	**32**(1)	**81**(15)	**60**(16)	**20**(0)	**21**(7)

Network	NAVA	PEFO	PETR	RABR	SAPU	SUCR	WACA	WUPA	YUHO
AQ	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
AZMET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(0)	**0**(0)
CASTNet	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)
CCRFCD	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
COOP	**12**(1)	**18**(3)	**77**(1)	**4**(1)	**49**(1)	**21**(0)	**21**(1)	**21**(1)	**7**(0)
CRBFC	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**2**(0)
CRN	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)
CWOP	**0**(0)	**2**(0)	**17**(0)	**0**(0)	**15**(0)	**1**(0)	**1**(0)	**1**(0)	**1**(0)
GPMP	**0**(0)	**1**(1)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)
GPS-MET	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**1**(0)	**0**(0)
GSE	**0**(0)	**0**(0)	**0**(0)	**3**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
LANL	**0**(0)	**0**(0)	**6**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
NRCS-SC	**0**(0)	**2**(0)	**1**(0)	**0**(0)	**0**(0)	**8**(0)	**8**(0)	**8**(0)	**0**(0)
POMS	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
RAWS	**0**(0)	**1**(0)	**18**(0)	**0**(0)	**4**(0)	**5**(0)	**5**(0)	**5**(0)	**2**(0)
SAO	**1**(0)	0(0)	**5**(0)	**0**(0)	**5**(0)	**1**(0)	**1**(0)	**1**(0)	**1**(0)
SNOTEL	**0**(0)	**0**(0)	**2**(0)	**0**(0)	**0**(0)	**3**(0)	**3**(0)	**3**(0)	**0**(0)
SNOWNET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
WX4U	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**0**(0)
Other	**0**(0)	**1**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
Total	**13**(1)	**26**(5)	**68**(1)	**7**(1)	**46**(1)	**42**(0)	**43**(1)	**43**(1)	**16**(0)

late 1980s or the 1990s. There are also 14 GSE stations that also provide automated weather data in and near GLCA, along with three SAO stations at airport sites around GLCA (Table 4.3).

Grand Canyon National Park (GRCA) has 16 active and historical weather/climate stations inside the park. Four of the active sites within GRCA are COOP stations. The COOP station with the longest period of operation is “Bright Angel R S”, which is located on Grand Canyon’s north rim and has been active since 1925 (Table 4.3). Station data are readily available after the late 1940s. This site did not take measurements during the winter and early spring months from the late 1950s to the early 1970s. Other than these large gaps, the data record is fairly complete. The Bright Angel area also has a NRCS-SC station, which has been in operation since 1947, and a RAWS station which has operated since 1995 (Figure 4.1; Table 4.3). Air quality has been a concern in GRCA in recent decades (Thomas et al. 2005). To address this issue, the park also hosts a couple of automated air quality monitoring sites, including a CASTNet station (The Abyss) and a POMS station (Tuweep). The CASTNet station has operated since 1989 while the GPMP station has operated since 2003. There was a GPMP site at The Abyss from 1989 to 1995. Outside of GRCA, the longest climate records are provided from the COOP station at Lees Ferry, discussed previously. The park is also surrounded by at least 18 RAWS stations. These stations have operated since the 1980s or later and provide near-real-time weather observations for the plateau regions surrounding the Grand Canyon. Two SAO sites (Page Municipal Airport; Grand Canyon NP Arpt.) also provide automated weather and climate data for the region (Table 4.3).

Most of the weather stations within the boundaries of GRCA are located along the canyon’s rim, which is over 2000 m in elevation (Figure 4.1; Table 4.3). In contrast to these, Phantom Ranch is a COOP station located on the canyon floor. This station, which has operated since 1935, is the only long-term climate station located on the canyon floor (Figure 4.1; Table 4.3). This COOP station has retained the same coordinates within the resolution of one minute of arc since at least 1948. However, the station clearly has moved. Known originally as "Inner Canyon USGS" starting in at least July 1948, the station moved from an elevation of 759 m (2490 ft) elevation up to its current elevation of 783 m (2570 ft) in November 1960. In August 1966 the station was given a new name, Phantom Ranch, but has remained its current elevation and position (within one arc-minute) up until present. The first part of the record from 1948-1966 does have numerous gaps of up to a month or two, with a number of missing individual days. Renamed Phantom Ranch in August 1966, the site had significant gaps of many months until the early 1970s, after which the records from a few isolated months are missing. The station did also change its ID number in 1966 as it changed from Inner Canyon USGS (02-4335) to Phantom Ranch (02-6471). It does appear that at least the precipitation portions of these records can be concatenated.

There are seven active and historical sites in Mesa Verde National Park (MEVE; Table 4.3). Of these, the longest period of record is at the COOP site “Mesa Verde NP”, which has operated since 1922. This station has a very reliable data record. The only data gaps of note occurred in April-June and December of 1976. The other sites in MEVE are automated sites, including one CASTNet station, one CRN station, and two RAWS stations. Other automated weather observations are provided by stations outside MEVE and include the SAO site at the Cortez Montezuma County Airport, 20 km northwest of MEVE (Figure 4.1). This SAO site has been in operation since 1949. A few COOP sites outside of MEVE also provide long-term climate records for the MEVE area. These include "Cortez", "Fort Lewis", and "Mancos" (Table 4.3). The Mancos site is just northeast of MEVE, while the Fort Lewis site is about 30 km east of MEVE. Mancos does not have reliable data during its period of operation. Although Cortez is closer to MEVE than Fort Lewis, Cortez has a significant data gap from April 1975 to November 1976. The Fort Lewis site has a very complete data record.

While there are no weather or climate stations within the boundaries of Yucca House National Monument (YUHO), many of the weather stations identified in and around MEVE are also listed for YUHO (see Table 4.3). In addition to these, there are three active COOP stations near YUHO that have operated since the 1950 or later. These stations are "Hovenweep NM" (1957-present), "Pleasant View 1 W" (1950-present), and "Yellow Jacket 4 NE" (2003-present). The data record for "Hovenweep NM" is fairly complete. However, there have been several data gaps lasting one or two months during the 1990s. These include gaps in February, 1993; June, August, and September of 1994; September, 1995; February and June of 1996; January, 1997; November and December of 1999; and February, 2002.

There is currently one station inside Navajo National Monument (NAVA; Table 4.3). This is a COOP station (Betatakin) which has operated since 1939 and has a reliably complete data record. The only significant data gaps in this record are one-month gaps in January, 1973 and December, 1995. The only other active COOP station within 40 km of NAVA is "Monument Valley" and is almost 40 km northeast of NAVA, along the Arizona / Utah border (Figure 4.1). This station has been active since 1980. There are no automated stations in NAVA. The only automated station identified for NAVA is a SAO site, "Kayenta Airport", which is about 20 km east of NAVA and has been in operation since 1991.

Very little climate monitoring is currently underway at Rainbow Bridge National Monument (RABR). There are no active weather/climate stations inside RABR. However, this park unit has had one historical station that operated inside the park boundaries (Figure 4.1; Table 4.3). This was a COOP station (Escalante River Mouth) that operated between 1951 and 1955. The only other active sites within 40 km of RABR are three GSE sites. These are all automated sites that are 20-40 km north and west of RABR.

Table 4.3. Weather/climate stations for SCPN park units in the greater Four Corners region. Stations inside park units and within 40 km of the park unit boundary are included. Each listing includes station name, location, and elevation; weather/climate network associated with station; operational start/end dates for station; and flag to indicate if station is located inside park boundaries. Missing entries are indicated by "M".

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Canyon de Chelly National Monument (CACH)							
Canyon de Chelly	36.153	-109.539	1710	COOP	12/2/1908	Present	YES
Black Mtn. Mission	36.117	-109.867	1938	COOP	1/1/1952	1/1/1966	NO
Cottonwood Pass	36.083	-108.867	2624	COOP	10/1/1951	9/30/1955	NO
Crystal	36.117	-109.033	2378	COOP	8/1/1913	2/28/1914	NO
Fluted Rock	35.883	-109.25	2404	COOP	12/1/1951	7/31/1976	NO
Fort Defiance	35.75	-109.083	2105	COOP	6/1/1897	12/31/1936	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Lukachukai	36.419	-109.227	1988	COOP	11/1/1914	Present	NO
Many Farms School	36.367	-109.617	1620	COOP	8/1/1951	7/17/1975	NO
Roof Butte	36.467	-109.15	2575	COOP	11/1/1951	7/31/1976	NO
Tohatchi Peak	35.917	-108.867	2563	COOP	10/1/1951	9/30/1955	NO
Washington Pass	36.076	-108.858	2855	COOP	12/1/1976	Present	NO
Whiskey Creek	36.167	-109.05	2288	COOP	11/1/1951	12/31/1951	NO
Whiskey Creek	36.133	-109.033	2273	COOP	12/1/1951	7/31/1976	NO
Arbabs Forest	35.7	-109.2	2341	NRCS-SC	1/1/1985	Present	NO
Beaver Spring	36.333	-109.05	2811	NRCS-SC	1/1/1986	Present	NO
Bowl Canyon	36.033	-108.883	2738	NRCS-SC	1/1/1986	Present	NO
Fluted Rock	35.883	-109.25	2378	NRCS-SC	1/1/1985	Present	NO
Hidden Valley	36.267	-109.0	2585	NRCS-SC	1/1/1988	Present	NO
Missionary Spring	36.1	-108.833	2421	NRCS-SC	1/1/1991	Present	NO
Tsaile Canyon #1	36.4	-109.1	2488	NRCS-SC	1/1/1985	Present	NO
Tsaile Canyon #3	36.45	-109.1	2720	NRCS-SC	1/1/1986	Present	NO
Whiskey Creek	36.183	-108.95	2759	NRCS-SC	1/1/1986	Present	NO
Piney Hill	35.761	-109.168	2470	RAWS	11/1/2003	Present	NO
Washington Pass	36.078	-108.858	2857	RAWS	2/1/2003	Present	NO
Glen Canyon National Recreation Area (GLCA)							
Bullfrog Basin	37.53	-110.72	1165	COOP	3/1/1967	Present	YES
Bullfrog Basin Marina	37.518	-110.726	1172	COOP	10/22/1999	Present	YES
Escalante River Mouth	37.317	-110.9	1220	COOP	4/1/1951	10/31/1955	YES
Glen Canyon Dam	36.936	-111.481	1155	COOP	1/1/2000	Present	YES
Hans Flat RS	38.255	-110.18	2012	COOP	10/1/1980	Present	YES
Hite	37.817	-110.433	1058	COOP	2/15/1900	11/30/1962	YES
Hite Marina	37.867	-110.4	1125	COOP	10/1/1968	8/10/1977	YES
Hite Marina Store	37.883	-110.383	1204	COOP	10/1/1987	10/1/1996	YES
Hite Ranger Station	37.875	-110.388	1220	COOP	2/1/1978	Present	YES
Lees Ferry	36.864	-111.602	979	COOP	4/1/1916	Present	YES
Wahweap	36.995	-111.491	1137	COOP	5/1/1961	Present	YES
Colorado – Lk. Powell G	36.939	-111.481	1155	CRBFC	M	Present	YES
Grand Bench	37.136	-111.216	1439	GSE	M	Present	YES
Bullfrog Basin	37.53	-110.72	1165	SAO	3/1/1967	Present	YES
Bullfrog Marina	37.5	-110.7	1159	SAO	7/14/1970	Present	YES
Bullfrog Marina	37.518	-110.729	1128	SNOWNET	M	Present	YES
Moab	38.78	-109.77	1396	AQ	M	Present	NO
Island In The Sky	38.459	-109.821	1809	CASTNet	7/1/1992	Present	NO
Arches NP Hqs.	38.616	-109.619	1259	COOP	6/1/1980	Present	NO
Bears Ears Lower	37.583	-109.883	2098	COOP	9/1/1960	9/30/1976	NO
Bears Ears Upper	37.617	-109.867	2472	COOP	9/1/1960	9/30/1976	NO
Betatakin	36.678	-110.541	2221	COOP	3/1/1939	Present	NO
Big Water	37.077	-111.664	1250	COOP	8/1/1962	Present	NO
Bluff	37.283	-109.558	1317	COOP	6/1/1911	Present	NO
Bluff 20 WSW	37.15	-109.867	1234	COOP	10/2/1986	3/8/2001	NO
Boulder	37.905	-111.42	2037	COOP	6/1/1954	Present	NO
Bullfrog 8 N	37.63	-110.728	1226	COOP	10/1/1999	12/7/2005	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Canyonlands The Neck	38.46	-109.821	1808	COOP	6/17/1965	Present	NO
Canyonlands-The Needle	38.151	-109.782	1524	COOP	6/1/1965	Present	NO
Church Wells	37.1	-111.767	1378	COOP	9/1/1975	2/28/1986	NO
Copper Mine Trading	36.633	-111.417	1947	COOP	3/13/1939	3/17/1977	NO
Dinnehotso	36.85	-109.85	1531	COOP	7/1/1950	7/17/1975	NO
Elk Ridge Kigalia	37.65	-109.833	2594	COOP	7/1/1961	9/30/1976	NO
Escalante	37.769	-111.598	1771	COOP	5/1/1901	Present	NO
Forty Mile Dance Hall	37.367	-111.083	1327	COOP	6/1/1954	9/30/1976	NO
Hanksville 25 SE	38.094	-110.407	1183	COOP	10/11/1985	11/1/2001	NO
House Rock	36.733	-112.05	1641	COOP	7/1/1948	7/31/1958	NO
Jacob Lake	36.733	-112.217	2386	COOP	8/1/1916	10/31/1987	NO
Kaibito	36.6	-111.083	1830	COOP	7/1/1950	2/28/1961	NO
Kayenta	36.733	-110.283	1739	COOP	6/2/1915	10/31/1978	NO
Lake Powell Yacht Club	37.65	-110.7	1220	COOP	9/1/1987	1/1/1998	NO
Marsh Pass	36.617	-110.467	2008	COOP	12/1/1952	3/31/1973	NO
Mexican Hat	37.15	-109.868	1255	COOP	7/1/1940	Present	NO
Monument Valley	36.982	-110.111	1696	COOP	9/1/1980	Present	NO
Monument Valley Goul	37.017	-110.2	1598	COOP	5/1/1956	10/10/1996	NO
Monument Vly Mission	37.017	-110.217	1616	COOP	8/1/1961	4/1/1991	NO
Natural Bridges NM	37.609	-109.977	1982	COOP	6/1/1965	Present	NO
Navajo Mountain	37.017	-110.8	1837	COOP	11/1/1956	6/11/1975	NO
Page	36.921	-111.448	1302	COOP	10/1/1957	Present	NO
Paria Ranger Station	37.105	-111.9	1341	COOP	12/1/1998	Present	NO
Rainbow Lodge	37	-110.9	1962	COOP	5/1/1952	3/31/1954	NO
Shifting Sands Ranch	38.067	-111.067	1674	COOP	11/17/1988	10/1/1992	NO
Cw1122 Page	36.905	-111.473	1280	CWOP	M	Present	NO
Cw5798 Big Water	37.063	-111.644	1250	CWOP	M	Present	NO
Island In The Sky	38.459	-109.821	1809	GPMP	7/1/1992	12/31/1994	NO
Forty Mile Ridge	37.384	-111.033	1433	GSE	M	Present	NO
Big Sage	37.505	-111.579	1999	GSE	M	Present	NO
Brigham Plains	37.215	-111.903	1719	GSE	M	Present	NO
Buckskin Mountain	37.079	-112.047	1756	GSE	M	Present	NO
Circle Cliffs	37.909	-111.117	1999	GSE	M	Present	NO
Deer Ck. Climate Station	37.848	-111.372	1783	GSE	M	Present	NO
Escalante Office	37.774	-111.616	1804	GSE	M	Present	NO
Four Mile Bench	37.344	-111.678	1878	GSE	M	Present	NO
Lake	37.297	-111.14	2268	GSE	M	Present	NO
Silver Falls	37.736	-111.087	1743	GSE	M	Present	NO
Smoky Mountain	37.202	-111.464	1707	GSE	M	Present	NO
Sunset	37.515	-111.261	1628	GSE	M	Present	NO
Willow Gulch	37.892	-111.469	2085	GSE	M	Present	NO
Barney Res. - Escalante	37.613	-111.421	1680	RAWS	6/1/1991	2/28/1997	NO
Four Springs	36.794	-112.042	2000	RAWS	9/1/1994	Present	NO
Gooseberry - Blanding 22NW	37.817	-109.767	2609	RAWS	5/1/1985	6/30/1985	NO
Houserock	36.564	-111.978	1646	RAWS	9/1/1994	Present	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Kane Gulch - Blanding 23WSW	37.526	-109.894	2012	RAWS	6/1/1991	Present	NO
North Long Point	37.855	-109.839	2646	RAWS	8/1/1997	Present	NO
Paria Point	36.728	-111.822	2206	RAWS	9/1/1994	Present	NO
Telegraph Flat - Kanab 17E	37.2	-112.025	1665	RAWS	9/1/1987	Present	NO
Warm Springs Canyon	36.7	-112.23	2442	RAWS	5/1/1986	Present	NO
Kayenta Airport	36.717	-110.233	1741	SAO	6/1/1991	Present	NO
Moab Canyonland AP	38.755	-109.754	1391	SAO	10/2/1964	Present	NO
Page Municipal AP	36.926	-111.448	1314	SAO	4/23/1959	Present	NO
Page	36.9	-111.47	1281	WX4U	M	Present	NO
Grand Canyon National Park (GRCA)							
The Abyss	36.06	-112.182	2073	CASTNet	8/1/1989	Present	YES
Bright Angel R S	36.215	-112.062	2439	COOP	5/1/1925	Present	YES
Grand Canyon Airways	36.05	-112.133	2127	COOP	7/1/1948	6/1/1967	YES
Grand Canyon Hqs.	36.05	-112.133	2102	COOP	9/1/1903	8/31/1957	YES
Grand Canyon NP	36.05	-112.133	2120	COOP	8/1/1957	5/31/1977	YES
Grand Canyon NP 2	36.053	-112.15	2069	COOP	5/1/1976	Present	YES
North Rim Check Stn	36.333	-112.117	2697	COOP	6/1/1950	5/31/1975	YES
Phantom Ranch	36.138	-112.096	783	COOP	6/1/1935	Present	YES
Tuweep	36.286	-113.064	1456	COOP	6/1/1941	Present	YES
The Abyss	36.06	-112.182	2073	GPMP	8/1/1989	3/31/1995	YES
Bright Angel	36.217	-112.067	2561	NRCS-SC	1/1/1947	Present	YES
Grand Canyon	35.967	-111.967	2287	NRCS-SC	1/1/1947	Present	YES
Tuweep	36.283	-113.096	1433	POMS	5/1/2003	Present	YES
Bright Angel	36.205	-112.062	2480	RAWS	6/1/1995	Present	YES
Lindbergh Hill	36.286	-112.079	2683	RAWS	7/1/1992	Present	YES
Grand Canyon	36.05	-112.133	2126	SAO	5/1/1935	9/16/1967	YES
Lake Mead City	35.962	-114.092	1028	CCRFCD	M	Present	NO
Meadview	36.002	-114.006	910	CCRFCD	M	Present	NO
Big Springs R S	36.6	-112.333	2013	COOP	1/1/1931	8/31/1948	NO
Big Water	37.077	-111.664	1250	COOP	8/1/1962	Present	NO
Buffalo Ranch	36.467	-111.95	1727	COOP	7/23/1959	7/31/1962	NO
Cameron 1 NNE	35.883	-111.4	1270	COOP	5/1/1962	9/20/1992	NO
Cedar Ridge Trading	36.383	-111.517	1806	COOP	6/1/1962	3/1/1967	NO
Church Wells	37.1	-111.767	1378	COOP	10/1/1975	2/28/1986	NO
Copper Mine Trading	36.633	-111.417	1947	COOP	3/13/1939	3/17/1977	NO
Diamond Bar Ranch	35.883	-114	1098	COOP	7/1/1952	7/31/1956	NO
Frazier Well 4 NE	35.833	-113.033	2002	COOP	10/1/1950	7/31/1976	NO
Fraziers Well	35.783	-113.067	1830	COOP	4/1/1940	10/31/1944	NO
Glen Canyon Dam	36.936	-111.481	1155	COOP	1/1/2000	Present	NO
Grand Canyon 23 SW	35.806	-112.428	1663	COOP	1/1/2000	Present	NO
Gray Mtn Trading Post	35.733	-111.483	1498	COOP	8/1/1956	4/30/1962	NO
House Rock	36.733	-112.05	1641	COOP	7/1/1948	7/31/1958	NO
Jacob Lake	36.733	-112.217	2386	COOP	8/1/1916	10/31/1987	NO
Kaibito	36.6	-111.083	1830	COOP	7/1/1950	2/28/1961	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Lees Ferry	36.864	-111.602	979	COOP	4/1/1916	Present	NO
Meadview 1 SE	36.003	-114.051	976	COOP	10/1/1996	Present	NO
Mount Trumbull	36.417	-113.35	1709	COOP	10/1/1919	6/30/1978	NO
Page	36.921	-111.448	1302	COOP	10/1/1957	Present	NO
Paria Ranger Station	37.105	-111.9	1341	COOP	12/1/1998	Present	NO
Peach Springs	35.541	-113.424	1473	COOP	7/1/1948	Present	NO
Pierce Ferry	36.117	-114	418	COOP	10/1/1948	6/30/1952	NO
Pierce Ferry 17 SSW	35.883	-114.083	1176	COOP	6/1/1963	8/1/1984	NO
Ryan Station	36.683	-112.35	1923	COOP	11/1/1920	7/31/1955	NO
Supai	36.2	-112.7	977	COOP	9/1/1899	6/1/1987	NO
Temple Bar	36.03	-114.329	390	COOP	12/1/1987	Present	NO
Tuba City 30 SW	35.917	-111.717	2194	COOP	1/1/1966	10/31/1974	NO
Valle	35.65	-112.2	1796	COOP	5/16/1957	6/16/1965	NO
Valle Airport	35.667	-112.15	1830	COOP	8/15/1947	Present	NO
Wahweap	36.995	-111.491	1137	COOP	5/1/1961	Present	NO
Colorado – Lk. Powell G	36.939	-111.481	1155	CRBFC	M	Present	NO
CW1122 Page	36.905	-111.473	1280	CWOP	M	Present	NO
CW5798 Big Water	37.063	-111.644	1250	CWOP	M	Present	NO
Buckskin Mountain	37.079	-112.047	1756	GSE	M	Present	NO
Grand Bench	37.136	-111.216	1439	GSE	M	Present	NO
Meadview	36.019	-114.069	881	POMS	5/1/2003	Present	NO
Ariz. Strip Portable L1	36.15	-113.7	1829	RAWS	7/1/1987	6/30/1990	NO
Dry Park	36.45	-112.24	2654	RAWS	5/1/1996	Present	NO
Four Springs	36.794	-112.042	2000	RAWS	9/1/1994	Present	NO
Frazier Wells	35.846	-113.055	2064	RAWS	11/1/1999	Present	NO
Gunsight	36.704	-112.583	1610	RAWS	9/1/1994	Present	NO
Houserock	36.564	-111.978	1646	RAWS	9/1/1994	Present	NO
Hurricane	36.699	-113.207	1660	RAWS	9/1/1994	Present	NO
Mount Logan	36.347	-113.199	2195	RAWS	1/1/1985	Present	NO
Music Mountain Arizona	35.615	-113.794	1652	RAWS	3/1/1996	Present	NO
Nixon Flats	36.39	-113.152	1982	RAWS	1/1/1992	Present	NO
Olaf Knolls	36.507	-113.816	884	RAWS	5/1/1985	Present	NO
Paria Point	36.728	-111.822	2206	RAWS	9/1/1994	Present	NO
Robinson Tank	36.471	-112.841	1695	RAWS	4/1/1986	Present	NO
Telegraph Flat – Kanab 17E	37.2	-112.025	1665	RAWS	9/1/1987	Present	NO
Truxton Canyon	35.783	-113.794	1631	RAWS	8/1/2002	Present	NO
Tusayan	35.99	-112.12	2043	RAWS	1/1/1986	Present	NO
Twin West	36.101	-113.634	1810	RAWS	5/1/1999	Present	NO
Warm Springs Canyon	36.7	-112.23	2442	RAWS	5/1/1986	Present	NO
Yellow John Mtn.	36.154	-113.542	1878	RAWS	12/1/1987	Present	NO
Grand Canyon NP Arpt.	35.946	-112.155	2014	SAO	10/1/1965	Present	NO
Page Municipal Airport	36.926	-111.448	1314	SAO	4/23/1959	Present	NO
Valle Airport	35.65	-112.167	1830	SAO	8/1/1947	9/30/1965	NO
Pierces Ferry	36.033	-114.2	869	WBAN	6/1/1936	10/31/1937	NO
Page	36.9	-111.47	1281	WX4U	M	Present	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Mesa Verde National Park (MEVE)							
Mesa Verde NP	37.198	-108.49	2166	CASTNet	4/1/1993	Present	YES
Mesa Verde NP	37.199	-108.488	2169	COOP	2/16/1922	Present	YES
Mesa Verde NP	37.199	-108.488	2155	CRBFC	M	Present	YES
Cortez 8 SE	37.255	-108.503	2449	CRN	M	M	YES
Mesa Verde	37.198	-108.49	2166	GPMP	4/1/1993	10/31/1994	YES
Chapin	37.199	-108.489	1886	RAWS	9/1/1999	Present	YES
Morefield	37.301	-108.413	2384	RAWS	11/1/1999	Present	YES
Cortez	37.344	-108.593	1876	COOP	4/1/1911	Present	NO
Dolores	37.475	-108.498	2119	COOP	10/1/1908	12/16/2004	NO
Fort Lewis	37.234	-108.05	2317	COOP	1/1/1915	Present	NO
Kline 3W	37.117	-108.183	2020	COOP	7/1/1941	6/30/1949	NO
Mancos	37.335	-108.316	2114	COOP	11/1/1898	Present	NO
Cortez	37.367	-108.55	1875	CRBFC	M	Present	NO
CW3195 Pleasant View	37.623	-108.708	2177	CWOP	M	Present	NO
La Plata	37.417	-108.05	2848	NRCS-SC	1/1/1950	Present	NO
Mancos T-Down	37.433	-108.167	3049	NRCS-SC	1/1/1975	Present	NO
Logchute	37.352	-107.915	2515	RAWS	8/1/2001	10/31/2002	NO
Salter	37.651	-108.536	2485	RAWS	4/1/1990	Present	NO
Cortez Montezuma Co. Arpt.	37.303	-108.628	1803	SAO	8/1/1949	Present	NO
Columbus Basin	37.433	-108.017	3288	SNOTEL	10/1/1994	Present	NO
Navajo National Monument (NAVA)							
Betatakin	36.678	-110.541	2221	COOP	3/1/1939	Present	YES
Cow Springs Trading	36.417	-110.85	1739	COOP	5/1/1965	5/18/1970	NO
Kaibito	36.6	-111.083	1830	COOP	7/1/1950	2/28/1961	NO
Kayenta	36.733	-110.283	1739	COOP	6/2/1915	10/31/1978	NO
Kayenta 21 SSW	36.45	-110.4	1989	COOP	12/1/1972	7/17/1975	NO
Marsh Pass	36.617	-110.467	2008	COOP	12/1/1952	3/31/1973	NO
Monument Valley	36.982	-110.111	1696	COOP	9/1/1980	Present	NO
Monument Valley Goul	37.017	-110.2	1598	COOP	5/1/1956	10/10/1996	NO
Monument Vly Mission	37.017	-110.217	1616	COOP	8/1/1961	4/1/1991	NO
Navajo Mountain	37.017	-110.8	1837	COOP	11/1/1956	6/11/1975	NO
Rainbow Lodge	37	-110.9	1962	COOP	5/1/1952	3/31/1954	NO
Tonalea	36.333	-110.95	1681	COOP	9/1/1939	2/28/1952	NO
Kayenta Airport	36.717	-110.233	1740	SAO	6/1/1991	Present	NO
Rainbow Bridge National Monument (RABR)							
Escalante River Mouth	37.317	-110.9	1220	COOP	4/1/1951	10/31/1955	YES
Forty Mile Dance Hall	37.367	-111.083	1327	COOP	6/1/1954	9/30/1976	NO
Navajo Mountain	37.017	-110.8	1837	COOP	11/1/1956	6/11/1975	NO
Rainbow Lodge	37	-110.9	1962	COOP	5/1/1952	3/31/1954	NO
Forty Mile Ridge	37.384	-111.033	1433	GSE	M	Present	NO
Grand Bench	37.136	-111.216	1439	GSE	M	Present	NO
Lake	37.297	-111.14	2268	GSE	M	Present	NO
Yucca House National Monument (YUHO)							

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Mesa Verde NP	37.198	-108.49	2166	CASTNet	4/1/1993	Present	NO
Dolores	37.475	-108.498	2119	COOP	10/1/1908	12/16/2004	NO
Hovenweep NM	37.386	-109.075	1588	COOP	4/2/1957	Present	NO
Mancos	37.335	-108.316	2114	COOP	11/1/1898	Present	NO
Mesa Verde NP	37.199	-108.488	2169	COOP	2/16/1922	Present	NO
Pleasant View 1 W	37.588	-108.784	2091	COOP	8/1/1950	Present	NO
Yellow Jacket 2 W	37.521	-108.756	2091	COOP	5/1/1962	12/5/2002	NO
Yellow Jacket 4 NE	37.556	-108.664	2158	COOP	2/1/2003	Present	NO
Cortez	37.367	-108.55	1875	CRBFC	M	Present	NO
Mesa Verde NP	37.199	-108.488	2155	CRBFC	M	Present	NO
Cortez 8 SE	37.255	-108.503	2449	CRN	M	M	NO
CW3195 Pleasant View	37.623	-108.708	2177	CWOP	M	Present	NO
Mesa Verde	37.198	-108.49	2166	GPMP	4/1/1993	10/31/1994	NO
Chapin	37.199	-108.489	1886	RAWS	9/1/1999	Present	NO
Morefield	37.301	-108.413	2384	RAWS	11/1/1999	Present	NO
Cortez Montezuma Co. Arpt.	37.303	-108.628	1803	SAO	8/1/1949	Present	NO

4.2.2. North-central Arizona

The greatest concentrations of weather and climate stations for the park units in north-central Arizona are found for the park units near Flagstaff (Figure 4.2; Table 4.4). Away from Flagstaff, the coverage of weather and climate stations drops off markedly; most of these stations are located near primary roadways.

Hubbell Trading Post National Historic Site (HUTR) is one of the park units in north-central Arizona with relatively sparse weather/climate station coverage. There are currently seven active weather/climate stations within 40 km of HUTR (Table 4.4). Four of these are COOP stations, two are NRCS-SC stations, and one is a RAWS station. The RAWS station (Piney Hill) is just over 30 km east of HUTR (Figure 4.2) and provides the only near-real-time weather observations in the vicinity of HUTR. There are no weather/climate stations inside the boundaries of HUTR (Table 4.4). The closest station to HUTR is the COOP station at Ganado. This station has been in operation since 1929 (Table 4.4). A two-month data gap occurred at Ganado in October-November, 1977. One-month gaps have occurred in December, 1983; March, 1986; and January, 1987. There are three periods during which there were no observations on weekends at the Ganado site. These three periods were 1978-1981, 1986-1990, and 1996-present.

Like HUTR, Petrified Forest National Park (PEFO) is also located in the eastern portions of north-central Arizona that have relatively sparse weather/climate station coverage (Figure 4.2). Unlike HUTR, however, there are a few active stations within the boundaries of PEFO (Figure 4.2; Table 4.4). These include one CASTNet station and two COOP stations. The CASTNet station has been active since 2002 and provides the only automated weather observations inside PEFO. There are no other automated stations near PEFO. Of the two COOP stations in PEFO, “Petrified Forest N P” has the longer period of record, going back to 1948 (Table 4.4), and its data record is very reliable. Outside of PEFO, the COOP station at Snowflake has been active

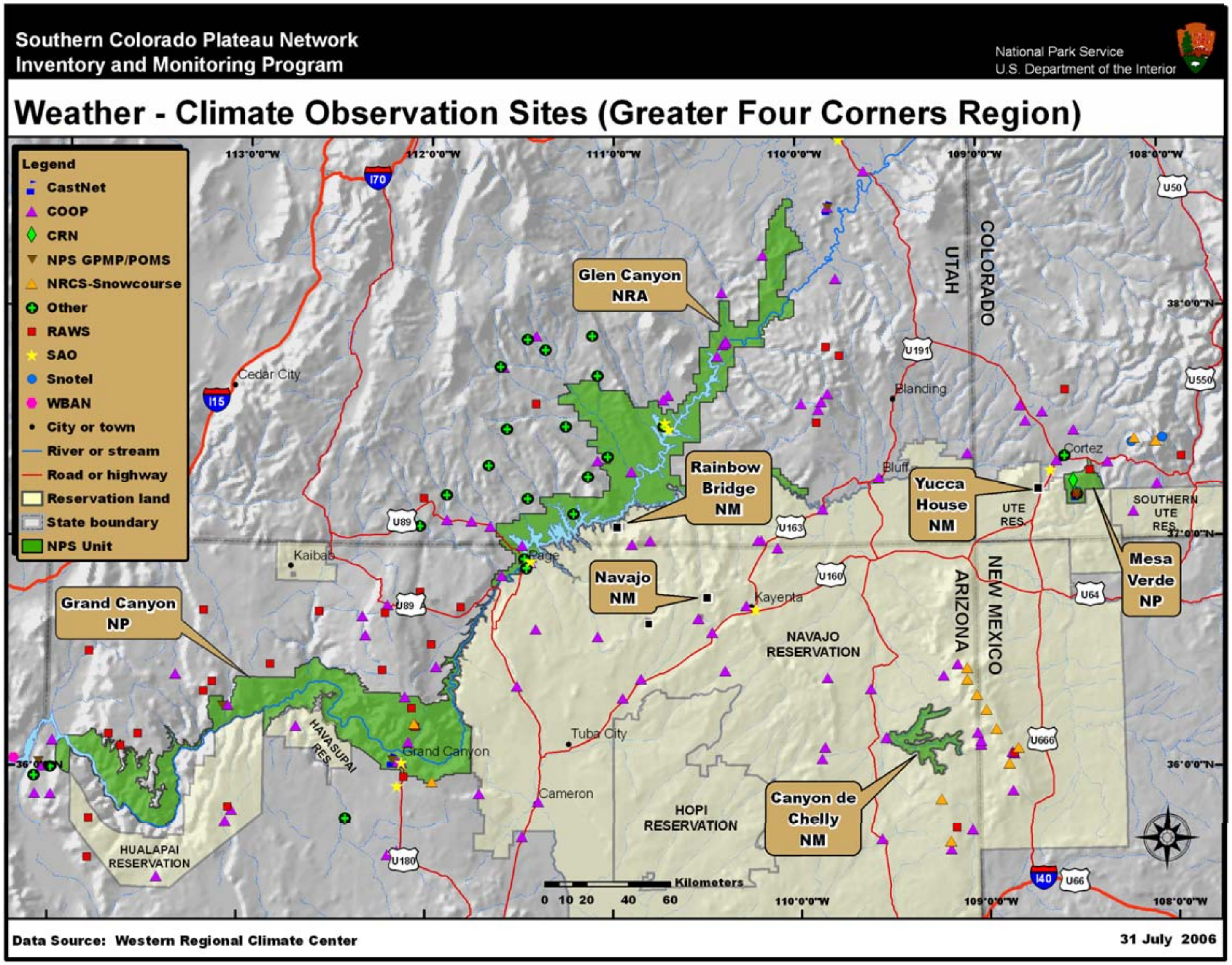


Figure 4.1. Station locations for SCPN park units in the greater Four Corners region.

since 1897 (Table 4.4) and despite early data gaps, (the latest gap being from September, 1966 to January, 1967) this station has provided a reliable data record over the last few decades.

Sunset Crater National Monument (SUCR) has no weather/climate stations inside its park boundaries. A COOP station (Sunset Crater NM) is located just west of the park unit, near the main entrance. This station has been active since 1969 (Table 4.4) and has a very complete data record. Useful long-term climate records can be found from the COOP station at Wupatki National Monument (WUPA), about 20 km north of SUCR. This station (Wupatki NM) has been active since 1940 and its data record is quite complete with the exception of a data gap in May-June of 2005. The COOP stations around Flagstaff provide the longest periods of record within 40 km of SUCR, with some stations operating since the 1890s. Besides the SNOTEL station at Snowslide Canyon, which is 20 km northwest of SUCR, the closest near-real-time weather observations are well south of SUCR. Of these, the closest station is the SAO site “Flagstaff Pulliam Airport”, about 30 km southwest of SUCR. This station has been in operation since 1950 (Table 4.4) and has reliable data.

One weather/climate station is currently active within Walnut Canyon National Monument (WACA). This is a COOP station (Walnut Canyon NM) that has been in operation since 1910 yet the data are only reliable since March, 2003. The closest reliable long-term climate records are to be found at the SAO site “Flagstaff Pulliam Airport”, about 10 km west of the park unit (Figure 4.2). Besides this SAO site and the AZMET and RAWS sites in Flagstaff, most of the other sources for automated weather observations come from stations that are well south of WACA (Figure 4.2). The RAWS stations at Mormon Lake and Oak Creek have data records starting in the 1990s. The SNOTEL stations at Fry and Mormon Mountain both have data records starting in 1982 (Table 4.4)

The only station that is currently active within WUPA is the previously-discussed COOP station “Wupatki NM” (Table 4.4). The nearest automated measurements come from the SNOTEL station “Snowslide Canyon”, which is about 10 km west of WUPA (Figure 4.2) and has been active since 1997 (Table 4.4).

Table 4.4. Weather/climate stations for SCPN park units in north-central Arizona. Stations inside park units and within 40 km of the park unit boundary are included. Each listing includes station name, location, and elevation; weather/climate network associated with station; operational start/end dates for station; and flag to indicate if station is located inside park boundaries. Missing entries are indicated by “M”.

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Hubbell Trading Post National Historic Site (HUTR)							
Bita Hochee Trading	35.417	-110.083	1800	COOP	1/1/1958	11/19/1965	NO
Chambers	35.202	-109.389	1762	COOP	1/2/2000	Present	NO
Chambers 1 SW	35.183	-109.450	1739	COOP	5/1/1972	5/5/1986	NO
Fluted Rock	35.883	-109.250	2403	COOP	12/1/1951	7/31/1976	NO
Ganado	35.716	-109.566	1932	COOP	2/1/1929	Present	NO
Houck 2 W	35.283	-109.233	1772	COOP	6/1/1957	6/30/1958	NO
Klagetoh	35.500	-109.533	1952	COOP	8/1/1950	11/30/1959	NO
Klagetoh 12 WNW	35.550	-109.700	1981	COOP	11/1/1959	5/30/1993	NO
Navajo	35.133	-109.533	1702	COOP	12/1/1892	10/29/1976	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Painted Desert N P	35.065	-109.781	1756	COOP	7/1/1973	Present	NO
Pinta	35.050	-109.650	1653	COOP	3/1/1905	4/30/1961	NO
Sanders	35.224	-109.322	1784	COOP	7/1/1949	Present	NO
Sanders 11 ESE	35.167	-109.167	1905	COOP	4/1/1961	8/31/1986	NO
St Michaels 6 WNW	35.667	-109.200	2330	COOP	1/1/1906	7/31/1976	NO
Window Rock 4 SW	35.617	-109.124	2109	COOP	3/1/1937	9/21/1999	NO
Petrified Forest	35.077	-109.770	1755	GPMP	4/1/1987	1/31/1992	NO
Arbabs Forest	35.700	-109.200	2341	NRCS-SC	1/1/1985	Present	NO
Fluted Rock	35.883	-109.250	2377	NRCS-SC	1/1/1985	Present	NO
Piney Hill	35.761	-109.168	2469	RAWS	11/1/2003	Present	NO
Holbrook	34.950	-110.033	1601	WBAN	2/1/1931	9/30/1933	NO
Petrified Forest National Park (PEFO)							
Petrified Forest NP	34.823	-109.892	1723	CASTNet	10/1/2002	Present	YES
Painted Desert N P	35.065	-109.781	1756	COOP	7/1/1973	Present	YES
Pinta	35.050	-109.650	1653	COOP	3/1/1956	4/30/1961	YES
Petrified Forest N P	34.799	-109.885	1660	COOP	7/1/1948	Present	YES
Petrified Forest	35.077	-109.770	1755	GPMP	4/1/1987	1/31/1992	YES
Bita Hochee Trading	35.417	-110.083	1800	COOP	1/1/1958	11/19/1965	NO
Chambers	35.202	-109.389	1762	COOP	1/2/2000	Present	NO
Chambers 1 SW	35.183	-109.450	1739	COOP	5/1/1972	5/5/1986	NO
Fluted Rock	35.883	-109.250	2403	COOP	12/1/1951	7/31/1976	NO
Ganado	35.716	-109.566	1932	COOP	2/1/1929	Present	NO
Houck 2 W	35.283	-109.233	1772	COOP	6/1/1957	6/30/1958	NO
Klagetoh	35.500	-109.533	1952	COOP	8/1/1950	11/30/1959	NO
Klagetoh 12 WNW	35.550	-109.700	1981	COOP	11/1/1959	5/30/1993	NO
Navajo	35.133	-109.533	1702	COOP	12/1/1892	10/29/1976	NO
Sanders	35.224	-109.322	1784	COOP	7/1/1949	Present	NO
Sanders 11 ESE	35.167	-109.167	1905	COOP	4/1/1961	8/31/1986	NO
Snowflake	34.508	-110.084	1720	COOP	6/1/1897	Present	NO
St Michaels 6 WNW	35.667	-109.200	2330	COOP	1/1/1906	7/31/1976	NO
Window Rock 4 SW	35.617	-109.124	2109	COOP	3/1/1937	9/21/1999	NO
Woodruff	34.783	-110.050	1565	COOP	9/1/1972	5/5/1986	NO
CW3239 Snowflake	34.509	-109.904	1769	CWOP	M	Present	NO
CW3356 Snowflake	34.498	-110.074	1707	CWOP	M	Present	NO
Arbabs Forest	35.700	-109.200	2341	NRCS-SC	1/1/1985	Present	NO
Fluted Rock	35.883	-109.250	2377	NRCS-SC	1/1/1985	Present	NO
Piney Hill	35.761	-109.168	2469	RAWS	11/1/2003	Present	NO
Holbrook	34.950	-110.033	1601	WBAN	2/1/1931	9/30/1933	NO
Sunset Creek National Monument (SUCR)							
Bellemont NWFO	35.230	-111.821	2180	COOP	11/1/1999	Present	NO
Burrus Ranch	35.267	-111.533	2074	COOP	10/24/1943	7/10/1969	NO
Cameron 1 NNE	35.883	-111.400	1269	COOP	5/1/1962	9/20/1992	NO
Flagstaff 4 SW	35.161	-111.731	2172	COOP	5/1/1984	Present	NO
Flagstaff 9 NNW	35.333	-111.667	3536	COOP	12/9/1980	Present	NO
Flagstaff Pulliam Airport	35.144	-111.666	2135	COOP	1/1/1893	Present	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Flagstaff WB City	35.200	-111.667	2110	COOP	9/10/1898	4/30/1951	NO
Fort Valley	35.268	-111.743	2239	COOP	1/1/1909	Present	NO
Gray Mtn. Trading Post	35.733	-111.483	1498	COOP	8/1/1956	4/30/1962	NO
Inner Basin	35.333	-111.650	2998	COOP	7/1/1948	9/30/1976	NO
Inner Basin 2	35.333	-111.667	3050	COOP	12/1/1967	9/30/1976	NO
Maine	35.150	-111.933	2071	COOP	11/1/1933	6/30/1948	NO
Mormon Lake R S	34.917	-111.450	2190	COOP	8/1/1916	4/21/1969	NO
Mormon Mountain	34.933	-111.533	2288	COOP	10/1/1962	12/31/1979	NO
Mund's Park	34.936	-111.639	1972	COOP	6/1/1986	Present	NO
Oak Creek Canyon	34.964	-111.761	1547	COOP	3/1/1935	Present	NO
Sedona	34.896	-111.764	1286	COOP	10/20/1943	Present	NO
Snow Bowl	35.333	-111.700	2974	COOP	7/1/1948	11/30/1967	NO
Sunset Crater NM	35.369	-111.544	2128	COOP	12/1/1969	Present	NO
Walnut Canyon NM	35.171	-111.507	2038	COOP	10/1/1910	Present	NO
Wupatki NM	35.525	-111.370	1496	COOP	1/1/1940	Present	NO
Flagstaff Airport	35.134	-111.676	2134	CRBFC	M	Present	NO
CW4321 Sedona	34.870	-111.801	1378	CWOP	M	Present	NO
Flagstaff	35.220	-111.820	2159	GPS-MET	M	Present	NO
Bear Paw	35.350	-111.650	3078	NRCS-SC	1/1/1968	Present	NO
Fort Valley	35.267	-111.750	2240	NRCS-SC	1/1/1947	Present	NO
Lake Mary	35.017	-111.450	2112	NRCS-SC	1/1/1975	Present	NO
Mormon Mtn. Summit #2	34.967	-111.517	2582	NRCS-SC	1/1/1975	Present	NO
Newman Park	35.000	-111.683	2057	NRCS-SC	1/1/1963	Present	NO
Snow Bowl #1 Alt.	35.333	-111.700	3024	NRCS-SC	1/1/1984	Present	NO
Snow Bowl #2	35.333	-111.700	3414	NRCS-SC	1/1/1965	Present	NO
Snowslide Canyon	35.350	-111.650	2972	NRCS-SC	1/1/1968	Present	NO
Coconini Micro #2	35.032	-111.904	M	RAWS	6/1/1995	1/31/1996	NO
Coconino Micro #1	35.145	-111.675	1372	RAWS	6/1/1995	1/31/1996	NO
Flagstaff	35.145	-111.675	2134	RAWS	1/1/1986	Present	NO
Mormon Lake	34.907	-111.445	2256	RAWS	10/1/1996	Present	NO
Oak Creek	34.942	-111.752	1501	RAWS	12/1/1992	Present	NO
Flagstaff Pulliam Airport	35.144	-111.666	2135	SAO	1/1/1950	Present	NO
Fry	35.067	-111.850	2195	SNOTEL	10/1/1982	Present	NO
Mormon Mountain	34.933	-111.517	2286	SNOTEL	10/1/1982	Present	NO
Snowslide Canyon	35.567	-111.650	2966	SNOTEL	10/1/1997	Present	NO
Aspen Trails Subdivision	35.130	-111.670	2135	WX4U	M	Present	NO
Walnut Canyon National Monument (WACA)							
Walnut Canyon NM	35.171	-111.507	2038	COOP	10/1/1910	Present	YES
Flagstaff	35.210	-111.579	2056	AZMET	M	Present	NO
Bellemont NWFO	35.230	-111.821	2180	COOP	11/1/1999	Present	NO
Burrus Ranch	35.267	-111.533	2074	COOP	10/24/1943	7/10/1969	NO
Cameron 1 NNE	35.883	-111.400	1269	COOP	5/1/1962	9/20/1992	NO
Flagstaff 4 SW	35.161	-111.731	2172	COOP	5/1/1984	Present	NO
Flagstaff 9 NNW	35.333	-111.667	3536	COOP	12/9/1980	Present	NO
Flagstaff Pulliam Airport	35.144	-111.666	2135	COOP	1/1/1893	Present	NO
Flagstaff WB City	35.200	-111.667	2110	COOP	9/10/1898	4/30/1951	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Fort Valley	35.268	-111.743	2239	COOP	1/1/1909	Present	NO
Gray Mtn. Trading Post	35.733	-111.483	1498	COOP	8/1/1956	4/30/1962	NO
Inner Basin	35.333	-111.650	2998	COOP	7/1/1948	9/30/1976	NO
Inner Basin 2	35.333	-111.667	3050	COOP	12/1/1967	9/30/1976	NO
Maine	35.150	-111.933	2071	COOP	11/1/1933	6/30/1948	NO
Mormon Lake R S	34.917	-111.450	2190	COOP	8/1/1916	4/21/1969	NO
Mormon Mountain	34.933	-111.533	2288	COOP	10/1/1962	12/31/1979	NO
Mund's Park	34.936	-111.639	1972	COOP	6/1/1986	Present	NO
Oak Creek Canyon	34.964	-111.761	1547	COOP	3/1/1935	Present	NO
Sedona	34.896	-111.764	1286	COOP	10/20/1943	Present	NO
Snow Bowl	35.333	-111.700	2974	COOP	7/1/1948	11/30/1967	NO
Sunset Crater NM	35.369	-111.544	2128	COOP	7/1/1969	Present	NO
Wupatki NM	35.525	-111.370	1496	COOP	1/1/1940	Present	NO
Flagstaff Airport	35.134	-111.676	2134	CRBFC	M	Present	NO
CW4321 Sedona	34.870	-111.801	1378	CWOP	M	Present	NO
Flagstaff	35.220	-111.820	2159	GPS-MET	M	Present	NO
Bear Paw	35.350	-111.650	3078	NRCS-SC	1/1/1968	Present	NO
Fort Valley	35.267	-111.750	2240	NRCS-SC	1/1/1947	Present	NO
Lake Mary	35.017	-111.450	2112	NRCS-SC	1/1/1975	Present	NO
Mormon Mtn. Summit #2	34.967	-111.517	2582	NRCS-SC	1/1/1975	Present	NO
Newman Park	35.000	-111.683	2057	NRCS-SC	1/1/1963	Present	NO
Snow Bowl #1 Alt.	35.333	-111.700	3024	NRCS-SC	1/1/1984	Present	NO
Snow Bowl #2	35.333	-111.700	3414	NRCS-SC	1/1/1965	Present	NO
Snowslide Canyon	35.350	-111.650	2972	NRCS-SC	1/1/1968	Present	NO
Coconini Micro #2	35.032	-111.904	M	RAWS	6/1/1995	1/31/1996	NO
Coconino Micro #1	35.145	-111.675	1372	RAWS	6/1/1995	1/31/1996	NO
Flagstaff	35.145	-111.675	2134	RAWS	1/1/1986	Present	NO
Mormon Lake	34.907	-111.445	2256	RAWS	10/1/1996	Present	NO
Oak Creek	34.942	-111.752	1501	RAWS	12/1/1992	Present	NO
Flagstaff Pulliam Airport	35.144	-111.666	2135	SAO	1/1/1950	Present	NO
Fry	35.067	-111.850	2195	SNOTEL	10/1/1982	Present	NO
Mormon Mountain	34.933	-111.517	2286	SNOTEL	10/1/1982	Present	NO
Snowslide Canyon	35.567	-111.650	2966	SNOTEL	10/1/1997	Present	NO
Aspen Trails Subdivision	35.130	-111.670	2135	WX4U	M	Present	NO
Wupatki National Monument (WUPA)							
Wupatki NM	35.525	-111.370	1496	COOP	1/1/1940	Present	YES
Flagstaff	35.210	-111.579	2056	AZMET	M	Present	NO
Bellemont NWFO	35.230	-111.821	2180	COOP	11/1/1999	Present	NO
Burrus Ranch	35.267	-111.533	2074	COOP	10/24/1943	7/10/1969	NO
Cameron 1 NNE	35.883	-111.400	1269	COOP	5/1/1962	9/20/1992	NO
Flagstaff 4 SW	35.161	-111.731	2172	COOP	5/1/1984	Present	NO
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Flagstaff Pulliam Airport	35.144	-111.666	2135	COOP	1/1/1893	Present	NO
Flagstaff WB City	35.200	-111.667	2110	COOP	9/10/1898	4/30/1951	NO
Fort Valley	35.268	-111.743	2239	COOP	1/1/1909	Present	NO
Gray Mtn. Trading Post	35.733	-111.483	1498	COOP	8/1/1956	4/30/1962	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Inner Basin	35.333	-111.650	2998	COOP	7/1/1948	9/30/1976	NO
Inner Basin 2	35.333	-111.667	3050	COOP	12/1/1967	9/30/1976	NO
Maine	35.150	-111.933	2071	COOP	11/1/1933	6/30/1948	NO
Mormon Lake R S	34.917	-111.450	2190	COOP	8/1/1916	4/21/1969	NO
Mormon Mountain	34.933	-111.533	2288	COOP	10/1/1962	12/31/1979	NO
Mund's Park	34.936	-111.639	1972	COOP	6/1/1986	Present	NO
Oak Creek Canyon	34.964	-111.761	1547	COOP	3/1/1935	Present	NO
Sedona	34.896	-111.764	1286	COOP	10/20/1943	Present	NO
Snow Bowl	35.333	-111.700	2974	COOP	7/1/1948	11/30/1967	NO
Sunset Crater NM	35.369	-111.544	2128	COOP	7/1/1969	Present	NO
Walnut Canyon NM	35.171	-111.507	2038	COOP	10/1/1910	Present	NO
Flagstaff Airport	35.134	-111.676	2134	CRBFC	M	Present	NO
CW4321 Sedona	34.870	-111.801	1378	CWOP	M	Present	NO
Flagstaff	35.220	-111.820	2159	GPS-MET	M	Present	NO
Bear Paw	35.350	-111.650	3078	NRCS-SC	1/1/1968	Present	NO
Fort Valley	35.267	-111.750	2240	NRCS-SC	1/1/1947	Present	NO
Lake Mary	35.017	-111.450	2112	NRCS-SC	1/1/1975	Present	NO
Mormon Mtn. Summit #2	34.967	-111.517	2582	NRCS-SC	1/1/1975	Present	NO
Newman Park	35.000	-111.683	2057	NRCS-SC	1/1/1963	Present	NO
Snow Bowl #1 Alt.	35.333	-111.700	3024	NRCS-SC	1/1/1984	Present	NO
Snow Bowl #2	35.333	-111.700	3414	NRCS-SC	1/1/1965	Present	NO
Snowslide Canyon	35.350	-111.650	2972	NRCS-SC	1/1/1968	Present	NO
Coconini Micro #2	35.032	-111.904	M	RAWS	6/1/1995	1/31/1996	NO
Coconino Micro #1	35.145	-111.675	1372	RAWS	6/1/1995	1/31/1996	NO
Flagstaff	35.145	-111.675	2134	RAWS	1/1/1986	Present	NO
Mormon Lake	34.907	-111.445	2256	RAWS	10/1/1996	Present	NO
Oak Creek	34.942	-111.752	1501	RAWS	12/1/1992	Present	NO
Flagstaff Pulliam Airport	35.144	-111.666	2135	SAO	1/1/1950	Present	NO
Fry	35.067	-111.850	2195	SNOTEL	10/1/1982	Present	NO
Mormon Mountain	34.933	-111.517	2286	SNOTEL	10/1/1982	Present	NO
Snowslide Canyon	35.567	-111.650	2966	SNOTEL	10/1/1997	Present	NO
Aspen Trails Subdivision	35.130	-111.670	2135	WX4U	M	Present	NO

4.2.3. New Mexico

Aztec Ruins National Monument (AZRU) has one station inside its boundaries. This is a COOP station (Aztec Ruins NM) that has been active since 1895 (Table 4.5). Reliable data are available for this station after the 1920s. A few other active COOP stations in the vicinity of AZRU also have been operating since the 1890s (Table 4.5). The SAO site at Farmington Four Corners Regional Airport has provided near-real-time weather data for the AZRU region since 1940 (Table 4.5).

No weather/climate stations were identified inside the boundaries of Bandelier National Monument (BAND; Table 4.5); however, the coverage of weather/climate stations around

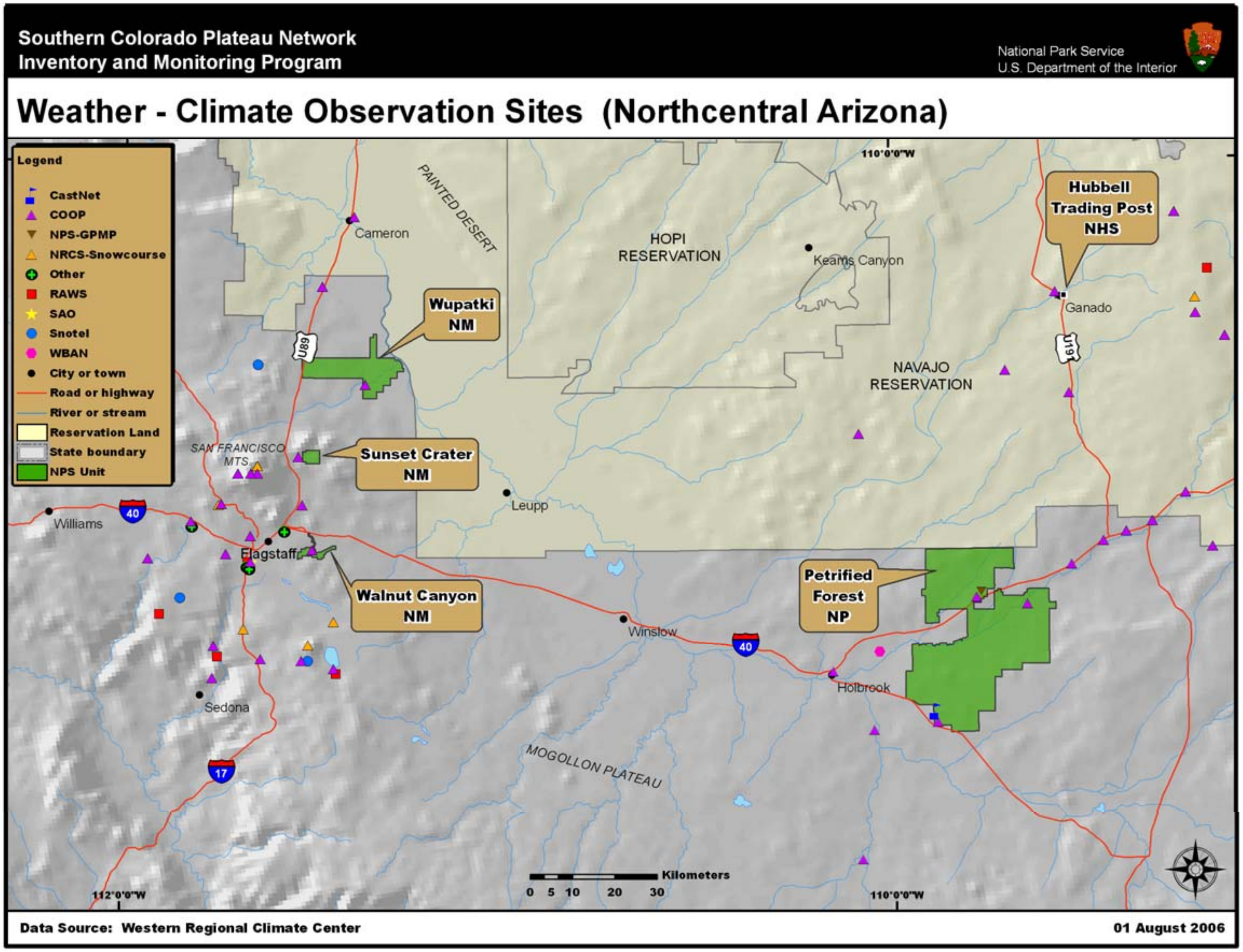

Figure 4.2. Station locations for SCPN park units in north-central Arizona.

BAND is quite dense (Figure 4.3). Of particular note are the relatively numerous RAWS stations (13) and the weather stations associated with the Los Alamos National Laboratory (6) that were identified within 40 km of BAND. Many of these are located on the north side of BAND. A COOP station “Bandelier NM” was in operation between 1924 and 1976, close to the northern boundary of BAND. A few COOP stations within 40 km of BAND provide long data records. The Los Alamos COOP station, just north and east of BAND, has been active since 1902 and has a very reliable data record. There is also a COOP station in Espanola that has operated since 1895, although its data record is not nearly as reliable as the record at Los Alamos. This station has had numerous data gaps in the past 10-15 years. For instance, the most recent gaps occurred in June-September of 1999 and January-September of 2001. Santa Fe County Municipal Airport, about 30 km southeast of BAND, is the closest SAO station to BAND. This SAO station has been active since 1941. A CRN station is located west of Los Alamos. This station started operating in 2004 (Table 4.5).

There is one station currently operating inside Chaco Culture National Historical Park (CHCU). This is a COOP station (Chaco Canyon NM) which has been active since 1909 (Table 4.5). However, the data for this station are only reliable since 1947. There are four automated stations within 40 km of CHCU. These include two RAWS stations (Coyote; Jemez), one SAO station (Star Lake) and one SNOTEL station (Senorita Divide #2). The SAO station has the longest period of record of these stations, as it has been active since 1946 (Table 4.5). In addition to the COOP station inside CHCU, there are a few COOP stations outside but within 40 km of CHCU that have data records going back to the early 1900s.

We have identified two stations within the boundaries of El Malpais National Monument (ELMA; Table 4.5). One of these is a historical COOP site (IX XI Ranch) which was active from 1939 to 1949. The other station is a RAWS station which has been in operation since 1985. Long-term climate records are available from COOP stations outside of ELMA. The COOP station “El Morro NM” is about 30 km west of ELMA (Figure 4.3) and has a very reliable data record that goes back to 1938 (Table 4.5). The only significant data gaps at this station occurred recently, in November, 1999 and February, 2001. The COOP station at Laguna has been active since 1936. Reliable data at Laguna have been available since October, 1947. No weekend observations have been taken, however, since about 1990. We have also observed an increasing number of data gaps at Laguna in the last five years, with the most recent gaps occurring in 2005 for the entire months of May, June, October, and the first half of December. The COOP station “Thoreau” has been active since 1929; however, the data from this station are of uncertain quality. Several NRCS-SC stations are located in the mountains to the north and west of ELMA (Figure 4.3) and have provided snow-depth measurements for the last 1-2 decades (Table 4.5). In addition to the RAWS station that is currently operating inside ELMA, we have identified several RAWS stations within 40 km of ELMA (Figure 4.3; Table 4.5). Of these stations, “Grants” has the longest period of record, extending back to 1986. The SAO site at Grants Milan Municipal Airport is also a useful source for near-real-time measurements in the ELMA vicinity; it has been active since 1953 (Table 4.5).

The only station that is located inside El Morro National Monument (ELMO) is the COOP station “El Morro NM”, which has been discussed previously. There are no automated stations in ELMO. Many of the manual and automated stations that have been identified for ELMA are also relevant for ELMO (see Table 4.5). In particular, the NRCS-SC sites that were previously identified for ELMA provide snow data that is even more relevant for ELMO, due to the closer proximity of ELMO to these sites compared to ELMA.

We have identified one station inside Petroglyph National Monument (PETR). This is a COOP station (Petroglyph NM) that has been active since 1994 (Table 4.5). There are no automated stations inside PETR. Within 40 km of PETR, there are a few COOP stations with long climate records in the Albuquerque vicinity, mostly east of PETR. Albuquerque International Airport is about 20 km southeast of PETR and has made observations since the late 1890s (Table 4.5). The nearby SAO station has been active since 1933. Both of these stations have reliable data. The COOP station “Estancia 4 N” is has been operating since 1904 and has a reliable data record beginning in the late 1920s. However, this site is about 40 km southeast of PETR, near the mountains east of Albuquerque, and thus may not be representative of the climate at PETR. Like “Estancia 4 N”, the COOP station “Las Lunas 3 SSW” is also about 40 km away from PETR, to the south. However, unlike “Estancia 4 N”, this station is located in the Rio Grande valley and thus may experience similar climate conditions to those experienced at PETR. Its climate record extends back to 1923 but its data are most reliable since the mid-1950s. Automated weather observations are provided for PETR by a number of stations in the Albuquerque vicinity. We have identified four SAO stations within 40 km of PETR (Table 4.5). The closest active SAO station to PETR is “Albuq. Double Eagle II AI”, which has an unknown period of record. The SAO station with the longest period of record is at Albuquerque International Airport, discussed previously. There are three RAWS stations that have been identified within 40 km of PETR (Table 4.5); however, these RAWS stations are all located in or near the mountains to the east of Albuquerque (Figure 4.3). At least a dozen CWOP stations in the Albuquerque area are within 40 km of PETR; however, CWOP data are not always consistent in quality and must therefore be used with caution.

Finally, Salinas Pueblo Missions National Monument (SAPU) has one station inside its boundaries. This is a COOP station (Gran Quivira NM) which has been active since 1905 (Table 4.5). The data from this site are reliably available after the late 1940s. Outside of SAPU, there are a few COOP stations that have periods of record that are comparable to “Gran Quivira NM”. The previously discussed station “Estancia 4 N” is located about 20 km north of the northernmost unit of SAPU (see Figure 4.3). The COOP station “Las Lunas 3 SSW” is about 40 km west of SAPU; however, due to its location in the Rio Grande valley, it may not be sufficiently representative of the climate around SAPU. Progresso, a COOP station about 20 km east of SAPU, has been active since 1929 (Table 4.5). This station has a reliable data record but only precipitation is measured. The most reliable automated measurements within 40 km of SAPU are the RAWS station “Mountainaire”, which has been active since 1986, and the SAO station “Corona Lincoln Compressor Stn”, which has been active since 1961.

Table 4.5. Weather/climate stations for SCPN park units in New Mexico. Stations inside park units and within 40 km of the park unit boundary are included. Each listing includes station name, location, and elevation; weather/climate network associated with station; operational start/end dates for station; and flag to indicate if station is located inside park boundaries. Missing entries are indicated by "M".

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Aztec Ruins National Monument (AZRU)							
Aztec Ruins NM	36.835	-108.001	1720	COOP	1/1/1895	Present	YES
Archuleta 1 NE	36.800	-107.700	1731	COOP	1/1/2000	Present	NO
Bloomfield 3 SE	36.667	-107.960	1770	COOP	12/1/1892	Present	NO
Farmington 3	36.717	-108.217	1594	COOP	7/1/1947	12/1/1992	NO
Farmington 4 NE	36.750	-108.167	1647	COOP	2/1/1914	3/31/1978	NO
Farmington Ag Sci Ctr	36.690	-108.309	1714	COOP	5/1/1978	Present	NO
Farmington Four Corners Regl A	36.744	-108.229	1675	COOP	10/1/1941	Present	NO
Fruitland	36.738	-108.348	1564	COOP	1/1/1893	Present	NO
Kline 3W	37.117	-108.183	2019	COOP	7/1/1941	6/30/1949	NO
Navajo Dam	36.805	-107.621	1759	COOP	6/1/1963	Present	NO
Navajo Reservoir	36.808	-107.609	1760	COOP	4/8/1986	Present	NO
Rosa Near	36.883	-107.583	1981	COOP	12/1/1894	12/27/1931	NO
Aztec	36.840	-107.910	1882	GPS-MET	M	Present	NO
Albino Canyon	36.977	-107.628	2012	RAWS	1/1/1985	Present	NO
Mesa Mountain	37.055	-107.707	2249	RAWS	11/1/1993	Present	NO
Durango La Plata Co. Arpt.	37.143	-107.760	2030	SAO	6/1/1947	Present	NO
Farmington Four Corners Regl A	36.744	-108.229	1675	SAO	5/1/1940	Present	NO
Bandelier National Monument (BAND)							
Abiquiu	36.167	-106.183	1800	COOP	10/1/1942	11/30/1949	NO
Alcalde	36.091	-106.057	1731	COOP	4/1/1953	Present	NO
Bandelier NM	35.783	-106.267	1848	COOP	5/1/1924	8/31/1976	NO
Big Tesuque Ski Course	35.783	-105.800	2974	COOP	7/1/1946	11/30/1976	NO
Bland	35.767	-106.467	2256	COOP	4/1/1915	5/31/1923	NO
Buckmans	35.667	-106.117	2591	COOP	8/10/1896	1/25/1899	NO
Chamita Highway Bridge	36.067	-106.117	1723	COOP	6/1/1978	12/1/1992	NO
Cochiti Dam	35.641	-106.332	1695	COOP	2/1/1975	Present	NO
Cundiyo	35.950	-105.900	2100	COOP	4/1/1909	9/30/1923	NO
Espanola	35.988	-106.081	1702	COOP	4/1/1895	Present	NO
Espanola Highway Bridge	35.955	-106.075	1699	COOP	7/1/1947	Present	NO
Jemez Springs	35.778	-106.687	1909	COOP	5/1/1910	Present	NO
La Bajada	35.550	-106.250	M	COOP	9/6/1942	6/30/1948	NO
Lazy Ray Ranch	35.950	-106.667	2492	COOP	6/19/1951	3/31/1954	NO
Lee Ranch	35.833	-106.500	2650	COOP	10/1/1923	9/30/1941	NO
Los Alamos	35.864	-106.321	2263	COOP	1/1/1902	Present	NO
Los Alamos 13 W	35.858	-106.521	2653	COOP	7/31/2004	Present	NO
Nambe 1	35.900	-105.983	1845	COOP	1/30/1893	11/1/1974	NO
Nambe 2	35.883	-105.950	1830	COOP	1/1/1942	11/30/1949	NO
Otowi	35.867	-106.150	1674	COOP	7/1/1947	12/1/1992	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Pena Blanca	35.583	-106.333	1595	COOP	8/1/1958	2/15/1968	NO
Ponderosa	35.667	-106.667	1812	COOP	1/1/1920	4/1/1974	NO
Santa Clara RS	36.000	-106.283	2257	COOP	8/1/1937	10/31/1948	NO
Santa Fe	35.683	-105.900	2196	COOP	10/1/1867	3/21/1972	NO
Santa Fe 2	35.619	-105.975	2059	COOP	4/1/1972	Present	NO
Santa Fe 2 SE	35.683	-105.933	2208	COOP	6/1/1948	9/30/1951	NO
Santa Fe 7 SE	35.543	-105.920	2079	COOP	7/1/1998	Present	NO
Santa Fe Caja D R	35.717	-106.100	1952	COOP	6/1/1948	5/31/1950	NO
Santa Fe Canyon	35.717	-105.800	2560	COOP	1/1/1910	11/27/1928	NO
Santa Fe Co. Municipal AP	35.617	-106.089	1934	COOP	5/27/1941	6/30/1958	NO
Santa Fe Lake	35.783	-105.767	3538	COOP	7/1/1946	11/30/1976	NO
Santa Fe Seton	35.601	-105.932	2134	COOP	1/6/2000	Present	NO
Santa Fe Synoptic	35.667	-105.967	M	COOP	M	Present	NO
Seven Springs Fish Hatchery	35.933	-106.700	2416	COOP	9/1/1943	5/31/1951	NO
Truchas	36.033	-105.817	2449	COOP	4/1/1909	6/30/1962	NO
Turquoise Bonanza Creek	35.550	-106.100	1867	COOP	6/11/1953	3/31/1996	NO
Velarde	36.133	-105.917	1739	COOP	7/1/1942	11/30/1949	NO
Wolf Canyon	35.948	-106.747	2505	COOP	5/1/1912	Present	NO
Woodbury	35.700	-106.383	2012	COOP	2/1/1900	8/31/1902	NO
Los Alamos 13 W	35.858	-106.521	2657	CRN	7/31/2004	Present	NO
CW0410 Los Alamos	35.809	-106.221	1985	CWOP	M	Present	NO
W5VBQ Santa Fe	35.709	-105.921	2218	CWOP	M	Present	NO
Los Alamos Laboratory	35.813	-106.298	2117	GPMP	10/1/1989	12/1/1994	NO
Lanlta54	35.826	-106.223	1996	LANL	M	Present	NO
Lanlta6	35.861	-106.322	2263	LANL	M	Present	NO
Pajarito Mtn.	35.886	-106.395	3158	LANL	M	Present	NO
TA41	35.876	-106.296	2107	LANL	M	Present	NO
TA49	35.813	-106.299	2147	LANL	M	Present	NO
TA53	35.870	-106.221	2131	LANL	M	Present	NO
Elk Cabin	35.700	-105.800	2515	NRCS-SC	1/1/1948	Present	NO
Rio En Medio	35.800	-105.800	3139	NRCS-SC	1/1/1950	Present	NO
Vacas Locas	36.017	-106.800	2836	NRCS-SC	1/1/1996	Present	NO
Coyote	36.067	-106.647	2682	RAWS	8/1/1996	Present	NO
Garcia Canyon	35.945	-106.310	2486	RAWS	6/1/2000	7/31/2004	NO
Guaje	35.922	-106.323	2533	RAWS	6/1/2000	7/31/2004	NO
Jemez	35.841	-106.619	2438	RAWS	5/1/1985	Present	NO
Pajarito	35.874	-106.363	M	RAWS	6/1/2000	6/30/2004	NO
Pueblo Canyon	35.895	-106.344	2591	RAWS	6/1/2000	6/30/2004	NO
Quemazon Canyon	35.926	-106.384	2978	RAWS	6/1/2000	7/31/2004	NO
Santa Clara Canyon	35.997	-106.281	2420	RAWS	6/1/2000	7/31/2004	NO
Taos	35.929	-105.890	2810	RAWS	M	Present	NO
Tower	35.833	-106.333	1981	RAWS	3/1/2000	Present	NO
Upper Los Alamos	35.893	-106.371	2682	RAWS	6/1/2000	6/30/2004	NO
Upper Santa Clara Canyon	35.994	-106.360	3200	RAWS	6/1/2000	7/31/2004	NO
Water Canyon	35.843	-106.372	2484	RAWS	6/1/2000	7/31/2004	NO
Santa Fe Co. Municipal AP	35.617	-106.089	1934	SAO	5/27/1941	Present	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Quemazon	35.917	-106.383	2896	SNOTEL	6/4/1980	Present	NO
Santa Fe	35.767	-105.783	3488	SNOTEL	M	M	NO
Senorita Divide #2	36.000	-106.833	2621	SNOTEL	10/1/1980	Present	NO
Los Alamos	35.883	-106.283	2181	WBAN	6/1/1975	Present	NO
Santa Fe	35.683	-105.950	2138	WBAN	12/1/1889	12/31/1941	NO
Chaco Culture National Historical Park (CHCU)							
Chaco Canyon NM	36.029	-107.911	1882	COOP	12/1/1909	Present	YES
Bluewater 3 WSW	35.250	-108.033	2074	COOP	5/1/1896	9/30/1960	NO
Bluewater Lake	35.300	-108.117	2257	COOP	11/1/1908	4/30/1951	NO
Coolidge	35.483	-108.433	2135	COOP	12/1/1892	6/30/1949	NO
Crownpoint	35.683	-108.150	2123	COOP	7/1/1914	11/13/1969	NO
Hospah	35.733	-107.750	2385	COOP	9/1/1943	6/30/1950	NO
Jemez Springs	35.778	-106.687	1909	COOP	5/1/1910	Present	NO
Lazy Ray Ranch	35.950	-106.667	2492	COOP	6/19/1951	3/31/1954	NO
Lybrook	36.230	-107.547	2179	COOP	5/25/1951	Present	NO
McGaffey RS	35.367	-108.517	2440	COOP	10/1/1911	9/30/1948	NO
McGaffey 5 SE	35.336	-108.445	2438	COOP	1/1/1949	Present	NO
Nageezi	36.267	-107.750	2074	COOP	10/1/1949	5/31/1951	NO
Otero	36.267	-107.383	2013	COOP	11/29/1909	12/31/1957	NO
Otis	36.334	-107.841	2097	COOP	11/1/1905	Present	NO
Pitt Ranch	35.800	-108.017	1970	COOP	11/1/1942	8/6/1968	NO
Ponderosa	35.667	-106.667	1812	COOP	1/1/1920	4/1/1974	NO
Prewitt	35.367	-108.033	2074	COOP	7/1/1944	9/30/1953	NO
San Mateo	35.333	-107.650	2207	COOP	4/1/1918	3/31/1988	NO
Seven Springs Fish Hatchery	35.933	-106.700	2416	COOP	9/1/1943	5/31/1951	NO
Smith Lake	35.517	-108.150	M	COOP	10/1/1945	6/30/1948	NO
Standing Rock	35.833	-108.333	2013	COOP	7/1/1947	7/31/1949	NO
Star Lake	35.925	-107.466	2022	COOP	1/1/1922	Present	NO
Stepp Ranch	35.833	-107.917	2095	COOP	2/1/1969	5/19/1972	NO
Thoreau	35.417	-108.233	2177	COOP	9/1/1929	Present	NO
Thoreau	35.400	-108.217	2166	COOP	7/1/1915	3/31/1938	NO
Thoreau 12 SE	35.300	-108.147	2263	COOP	7/1/1994	Present	NO
Westbrook Ranch	35.933	-108.200	2013	COOP	11/1/1942	9/30/1953	NO
White Horse	35.817	-107.750	2031	COOP	10/1/1968	2/4/1969	NO
Wolf Canyon	35.948	-106.747	2505	COOP	5/1/1912	Present	NO
Boon	35.283	-108.400	2481	NRCS-SC	1/1/1994	Present	NO
McGaffey	35.333	-108.450	2475	NRCS-SC	1/1/1999	Present	NO
Rice Park	35.233	-108.267	2579	NRCS-SC	1/1/1985	Present	NO
Vacas Locas	36.017	-106.800	2836	NRCS-SC	1/1/1996	Present	NO
Coyote	36.067	-106.647	2682	RAWS	8/1/1996	Present	NO
Jemez	35.841	-106.619	2438	RAWS	5/1/1985	Present	NO
Star Lake	35.925	-107.466	2022	SAO	7/1/1946	Present	NO
Senorita Divide #2	36.000	-106.833	2621	SNOTEL	10/1/1980	Present	NO
Crownpoint	35.667	-108.217	2127	WBAN	3/1/1937	12/31/1948	NO
El Malpais National Monument (ELMA)							

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
IX XI Ranch	34.950	-107.933	2135	COOP	12/1/1939	10/31/1949	YES
Malpias Lava Flow	34.900	-108.096	2274	RAWS	5/1/1985	Present	YES
Acomita FAA Airport	35.050	-107.717	2007	COOP	1/1/1941	4/30/1953	NO
Adams Diggings	34.467	-108.300	2397	COOP	5/1/1948	8/31/1951	NO
Bluewater 3 WSW	35.250	-108.033	2074	COOP	5/1/1896	9/30/1960	NO
Bluewater Lake	35.300	-108.117	2257	COOP	11/1/1908	4/30/1951	NO
Cubero	35.088	-107.518	1888	COOP	1/1/1977	Present	NO
Diener	35.183	-108.133	2438	COOP	5/1/1921	7/31/1927	NO
El Morro CAA Airport	35.017	-108.400	2171	COOP	3/1/1940	2/28/1949	NO
El Morro NM	35.038	-108.349	2202	COOP	3/1/1938	Present	NO
Grants	35.167	-107.867	1983	COOP	5/20/1945	12/31/1956	NO
Grants Milan Muni. Airport	35.166	-107.899	1987	COOP	5/1/1953	Present	NO
Hickman	34.517	-107.933	2379	COOP	9/1/1943	3/31/1985	NO
La Mosca Peak	35.250	-107.600	3242	COOP	7/1/1946	11/30/1976	NO
Laguna	35.046	-107.374	1777	COOP	1/1/1936	Present	NO
Marmon Ranch	34.850	-107.450	1769	COOP	9/1/1943	7/31/1950	NO
McGaffey RS	35.367	-108.517	2440	COOP	10/1/1911	9/30/1948	NO
McGaffey 5 SE	35.336	-108.445	2438	COOP	1/1/1949	Present	NO
Pietown 19 NE	34.493	-107.888	2427	COOP	9/1/1988	Present	NO
Prewitt	35.367	-108.033	2074	COOP	7/1/1944	9/30/1953	NO
Ramah	35.133	-108.467	2196	COOP	7/1/1922	6/30/1949	NO
San Fidel 2 E	35.100	-107.600	1879	COOP	5/1/1920	12/31/1976	NO
San Mateo	35.333	-107.650	2207	COOP	4/1/1918	3/31/1988	NO
San Rafael	35.117	-107.883	1981	COOP	1/1/1904	8/31/1915	NO
Slash O E Ranch	34.567	-107.700	1920	COOP	7/1/1942	8/31/1944	NO
Thoreau	35.400	-108.217	2166	COOP	9/1/1929	Present	NO
Thoreau	35.417	-108.233	2177	COOP	7/1/1915	3/31/1938	NO
Thoreau 12 SE	35.300	-108.147	2263	COOP	7/1/1994	Present	NO
Boon	35.283	-108.400	2481	NRCS-SC	1/1/1994	Present	NO
Dan Valley	35.217	-108.433	2329	NRCS-SC	1/1/1994	Present	NO
McGaffey	35.333	-108.450	2475	NRCS-SC	1/1/1999	Present	NO
Ojo Redondo	35.167	-108.183	2499	NRCS-SC	1/1/1982	Present	NO
Post Office Flats	35.167	-108.167	2560	NRCS-SC	1/1/1982	Present	NO
Rice Park	35.233	-108.267	2579	NRCS-SC	1/1/1985	Present	NO
Bluewater Creek	35.223	-108.155	2324	RAWS	6/1/2003	Present	NO
Bluewater Ridge	35.194	-108.163	2526	RAWS	7/1/2003	Present	NO
Brushy Mountain	34.719	-107.848	2671	RAWS	8/1/1992	Present	NO
Grants	35.242	-107.670	2515	RAWS	1/1/1986	Present	NO
Laguna	35.039	-107.373	1760	RAWS	12/1/2004	Present	NO
Ramah	34.995	-108.413	2145	RAWS	12/1/2004	Present	NO
Zuni	35.044	-108.482	1926	RAWS	2/1/2003	5/31/2005	NO
Grants Milan Muni. Airport	35.166	-107.899	1987	SAO	4/1/1953	Present	NO
Rice Park	35.233	-108.267	2579	SNOTEL	9/25/1998	Present	NO
Paxton Springs	35.050	-108.083	2332	WBAN	10/1/1931	6/30/1942	NO
El Morro National Monument (ELMO)							
El Morro NM	35.038	-108.349	2202	COOP	3/1/1938	Present	YES

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Adams Diggings	34.467	-108.300	2397	COOP	5/1/1948	8/31/1951	NO
Black Rock	35.100	-108.783	1967	COOP	6/1/1908	12/3/1974	NO
Bluewater 3 WSW	35.250	-108.033	2074	COOP	5/1/1896	9/30/1960	NO
Bluewater Lake	35.300	-108.117	2257	COOP	11/1/1908	4/30/1951	NO
Diener	35.183	-108.133	2438	COOP	5/1/1921	7/31/1927	NO
El Morro CAA Airport	35.017	-108.400	2171	COOP	3/1/1940	2/28/1949	NO
Grants	35.167	-107.867	1983	COOP	5/20/1945	12/31/1956	NO
Grants Milan Muni. Airport	35.166	-107.899	1987	COOP	5/1/1953	Present	NO
Hickman	34.517	-107.933	2379	COOP	9/1/1943	3/31/1985	NO
IX XI Ranch	34.950	-107.933	2135	COOP	12/1/1939	10/31/1949	NO
McGaffey RS	35.367	-108.517	2440	COOP	10/1/1911	9/30/1948	NO
McGaffey 5 SE	35.336	-108.445	2438	COOP	1/1/1949	Present	NO
Prewitt	35.367	-108.033	2074	COOP	7/1/1944	9/30/1953	NO
Ramah	35.133	-108.467	2196	COOP	7/1/1922	6/30/1949	NO
Thoreau	35.400	-108.217	2166	COOP	9/1/1929	Present	NO
Thoreau	35.417	-108.233	2177	COOP	7/1/1915	3/31/1938	NO
Thoreau 12 SE	35.300	-108.147	2263	COOP	7/1/1994	Present	NO
Boon	35.283	-108.400	2481	NRCS-SC	1/1/1994	Present	NO
Dan Valley	35.217	-108.433	2329	NRCS-SC	1/1/1994	Present	NO
McGaffey	35.333	-108.450	2475	NRCS-SC	1/1/1999	Present	NO
Ojo Redondo	35.167	-108.183	2499	NRCS-SC	1/1/1982	Present	NO
Post Office Flats	35.167	-108.167	2560	NRCS-SC	1/1/1982	Present	NO
Rice Park	35.233	-108.267	2579	NRCS-SC	1/1/1985	Present	NO
Bluewater Creek	35.223	-108.155	2324	RAWS	6/1/2003	Present	NO
Bluewater Ridge	35.194	-108.163	2526	RAWS	7/1/2003	Present	NO
Malpias Lava Flow	34.900	-108.096	2274	RAWS	5/1/1985	Present	NO
Ramah	34.995	-108.413	2145	RAWS	12/1/2004	Present	NO
Zuni	35.044	-108.482	1926	RAWS	2/1/2003	5/31/2005	NO
Grants Milan Muni. Airport	35.166	-107.899	1987	SAO	4/1/1953	Present	NO
Rice Park	35.233	-108.267	2579	SNOTEL	9/25/1998	Present	NO
Paxton Springs	35.050	-108.083	2332	WBAN	10/1/1931	6/30/1942	NO
Petroglyph National Monument (PETR)							
Petroglyph NM	35.139	-106.711	1561	COOP	4/1/1994	Present	YES
Albuquerque Foothills NE	35.134	-106.488	1865	COOP	10/1/1991	Present	NO
Albuquerque Intl Airport	35.036	-106.622	1618	COOP	1/1/1897	Present	NO
Albuquerque Old Town	35.083	-106.683	1510	COOP	7/1/1946	12/1/1992	NO
Albuquerque Valley	35.022	-106.694	1510	COOP	10/1/1991	Present	NO
Barton	35.083	-106.250	2096	COOP	7/1/1914	12/31/1925	NO
Bernalillo	35.317	-106.550	1540	COOP	5/1/1895	8/31/1982	NO
Capulin Springs	35.217	-106.417	2699	COOP	11/22/1941	11/12/1974	NO
Cerrillos	35.433	-106.117	1737	COOP	11/1/1905	8/31/1945	NO
Corbin Farms	34.750	-106.183	1935	COOP	5/1/1920	4/30/1921	NO
Corrales	35.226	-106.600	1529	COOP	10/6/1982	Present	NO
Correo	34.950	-107.150	M	COOP	7/1/1947	10/31/1948	NO
Diamond T Ranch	34.350	-106.617	1830	COOP	12/21/1946	2/28/1953	NO
Estancia 4 N	34.824	-106.034	1871	COOP	11/1/1904	Present	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Experiment Farm	35.017	-106.683	1504	COOP	9/1/1938	7/31/1957	NO
Hagan	35.300	-106.317	1723	COOP	4/1/1953	5/31/1956	NO
Jemez Dam	35.389	-106.544	1642	COOP	9/1/1953	Present	NO
La Bajada	35.550	-106.250	M	COOP	9/6/1942	6/30/1948	NO
La Madera Ski Area	35.217	-106.417	2440	COOP	1/1/1950	2/28/1953	NO
La Mesa	35.083	-106.567	1626	COOP	10/27/1946	1/31/1951	NO
Los Lunas	34.800	-106.733	1491	COOP	12/1/1892	7/31/1958	NO
Los Lunas 3 SSW	34.768	-106.761	1475	COOP	7/1/1923	Present	NO
Mc Intosh 4 NW	34.917	-106.083	1906	COOP	1/1/1928	8/31/1976	NO
Montano Grant	35.167	-107.017	1809	COOP	6/1/1948	10/31/1967	NO
Netherwood Park	35.100	-106.617	1565	COOP	5/1/1935	5/1/1957	NO
Pena Blanca	35.583	-106.333	1595	COOP	8/1/1958	2/15/1968	NO
Placitas 2 N	35.338	-106.439	1762	COOP	6/1/2000	Present	NO
Placitas 4 W	35.304	-106.497	1681	COOP	1/1/1992	Present	NO
Rio Grande Industrial School	35.017	-106.667	1509	COOP	3/1/1911	3/31/1922	NO
Sandia Crest	35.217	-106.450	3257	COOP	2/1/1953	4/30/1979	NO
Sandia Park	35.211	-106.366	2143	COOP	1/1/1939	Present	NO
Sandia Ranger Station	35.067	-106.383	1922	COOP	4/1/1910	1/20/1975	NO
South Garcia	34.917	-107.083	1501	COOP	7/1/1946	7/31/1947	NO
Tajique	34.750	-106.283	2040	COOP	11/1/1970	4/30/1979	NO
Tajique 4 N	34.800	-106.300	2129	COOP	4/1/1910	10/28/1970	NO
Turquoise Bonanza Cr	35.550	-106.100	1867	COOP	6/11/1953	3/31/1996	NO
Van Huss Ranch	35.367	-106.350	1647	COOP	7/1/1944	6/30/1951	NO
CW0082 Albuquerque	35.046	-106.492	1768	CWOP	M	Present	NO
CW0599 Corrales	35.246	-106.621	1521	CWOP	M	Present	NO
CW1748 Edgewood	35.115	-106.254	2097	CWOP	M	Present	NO
CW2107 Albuquerque	35.130	-106.718	1587	CWOP	M	Present	NO
CW2128 Rio Rancho	35.170	-106.666	1527	CWOP	M	Present	NO
CW2906 Albuquerque	35.180	-106.559	1675	CWOP	M	Present	NO
CW3739 Carnuel	35.059	-106.465	1769	CWOP	M	Present	NO
CW3873 Albuquerque	35.110	-106.737	1599	CWOP	M	Present	NO
CW5172 Albuquerque	35.158	-106.690	1554	CWOP	M	Present	NO
K5MJE-1 Tijeras	35.101	-106.340	2027	CWOP	M	Present	NO
KB5GAS-1 Balloon Fiesta	35.185	-106.598	1553	CWOP	M	Present	NO
KM5VY Escabosa	34.970	-106.305	2218	CWOP	M	Present	NO
W5MPZ-4 Kirtland AFB	35.054	-106.540	1668	CWOP	M	Present	NO
WA5SJW-10 E.Albuquerque	35.175	-106.481	1936	CWOP	M	Present	NO
Kirtland AFB	34.960	-106.490	1740	GPS-MET	M	Present	NO
Oak Flats	35.004	-106.322	2301	RAWS	1/1/2004	Present	NO
Sandia Lakes	35.230	-106.591	1524	RAWS	1/1/2004	Present	NO
Tijeras	35.070	-106.380	1981	RAWS	3/1/2000	2/29/2004	NO
Albuquerque CWSU	35.167	-106.567	1621	SAO	11/20/1972	Present	NO
Albuq. Double Eagle II AI	35.145	-106.795	1779	SAO	M	Present	NO
Albuquerque Intl Airport	35.036	-106.622	1618	SAO	1/1/1933	Present	NO
Kirtland AFB	35.050	-106.617	1635	SAO	6/1/1941	12/31/1971	NO
Albuquerque	35.083	-106.650	1524	WBAN	7/1/1919	1/31/1933	NO

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Salinas Pueblo Missions National Monument (SAPU)							
Gran Quivira NM	34.259	-106.093	2012	COOP	5/1/1905	Present	YES
Boys Ranch	34.433	-106.783	1440	COOP	2/1/1953	6/30/1958	NO
Brizendine Ranch	34.650	-106.283	2044	COOP	1/1/1948	7/2/1948	NO
Capillo Peak	34.683	-106.400	2736	COOP	7/1/1946	11/30/1976	NO
Claunch	34.133	-106.000	1958	COOP	5/1/1940	3/31/1953	NO
Corbin Farms	34.750	-106.183	1935	COOP	5/1/1920	4/30/1921	NO
Corona 10 SW	34.149	-105.698	2036	COOP	10/1/1992	Present	NO
Corona Lincoln Compressor Stn	34.100	-105.683	1981	COOP	12/1/1977	8/31/1992	NO
Diamond T Ranch	34.350	-106.617	1830	COOP	12/21/1946	2/28/1953	NO
Estancia 4 N	34.824	-106.034	1871	COOP	11/1/1904	Present	NO
Hill E G Ranch	34.117	-106.450	1769	COOP	12/1/1941	9/30/1948	NO
Los Lunas	34.800	-106.733	1491	COOP	12/1/1892	7/31/1958	NO
Los Lunas 3 SSW	34.768	-106.761	1475	COOP	7/1/1923	Present	NO
Manzano	34.650	-106.283	2044	COOP	1/1/1948	6/4/1949	NO
Mc Intosh 4 NW	34.917	-106.083	1906	COOP	1/1/1928	8/31/1976	NO
Mountainair	34.521	-106.261	1987	COOP	5/1/1902	Present	NO
Pfeister Ranch	34.600	-106.217	2013	COOP	3/1/1942	6/30/1955	NO
Progresso	34.421	-105.891	1919	COOP	7/1/1929	Present	NO
Sabinal	34.533	-106.800	1434	COOP	7/1/1933	2/28/1953	NO
South Capillo Peak	34.700	-106.400	2776	COOP	M	Present	NO
Tajique	34.750	-106.283	2040	COOP	11/1/1970	4/30/1979	NO
Tajique 4 N	34.800	-106.300	2129	COOP	4/1/1910	10/28/1970	NO
Willard Near	34.633	-106.033	1853	COOP	9/26/1912	3/31/1923	NO
CW2406 Mountainair	34.522	-106.241	2164	CWOP	M	Present	NO
KM5VY Escabosa	34.970	-106.305	2218	CWOP	M	Present	NO
Kirtland AFB	34.960	-106.490	1740	GPS-MET	M	Present	NO
Mountainaire	34.521	-106.261	1981	RAWS	1/1/1986	Present	NO
Corona Lincoln Compressor Stn	34.100	-105.683	1981	SAO	7/1/1961	Present	NO

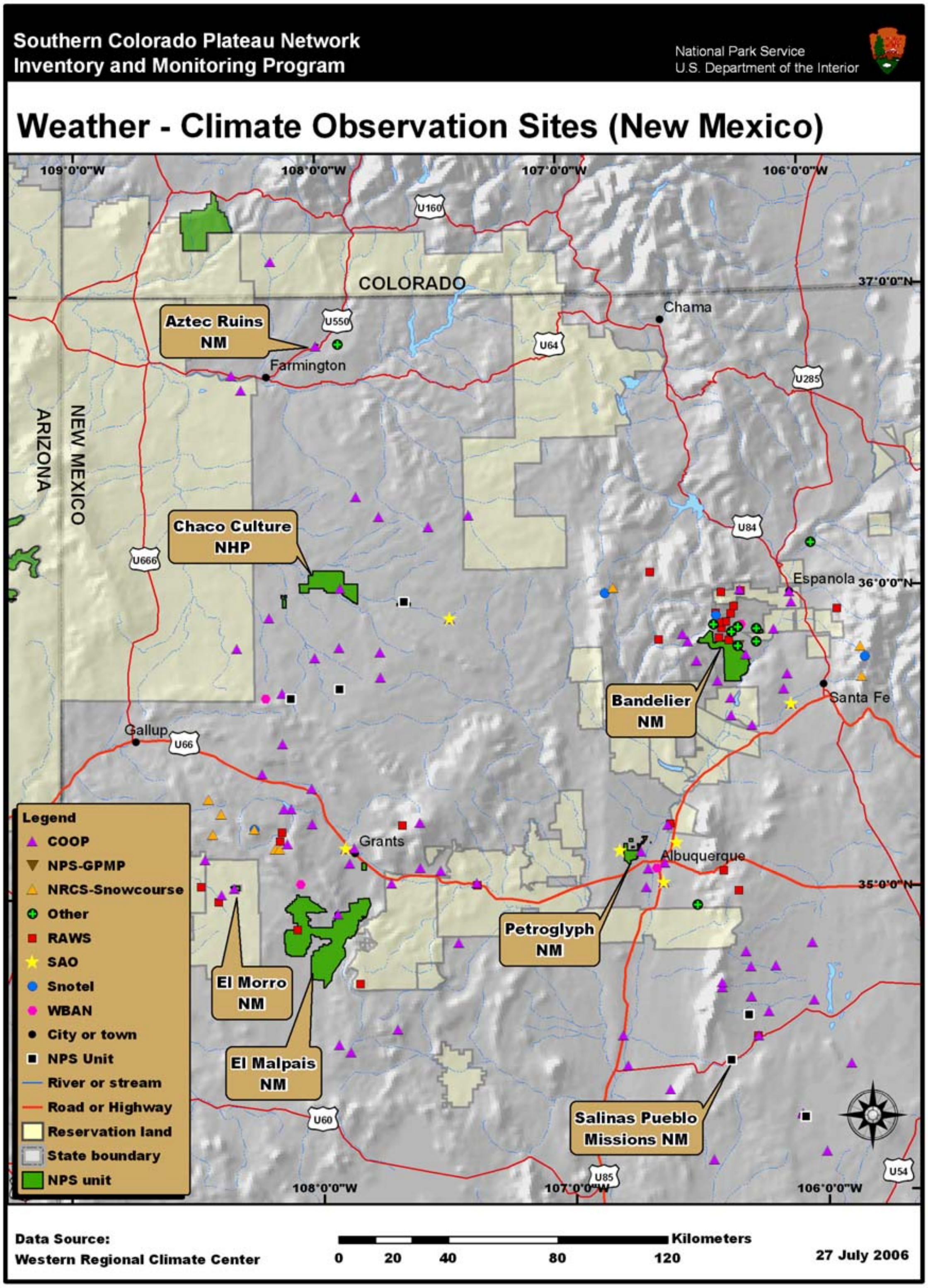

Figure 4.3. Station locations for SCPN park units in New Mexico.

5.0. Conclusions and Recommendations

We have based our findings on an examination of the available records and the topography and climate within SCPN units, discussions with NPS staff and other collaborators, and prior knowledge of the area. Here, we offer an evaluation and general comments pertaining to the status, prospects, and needs for climate-monitoring capabilities in the SCPN.

We encourage the continued operation of those active stations in the SCPN that have long-term climate records, especially those with records that are several decades or longer in length. These stations provide extremely valuable data for investigations of long-term climate trends and variations in the region.

5.1. Southern Colorado Plateau Inventory and Monitoring Network

5.1.1. Greater Four Corners Region

There are already numerous manual and automated weather/climate stations in and within 40 km of GRCA. However, most of these stations are located on the north and south rims of the canyon, while there is only one manual station inside GRCA that is located on the canyon floor (the COOP station "Phantom Ranch"). Investigations on long-term climate trends in Phantom Ranch data should be conducted cautiously, as the station has moved a few times during its period of record. Climate monitoring efforts in GRCA could benefit greatly by installing an automated weather/climate station somewhere on the floor of the Grand Canyon: Phantom Ranch, for example. The installation of such a station on the canyon floor would not only provide near-real-time weather data from these locations, but would also facilitate investigations of real-time climate gradients between the canyon rim and floor. Currently these gradients can only be investigated on a once-daily basis, looking at elements such as daily precipitation and daily maximum, minimum, and mean temperature. During the summer, such information could be extremely useful for planning pack trips from the rim down to the canyon floor, and in monitoring potential flash flooding in side canyons caused by afternoon and evening thunderstorms. Wintertime temperature variations between the canyon rim and floor also play a key role in defining GRCA ecosystems and could be monitored in near-real-time.

With the exception of the SAO sites in and near Bullfrog Basin and a couple of stations from the GSE network, GLCA has very few automated weather stations inside its boundaries. This is particularly true along the southern boundary and in the far northern reaches of the park by Canyonlands National Park (Figure 4.1). The NPS could benefit by partnering with the BLM to expand the RAWS network in these areas. The GSE network provides useful automated weather data on the west side of GLCA.

Navajo National Monument (NAVA) and CACH could also benefit through partnerships with cooperating agencies to expand the RAWS network in northeastern Arizona and along the Arizona/Utah border. Some of the NAVA units are more than 40 km distant from the nearest automated measurements at Kayenta Airport, which provides the only automated weather observations over a large portion of the Hopi and Navajo Reservations in northeast Arizona (Figure 4.1).

We have concluded that the SCPN park units in southwestern Colorado (MEVE, YUHO) are well sampled by manual and automated weather and climate stations in and near these park units. This is especially true for MEVE.

5.1.2. North-central Arizona

This region has very few automated stations (Figure 4.2). As has previously been suggested, the NPS could benefit greatly by partnering with the BLM and other agencies to have RAWS stations installed in or near SCPN park units. For example, there are significant portions of PEFO, both north and south of Interstate 40, that currently have no weather observations (Figure 4.2) and could benefit from the installation of a RAWS station. The continuation of those stations in the region with long climate records is encouraged, including the Ganado COOP site near HUTR.

The SCPN park units that are north of Flagstaff (in particular, SUCR and WUPA) have few or no on-site or nearby automated stations. Most of the automated stations in this area are around or south of Flagstaff. Pursuing partnerships to expand the RAWS network in this area would likely be beneficial. Alternatively, due to the proximity of the San Francisco Peaks, which receive substantial amounts of snow during the winter months, the NPS could coordinate with NRCS to have a SNOTEL installed in the eastern San Francisco Peaks area, particularly in those areas immediately west of SUCR.

5.1.3. New Mexico

The majority of the SCPN park units in New Mexico appear to be well sampled by both manual and automated weather and climate stations. Despite there being no stations inside BAND boundaries, there are numerous manual and automated stations near BAND that provide useful weather and climate data, particularly north of the park unit. Petroglyph National Monument (PETR) has a number of nearby manual and automated sites, especially from the Albuquerque area, which sample weather and climate conditions in the area. Both ELMA and ELMO are well-sampled by weather/climate stations. Although there are no weather/climate stations in the southernmost portion of ELMA, a RAWS station just southeast of ELMA (Brushy Mountain) provides real-time weather data for that local area.

Of those SCPN park units that are located in New Mexico, the park units in northwestern New Mexico (AZRU, CHCU) have the least coverage of weather and climate stations (see Table 4.5). As resources allow, parternships with other government agencies to install automated stations such as RAWS stations in the area would likely prove to be beneficial.

5.2. Spatial Variations in Mean Climate

Topography is a major controlling factor on the park units within SCPN, leading to systematic spatial variations in mean surface climate. With local variations over short horizontal and vertical distances, topography introduces considerable fine-scale structure to mean climate (temperature and precipitation). Issues encountered in mapping mean climate are discussed in Appendix E and in Redmond et al. (2005).

If only a few stations will be emplaced, the primary goal should be overall characterization of the main climate elements (temperature and precipitation and their joint relative, snow). This level of characterization generally requires that (a) stations should not be located in deep valley bottoms (cold air drainage pockets) or near excessively steep slopes and (b) stations should be distributed spatially in the major biomes of each park. If such stations already are present in the vicinity, then additional stations would be best used for two important and somewhat competing purposes: (a) add redundancy as backup for loss of data from current stations (or loss of the physical stations) or (b) provide added information on spatial heterogeneity in climate arising from topographic diversity.

5.3. Climate Change Detection

The Colorado Plateau is one of the most rapidly warming areas in the U.S. Along with these warming trends, this region is also receiving less precipitation over time. Thus, the need for credible, accurate, complete, and long-term climate records for SCPN—from any location—cannot be overemphasized. This consideration always should have a high priority. However, because of spatial diversity in climate, monitoring that fills knowledge gaps and provides information on long-term temporal variability in short-distance relationships also will be valuable. We cannot be sure that climate variability and climate change will affect all parts of a given park unit equally. In fact, it is appropriate to speculate that this is not the case, and spatial variations in temporal variability extend to small spatial scales (a few kilometers or less in some cases), a consequence of extreme topographic diversity within SCPN.

5.4. Aesthetics

This issue arises frequently enough to deserve comment. Standards for quality climate measurements require open exposures away from heat sources, buildings, pavement, close vegetation and tall trees, and human intrusion (thus away from property lines). By their nature, sites that meet these standards are usually quite visible. In many settings (such as heavily forested areas) these sites also are quite rare, making them precisely the same places that managers wish to protect from aesthetic intrusion. The most suitable and scientifically defensible sites frequently are rejected as candidate locations for weather/climate stations. Most weather/climate stations, therefore, tend to be “hidden” but many of these hidden locations have inferior exposures. Some measure of compromise is nearly always called for in siting weather and climate stations.

The public has vast interest and curiosity in weather and climate, and within the NPS I&M networks, such measurements consistently rate near or at the top of desired public information. There seem to be many possible opportunities for exploiting and embracing this widespread interest within the interpretive mission of the NPS. One way to do this would be to highlight rather than hide these stations and educate the public about the need for adequate siting. A number of weather displays we have encountered during visits have proven inadvertently to serve as counterexamples for how measurements should not be made.

5.5. Information Access

Access to information promotes its use, which in turn promotes attention to station care and maintenance, better data, and more use. An end-to-end view that extends from sensing to decision support is far preferable to isolated and disconnected activities and aids the support infrastructure that is ultimately so necessary for successful, long-term climate monitoring.

Decisions about improvements in monitoring capacity are facilitated greatly by the ability to examine available climate information. Various methods are being created at WRCC to improve access to that information. Web pages providing historic and ongoing climate data, and information from SCPN park units can be accessed at http://www.wrcc.dri.edu/nps. In the event that this URL changes, there still will be links from the main WRCC Web page entitled "Projects" under NPS.

The WRCC has been steadily developing software to summarize data from hourly sites. This has been occurring under the aegis of the RAWS program and a growing array of product generators ranging from daily and monthly data lists to wind roses and hourly frequency distributions. All park data are available to park personnel via an access code (needed only for data listings) that can be acquired by request. The WRCC RAWS Web page is located at http://www.wrcc.dri.edu/wraws or http://www.raws.dri.edu.

Web pages have been developed to provide access not only to historic and ongoing climate data and information from SCPN park units but also to climate-monitoring efforts for SCPN. These pages can be found through http://www.wrcc.dri.edu/nps.

Additional access to more standard climate information is accessible though the previously mentioned Web pages, as well as through http://www.wrcc.dri.edu/summary. These summaries are generally for COOP stations.

5.6. Summarized Conclusions and Recommendations

- Climate within SCPN is highly variable spatially due to regional topography and the spatially-varying influence of the summertime monsoonal flow.
- Park units in northeastern Arizona currently are lacking in automated weather stations. Exploring partnerships to expand the RAWS network in this region could be very useful.
- Most of the park units in New Mexico appear to be well sampled by manual and automated stations. This is particularly true with BAND.
- The SCPN park units in southwestern Colorado (MEVE, YUHO) appear to be well sampled by manual and automated stations.
- We have not identified any automated stations on the canyon floor at GRCA. A RAWS station would provide near-real-time conditions from the canyon floor and facilitate investigations of climate gradients between the canyon rim and floor.
- We recommend the continued operation of those stations inside SCPN park units that have long-term climate records. Some records exceed 100 years in length.

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Appendix A. Climate-monitoring principles.

Since the late 1990s, frequent references have been made to a set of climate-monitoring principles enunciated in 1996 by Tom Karl, director of the NOAA NCDC in Asheville, North Carolina. These monitoring principles also have been referred to informally as the "Ten Commandments of Climate Monitoring." Both versions are given here. In addition, these principles have been adopted by the Global Climate Observing System (GCOS 2004).

(Compiled by Kelly Redmond, Western Regional Climate Center, Desert Research Institute, August 2000.)

A.1. Full Version (Karl et al. 1996)

A. Effects on climate records of instrument changes, observing practices, observation locations, sampling rates, etc., must be known before such changes are implemented. This can be ascertained through a period where overlapping measurements from old and new observing systems are collected or sometimes by comparing the old and new observing systems with a reference standard. Site stability for in situ measurements, both in terms of physical location and changes in the nearby environment, also should be a key criterion in site selection. Thus, many synoptic network stations, which are primarily used in weather forecasting but also provide valuable climate data, and dedicated climate stations intended to be operational for extended periods must be subject to this policy.

B. Processing algorithms and changes in these algorithms must be well documented. Documentation should be carried with the data throughout the data-archiving process.

C. Knowledge of instrument, station, and/or platform history is essential for interpreting and using the data. Changes in instrument sampling time, local environmental conditions for in situ measurements, and other factors pertinent to interpreting the observations and measurements should be recorded as a mandatory part in the observing routine and be archived with the original data.

D. In situ and other observations with a long, uninterrupted record should be maintained. Every effort should be applied to protect the data sets that have provided long-term, homogeneous observations. "Long-term" for space-based measurements is measured in decades, but for more conventional measurements, "long-term" may be a century or more. Each element in the observational system should develop a list of prioritized sites or observations based on their contribution to long-term climate monitoring.

E. Calibration, validation, and maintenance facilities are critical requirements for long-term climatic data sets. Homogeneity in the climate record must be assessed routinely, and corrective action must become part of the archived record.

F. Where feasible, some level of "low-technology" backup to "high-technology" observing systems should be developed to safeguard against unexpected operational failures.

G. Regions having insufficient data, variables and regions sensitive to change, and key measurements lacking adequate spatial and temporal resolution should be given the highest priority in designing and implementing new climate-observing systems.

H. Network designers and instrument engineers must receive long-term climate requirements at the outset of the network design process. This is particularly important because most observing systems have been designed for purposes other than long-term climate monitoring. Instruments must possess adequate accuracy with biases small enough to document climate variations and changes.

I. Much of the development of new observational capabilities and the evidence supporting the value of these observations stem from research-oriented needs or programs. A lack of stable, long-term commitment to these observations and lack of a clear transition plan from research to operations are two frequent limitations in the development of adequate, long-term monitoring capabilities. Difficulties in securing a long-term commitment must be overcome in order to improve the climate-observing system in a timely manner with minimal interruptions.

J. Data management systems that facilitate access, use, and interpretation are essential. Freedom of access, low cost, mechanisms that facilitate use (directories, catalogs, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.) and quality control should guide data management. International cooperation is critical for successful management of data used to monitor long-term climate change and variability.

A.2. Abbreviated version, "Ten Commandments of Climate Monitoring"

A. Assess the impact of new climate-observing systems or changes to existing systems before they are implemented.

   "Thou shalt properly manage network change." (assess effects of proposed changes)

B. Require a suitable period where measurement from new and old climate-observing systems will overlap.

   "Thou shalt conduct parallel testing." (compare old and replacement systems)

C. Treat calibration, validation, algorithm-change, and data-homogeneity assessments with the same care as the data.

   "Thou shalt collect metadata." (fully document system and operating procedures)

D. Verify capability for routinely assessing the quality and homogeneity of the data including high-resolution data for extreme events.

“Thou shalt assure data quality and continuity.” (assess as part of routine operating procedures)

E. Integrate assessments like those conducted by the International Panel on Climate Change into global climate-observing priorities.

   “Thou shalt anticipate the use of data.” (integrated environmental assessment; component in operational plan for system)

F. Maintain long-term weather and climate stations.

   “Thou shalt worship historic significance.” (maintain homogeneous data sets from long–term, climate-observing systems)

G. Place high priority on increasing observations in regions lacking sufficient data and in regions sensitive to change and variability.

   "Thou shalt acquire complementary data." (new sites to fill observational gaps)

H. Provide network operators, designers, and instrument engineers with long-term requirements at the outset of the design and implementation phases for new systems.

   “Thou shalt specify requirements for climate observation systems.” (application and usage of observational data)

I. Carefully consider the transition from research-observing system to long-term operation.

   “Thou shalt have continuity of purpose.” (stable long-term commitments)

J. Focus on data-management systems that facilitate access, use, and interpretation of weather data and metadata.

   “Thou shalt provide access to data and metadata.” (readily-available weather and climate information)

A.3. Literature Cited

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Appendix B. Glossary.

Climate—Complete and entire ensemble of statistical descriptors of temporal and spatial properties comprising the behavior of the atmosphere. These descriptors include means, variances, frequency distributions, autocorrelations, spatial correlations and other patterns of association, temporal lags, and element-to-element relationships. The descriptors have a physical basis in flows and reservoirs of energy and mass. Climate and weather phenomena shade gradually into each other and are ultimately inseparable.

Climate Element—(same as Weather Element) Attribute or property of the state of the atmosphere that is measured, estimated, or derived. Examples of climate elements include temperature, wind speed, wind direction, precipitation amount, precipitation type, relative humidity, dewpoint, solar radiation, snow depth, soil temperature at a given depth, etc. A derived element is a function of other elements (like degree days or number of days with rain) and is not measured directly with a sensor. The terms "parameter" or "variable" are not used to describe elements.

Climate Network—Group of climate stations having a common purpose; the group is often owned and maintained by a single organization.

Climate Station—Station where data are collected to track atmospheric conditions over the long-term. Often, this station operates to additional standards to verify long-term consistency. For these stations, the detailed circumstances surrounding a set of measurements (siting and exposure, instrument changes, etc.) are important.

Data—Measurements specifying the state of the physical environment. Does not include metadata.

Data Inventory—Information about overall data properties for each station within a weather or climate network. A data inventory may include start/stop dates, percentages of available data, breakdowns by climate element, counts of actual data values, counts or fractions of data types, etc. These properties must be determined by actually reading the data and thus require the data to be available, accessible, and in a readable format.

NPS I&M Network—A set of NPS park units grouped by a common theme, typically by natural resource and/or geographic region.

Metadata—Information necessary to interpret environmental data properly, organized as a history or series of snapshots—data about data. Examples include details of measurement processes, station circumstances and exposures, assumptions about the site, network purpose and background, types of observations and sensors, pre-treatment of data, access information, maintenance history and protocols, observational methods, archive locations, owner, and station start/end period.

Quality Assurance—Planned and systematic set of activities to provide adequate confidence that products and services are resulting in credible and correct information. Includes quality control.

Quality Control—Evaluation, assessment, and improvement of imperfect data by utilizing other imperfect data.

Station Inventory—Information about a set of stations obtained from metadata that accompany the network or networks. A station inventory can be compiled from direct and indirect reports prepared by others.

Weather—Instantaneous state of the atmosphere at any given time, mainly with respect to its effects on biological activities. As distinguished from climate, weather consists of the short-term (minutes to days) variations in the atmosphere. Popularly, weather is thought of in terms of temperature, precipitation, humidity, wind, sky condition, visibility, and cloud conditions.

Weather Element (same as Climate Element)**—**Attribute or property of the state of the atmosphere that is measured, estimated, or derived. Examples of weather elements include temperature, wind speed, wind direction, precipitation amount, precipitation type, relative humidity, dewpoint, solar radiation, snow depth, soil temperature at a given depth, etc. A derived weather element is a function of other elements (like degree days or number of days with rain) and is not measured directly. The terms “parameter” and “variable” are not used to describe weather elements.

Weather Network—Group of weather stations usually owned and maintained by a particular organization and usually for a specific purpose.

Weather Station—Station where collected data are intended for near-real-time use with less need for reference to long-term conditions. In many cases, the detailed circumstances of a set of measurements (siting and exposure, instrument changes, etc.) from weather stations are not as important as for climate stations.

Appendix C. Factors in operating a climate network.

C.1. Climate versus Weather

- Climate measurements require *consistency through time.*

C.2. Network Purpose

- Anticipated or desired lifetime.
- Breadth of network mission (commitment by needed constituency).
- Dedicated constituency—no network survives without a dedicated constituency.

C.3. Site Identification and Selection

- Spanning gradients in climate or biomes with transects.
- Issues regarding representative spatial scale—site uniformity versus site clustering.
- Alignment with and contribution to network mission.
- Exposure—ability to measure representative quantities.
- Logistics—ability to service station (Always or only in favorable weather?).
- Site redundancy (positive for quality control, negative for extra resources).
- Power—is AC needed?
- Site security—is protection from vandalism needed?
- Permitting often a major impediment and usually underestimated.

C.4. Station Hardware

- Survival—weather is the main cause of lost weather/climate data.
- Robustness of sensors—ability to measure and record in any condition.
- Quality—distrusted records are worthless and a waste of time and money.
  - High quality—will cost up front but pays off later.
  - Low quality—may provide a lower start-up cost but will cost more later (low cost can be expensive).
- Redundancy—backup if sensors malfunction.
- Ice and snow—measurements are much more difficult than rain measurements.
- Severe environments (expense is about two–three times greater than for stations in more benign settings).

C.5. Communications

- Reliability—live data have a much larger constituency.
- One-way or two-way.
  - Retrieval of missed transmissions.
  - Ability to reprogram data logger remotely.
  - Remote troubleshooting abilities.
  - Continuing versus one-time costs.
- Back-up procedures to prevent data loss during communication outages.
- Live communications increase problems but also increase value.

C.6. Maintenance

- Main reason why networks fail (and most networks do eventually fail!).

- Key issue with nearly every network.
- Who will perform maintenance?
- Degree of commitment and motivation to contribute.
- Periodic? On-demand as needed? Preventive?
- Equipment change-out schedules and upgrades for sensors and software.
- Automated stations require skilled and experienced labor.
- Calibration—sensors often drift (climate).
- Site maintenance essential (constant vegetation, surface conditions, nearby influences).
- Typical automated station will cost about $2K per year to maintain.
- Documentation—photos, notes, visits, changes, essential for posterity.
- Planning for equipment life cycle and technological advances.

C.7. Maintaining Programmatic Continuity and Corporate Knowledge

- Long-term vision and commitment needed.
- Institutionalizing versus personalizing—developing appropriate dependencies.

C.8. Data Flow

- Centralized ingest?
- Centralized access to data and data products?
- Local version available?
- Contract out work or do it yourself?
- Quality control of data.
- Archival.
- Metadata—historic information, not a snapshot. Every station should collect metadata.
- Post-collection processing, multiple data-ingestion paths.

C.9. Products

- Most basic product consists of the data values.
- Summaries.
- Write own applications or leverage existing mechanisms?

C.10. Funding

- Prototype approaches as proof of concept.
- Linking and leveraging essential.
- Constituencies—every network needs a constituency.
- Bridging to practical and operational communities? Live data needed.
- Bridging to counterpart research efforts and initiatives—funding source.
- Creativity, resourcefulness, and persistence usually are essential to success.

C.11. Final Comments

- Deployment is by far the easiest part in operating a network.
- Maintenance is the main issue.
- Best analogy: Operating a network is like raising a child; it requires constant attention.

Source: Western Regional Climate Center (WRCC)

Appendix D. Master metadata field list.

Field Name	Field Type	Field Description
begin_date	date	Effective beginning date for a record.
begin_date_flag	char(2)	Flag describing the known accuracy of the begin date for a station.
best_elevation	float(4)	Best known elevation for a station (in feet).
clim_div_code	char(2)	Foreign key defining climate division code (primary in table: clim_div).
clim_div_key	int2	Foreign key defining climate division for a station (primary in table: clim_div.
clim_div_name	varchar(30)	English name for a climate division.
controller_info	varchar(50)	Person or organization who maintains the identifier system for a given weather or climate network.
country_key	int2	Foreign key defining country where a station resides (primary in table: none).
county_key	int2	Foreign key defining county where a station resides (primary in table: county).
county_name	varchar(31)	English name for a county.
description	text	Any description pertaining to the particular table.
end_date	date	Last effective date for a record.
end_date_flag	char(2)	Flag describing the known accuracy of station end date.
fips_country_code	char(2)	FIPS (Federal Information Processing Standards) country code.
fips_state_abbr	char(2)	FIPS state abbreviation for a station.
fips_state_code	char(2)	FIPS state code for a station.
history_flag	char(2)	Describes temporal significance of an individual record among others from the same station.
id_type_key	int2	Foreign key defining the id_type for a station (usually defined in code).
last_updated	date	Date of last update for a record.
latitude	float(8)	Latitude value.
longitude	float(8)	Longitude value.
name_type_key	int2	“3”: COOP station name, “2”: best station name.
name	varchar(30)	Station name as known at date of last update entry.
ncdc_state_code	char(2)	NCDC, two-character code identifying U.S. state.
network_code	char(8)	Eight-character abbreviation code identifying a network.
network_key	int2	Foreign key defining the network for a station (primary in table: network).
network_station_id	int4	Identifier for a station in the associated network, which is defined by id_type_key.
remark	varchar(254)	Additional information for a record.
src_quality_code	char(2)	Code describing the data quality for the data source.
state_key	int2	Foreign key defining the U.S. state where a station resides (primary in table: state).
state_name	varchar(30)	English name for a state.
station_alt_name	varchar(30)	Other English names for a station.
station_best_name	varchar(30)	Best, most well-known English name for a station.
time_zone	float4	Time zone where a station resides.
ucan_station_id	int4	Unique station identifier for every station in ACIS.
unit_key	int2	Integer value representing a unit of measure.

Field Name	Field Type	Field Description
updated_by	char(8)	Person who last updated a record.
var_major_id	int2	Defines major climate variable.
var_minor_id	int2	Defines data source within a var_major_id.
zipcode	char(5)	Zipcode where a latitude/longitude point resides.
nps_netcode	char(4)	Network four-character identifier.
nps_netname	varchar(128)	Displayed English name for a network.
parkcode	char(4)	Park four-character identifier.
parkname	varchar(128)	Displayed English name for a park/
im_network	char(4)	NPS I&M network where park belongs (a net code)/
station_id	varchar(16)	Station identifier.
station_id_type	varchar(16)	Type of station identifier.
network.subnetwork.id	varchar(16)	Identifier of a sub-network in associated network.
subnetwork_key	int2	Foreign key defining sub-network for a station.
subnetwork_name	varchar(30)	English name for a sub-network.
slope	integer	Terrain slope at the location.
aspect	integer	Terrain aspect at the station.
gps	char(1)	Indicator of latitude/longitude recorded via GPS (Global Positioning System).
site_description	text(0)	Physical description of site.
route_directions	text(0)	Driving route or site access directions.
station_photo_id	integer	Unique identifier associating a group of photos to a station. Group of photos all taken on same date.
photo_id	char(30)	Unique identifier for a photo.
photo_date	datetime	Date photograph taken.
photographer	varchar(64)	Name of photographer.
maintenance_date	datetime	Date of station maintenance visit.
contact_key	Integer	Unique identifier associating contact information to a station.
full_name	varchar(64)	Full name of contact person.
organization	varchar(64)	Organization of contact person.
contact_type	varchar(32)	Type of contact person (operator, administrator, etc.)
position_title	varchar(32)	Title of contact person.
address	varchar(32)	Address for contact person.
city	varchar(32)	City for contact person.
state	varchar(2)	State for contact person.
zip_code	char(10)	Zipcode for contact person.
country	varchar(32)	Country for contact person.
email	varchar(64)	E-mail for contact person.
work_phone	varchar(16)	Work phone for contact person.
contact_notes	text(254)	Other details regarding contact person.
equipment_type	char(30)	Sensor measurement type; i.e., wind speed, air temperature, etc.
eq_manufacturer	char(30)	Manufacturer of equipment.
eq_model	char(20)	Model number of equipment.
serial_num	char(20)	Serial number of equipment.
eq_description	varchar(254)	Description of equipment.
install_date	datetime	Installation date of equipment.
remove_date	datetime	Removal date of equipment.
ref_height	integer	Sensor displacement height from surface.
sampling_interval	varchar(10)	Frequency of sensor measurement.

Appendix E. General design considerations for weather/ climate-monitoring programs.

The process for designing a climate-monitoring program benefits from anticipating design and protocol issues discussed here. Much of this material is been excerpted from a report addressing the Channel Islands National Park (Redmond and McCurdy 2005), where an example is found illustrating how these factors can be applied to a specific setting. Many national park units possess some climate or meteorology feature that sets them apart from more familiar or “standard” settings.

E.1. Introduction

There are several criteria that must be used in deciding to deploy new stations and where these new stations should be sited.

- Where are existing stations located?
- Where have data been gathered in the past (discontinued locations)?
- Where would a new station fill a knowledge gap about basic, long-term climatic averages for an area of interest?
- Where would a new station fill a knowledge gap about how climate behaves over time?
- As a special case for behavior over time, what locations might be expected to show a more sensitive response to climate change?
- How do answers to the preceding questions depend on the climate element? Are answers the same for precipitation, temperature, wind, snowfall, humidity, etc.?
- What role should manual measurements play? How should manual measurements interface with automated measurements?
- Are there special technical or management issues, either present or anticipated in the next 5–15 years, requiring added climate information?
- What unique information is provided in addition to information from existing sites? “Redundancy is bad.”
- What nearby information is available to estimate missing observations because observing systems always experience gaps and lose data? “Redundancy is good.”
- How would logistics and maintenance affect these decisions?

In relation to the preceding questions, there are several topics that should be considered. The following topics are not listed in a particular order.

E.1.1. Network Purpose

Humans seem to have an almost reflexive need to measure temperature and precipitation, along with other climate elements. These reasons span a broad range from utilitarian to curiosity-driven. Although there are well-known recurrent patterns of need and data use, new uses are always appearing. The number of uses ranges in the thousands. Attempts have been made to categorize such uses (see NRC 1998; NRC 2001). Because climate measurements are accumulated over a long time, they should be treated as multi-purpose and should be undertaken in a manner that serves the widest possible applications. Some applications remain constant, while others rise and fall in importance. An insistent issue today may subside, while the next pressing issue of tomorrow barely may be anticipated. The notion that humans might affect the climate of the entire Earth was nearly unimaginable when the national USDA (later NOAA) cooperative weather network began in the late 1800s. Abundant experience has shown, however, that there always will be a demand for a history record of climate measurements and their properties. Experience also shows that there is an expectation that climate measurements will be taken and made available to the general public.

An exhaustive list of uses for data would fill many pages and still be incomplete. In broad terms, however, there are needs to document environmental conditions that disrupt or otherwise affect park operations (e.g., storms and droughts). Design and construction standards are determined by climatological event frequencies that exceed certain thresholds. Climate is a determinant that sometimes attracts and sometimes discourages visitors. Climate may play a large part in the park experience (e.g., Death Valley and heat are nearly synonymous). Some park units are large enough to encompass spatial or elevation diversity in climate, and the sequence of events can vary considerably inside or close to park boundaries. That is, temporal trends and statistics may not be the same everywhere, and this spatial structure should be sampled. The granularity of this structure depends on the presence of topography or large climate gradients or both, such as that found along the U.S. West Coast in summer with the rapid transition from the marine layer to the hot interior.

Plant and animal communities and entire ecosystems react to every nuance in the physical environment. No aspect of weather and climate goes undetected in the natural world. Wilson (1998) proposed “an informal rule of biological evolution” that applies here: “If an organic sensor can be imagined that is capable of detecting any particular environmental signal, a species exists somewhere that possesses this sensor.” Every weather and climate event, whether dull or extraordinary to humans, matters to some organism. Dramatic events and creeping incremental change both have consequences to living systems. Extreme events or disturbances can “reset the clock” or “shake up the system” and lead to reverberations that last for years to centuries or longer. Slow change can carry complex nonlinear systems (e.g., any living assemblage) into states where chaotic transitions and new behavior occur. These changes are seldom predictable, typically are observed after the fact, and understood only in retrospect. Climate changes may not be exciting, but as a well-known atmospheric scientist, Mike Wallace, from the University of Washington once noted, “subtle does not mean unimportant”.

Thus, individuals who observe the climate should be able to record observations accurately and depict both rapid and slow changes. In particular, an array of artificial influences easily can confound detection of slow changes. The record as provided can contain both real climate variability (that took place in the atmosphere) and fake climate variability (that arose directly from the way atmospheric changes were observed and recorded). As an example, trees growing near a climate station with an excellent anemometer will make it appear that the wind gradually slowed down over many years. Great care must be taken to protect against sources of fake climate variability on the longer-time scales of years to decades. Processes leading to the observed climate are not stationary; rather these processes draw from probability distributions that vary with time. For this reason, climatic time series do not exhibit statistical stationarity. The implications are manifold. There are no true climatic “normals” to which climate inevitably must return. Rather, there are broad ranges of climatic conditions. Climate does not demonstrate exact repetition but instead continual fluctuation and sometimes approximate repetition. In addition, there is always new behavior waiting to occur. Consequently, the business of climate monitoring is never finished, and there is no point where we can state confidently that “enough” is known.

E.1.2. Robustness

The most frequent cause for loss of weather data is the weather itself, the very thing we wish to record. The design of climate and weather observing programs should consider the meteorological equivalent of “peaking power” employed by utilities. Because environmental disturbances have significant effects on ecologic systems, sensors, data loggers, and communications networks should be able to function during the most severe conditions that realistically can be anticipated over the next 50–100 years. Systems designed in this manner are less likely to fail under more ordinary conditions, as well as more likely to transmit continuous, quality data for both tranquil and active periods.

E.1.3. Weather versus Climate

For “weather” measurements, pertaining to what is approximately happening here and now, small moves and changes in exposure are not as critical. For “climate” measurements, where values from different points in time are compared, siting and exposure are critical factors, and it is vitally important that the observing circumstances remain essentially unchanged over the duration of the station record.

Station moves can affect different elements to differing degrees. Even small moves of several meters, especially vertically, can affect temperature records. Hills and knolls act differently from the bottoms of small swales, pockets, or drainage channels (Whiteman 2000; Geiger et al. 2003). Precipitation is probably less subject to change with moves of 50–100 m than other elements (that is, precipitation has less intrinsic variation in small spaces) except if wind flow over the gauge is affected.

E.1.4. Physical Setting

Siting and exposure, and their continuity and consistency through time, significantly influence the climate records produced by a station. These two terms have overlapping connotations. We use the term “siting” in a more general sense, reserving the term “exposure” generally for the particular circumstances affecting the ability of an instrument to record measurements that are representative of the desired spatial or temporal scale.

E.1.5. Measurement Intervals

Climatic processes occur continuously in time, but our measurement systems usually record in discrete chunks of time: for example, seconds, hours, or days. These measurements often are referred to as “systematic” measurements. Interval averages may hide active or interesting periods of highly intense activity. Alternatively, some systems record “events” when a certain threshold of activity is exceeded (examples: another millimeter of precipitation has fallen, another kilometer of wind has moved past, the temperature has changed by a degree, a gust higher than 9.9 m/s has been measured). When this occurs, measurements from all sensors are reported. These measurements are known as “breakpoint” data. In relatively unchanging conditions (long calm periods or rainless weeks, for example), event recorders should send a signal that they are still “alive and well.” If systematic recorders are programmed to note and periodically report the highest, lowest, and mean value within each time interval, the likelihood is reduced that interesting behavior will be glossed over or lost. With the capacity of modern data loggers, it is recommended to record and report extremes within the basic time increment (e.g., hourly or 10 minutes). This approach also assists quality-control procedures.

There is usually a trade-off between data volume and time increment, and most automated systems now are set to record approximately hourly. A number of field stations maintained by WRCC are programmed to record in 5- or 10-minute increments, which readily serve to construct an hourly value. However, this approach produces 6–12 times as much data as hourly data. These systems typically do not record details of events at sub-interval time scales, but they easily can record peak values, or counts of threshold exceedance, within the time intervals.

Thus, for each time interval at an automated station, we recommend that several kinds of information—mean or sum, extreme maximum and minimum, and sometimes standard deviation—be recorded. These measurements are useful for quality control and other purposes. Modern data loggers and office computers have quite high capacity. Diagnostic information indicating the state of solar chargers or battery voltages and their extremes is of great value. This topic will be discussed in greater detail in a succeeding section.

Automation also has made possible adaptive or intelligent monitoring techniques where systems vary the recording rate based on detection of the behavior of interest by the software. Sub-interval behavior of interest can be masked on occasion (e.g., a 5-minute extreme downpour with high-erosive capability hidden by an innocuous hourly total). Most users prefer measurements that are systematic in time because they are much easier to summarize and manipulate.

For breakpoint data produced by event reporters, there also is a need to send periodically a signal that the station is still functioning, even though there is nothing more to report. “No report” does not necessarily mean “no data,” and it is important to distinguish between the actual observation that was recorded and the content of that observation (e.g., an observation of “0.00” is not the same as “no observation”).

E.1.6. Mixed Time Scales

There are times when we may wish to combine information from radically different scales. For example, over the past 100 years we may want to know how the frequency of 5-minute precipitation peaks has varied or how the frequency of peak 1-second wind gusts have varied. We may also want to know over this time if nearby vegetation gradually has grown up to increasingly block the wind or to slowly improve precipitation catch. Answers to these questions require knowledge over a wide range of time scales.

E.1.7. Elements

For manual measurements, the typical elements recorded included temperature extremes, precipitation, and snowfall/snow depth. Automated measurements typically include temperature, precipitation, humidity, wind speed and direction, and solar radiation. An exception to this exists in very windy locations where precipitation is difficult to measure accurately. Automated measurements of snow are improving, but manual measurements are still preferable, as long as shielding is present. Automated measurement of frozen precipitation presents numerous challenges that have not been resolved fully, and the best gauges are quite expensive ($3–8K). Soil temperatures also are included sometimes. Soil moisture is extremely useful, but measurements are not made at many sites. In addition, care must be taken in the installation and maintenance of instruments used in measuring soil moisture. Soil properties vary tremendously in short distances as well, and it is often very difficult ("impossible") to accurately document these variations (without digging up all the soil!). In cooler climates, ultrasonic sensors that detect snow depth are becoming commonplace.

E.1.8. Wind Standards

Wind varies the most in the shortest distance, since it always decreases to zero near the ground and increases rapidly (approximately logarithmically) with height near the ground. Changes in anemometer height obviously will affect distribution of wind speed as will changes in vegetation, obstructions such as buildings, etc. A site that has a 3-m (10-ft) mast clearly will be less windy than a site that has a 6-m (20-ft) or 10-m (33-ft) mast. Historically, many U.S. airports (FAA and NWS) and most current RAWS sites have used a standard 6-m (20-ft) mast for wind measurements. Some NPS RAWS sites utilize shorter masts. Over the last decade, as Automated Surface Observing Systems (ASOSs, mostly NWS) and Automated Weather Observing Systems (AWOSs, mostly FAA) have been deployed at most airports, wind masts have been raised to 8 or 10 m (26 or 33 ft), depending on airplane clearance. The World Meteorological Organization recommends 10 m as the height for wind measurements (WMO 1983; 2005), and more groups are migrating slowly to this standard. The American Association of State Climatologists (AASC 1985) have recommended that wind be measured at 3 m, a standard geared more for agricultural applications than for general purpose uses where higher levels usually are preferred. Different anemometers have different starting thresholds; therefore, areas that frequently experience very light winds may not produce wind measurements thus affecting long-term mean estimates of wind speed. For both sustained winds (averages over a short interval of 2–60 minutes) and especially for gusts, the duration of the sampling interval makes considerable difference. For the same wind history, 1–second gusts are higher than gusts averaging 3 seconds, which in turn are greater than 5-second averages, so that the same sequence would be described with different numbers (all three systems and more are in use). Changes in the averaging procedure, or in height or exposure, can lead to "false" or "fake" climate change with no change in actual climate. Changes in any of these should be noted in the metadata.

E.1.9. Wind Nomenclature

Wind is a vector quantity having a direction and a speed. Directions can be two- or three-dimensional; they will be three-dimensional if the vertical component is important. In all common uses, winds always are denoted by the direction they blow *from* (north wind or southerly breeze). This convention exists because wind often brings weather, and thus our attention is focused upstream. However, this approach contrasts with the way ocean currents are viewed. Ocean currents usually are denoted by the direction they are moving *towards* (e.g. eastward current moves from west to east). In specialized applications (such as in atmospheric modeling), wind velocity vectors point in the direction that the wind is blowing. Thus, a southwesterly wind (from the southwest) has both northward and eastward (to the north and to the east) components. Except near mountains, wind cannot blow up or down near the ground, so the vertical component of wind often is approximated as zero, and the horizontal component is emphasized.

E.1.10. Frozen Precipitation

Frozen precipitation is more difficult to measure than liquid precipitation, especially with automated techniques. Goodison et al. (1998), Sevruk and Harmon (1984), and Yang et al. (1998; 2001) provide many of the reasons to explain this. The importance of frozen precipitation varies greatly from one setting to another. This subject was discussed in greater detail in a related inventory and monitoring report for the Alaska park units (Redmond et al. 2005).

In climates that receive frozen precipitation, a decision must be made whether or not to try to record such events accurately. This usually means that the precipitation must be turned into liquid either by falling into an antifreeze fluid solution that is then weighed or by heating the precipitation enough to melt and fall through a measuring mechanism such as a nearly-balanced tipping bucket. Accurate measurements from the first approach require expensive gauges; tipping buckets can achieve this resolution readily but are more apt to lose some or all precipitation. Improvements have been made to the heating mechanism on the NWS tipping-bucket gauge used for the ASOS to correct its numerous deficiencies making it less problematic; however, this gauge is not inexpensive. A heat supply needed to melt frozen precipitation usually requires more energy than renewable energy (solar panels or wind recharging) can provide thus AC power is needed. The availability of AC power is severely limited in many cold or remote U.S. settings. Furthermore, periods of frozen precipitation or rime often provide less-than-optimal recharging conditions with heavy clouds, short days, low-solar-elevation angles and more horizon blocking, and cold temperatures causing additional drain on the battery.

E.1.11. Save or Lose

A second consideration with precipitation is determining if the measurement should be saved (as in weighing systems) or lost (as in tipping-bucket systems). With tipping buckets, after the water has passed through the tipping mechanism, it usually just drops to the ground. Thus, there is no checksum to ensure that the sum of all the tips adds up to what has been saved in a reservoir at some location. By contrast, the weighing gauges continually accumulate until the reservoir is emptied, the reported value is the total reservoir content (for example, the height of the liquid column in a tube), and the incremental precipitation is the difference in depth between two known times. These weighing gauges do not always have the same fine resolution. Some gauges only record to the nearest centimeter, which is usually acceptable for hydrology but not necessarily for other needs. (For reference, a millimeter of precipitation can get a person in street clothes quite wet.) This is how the NRCS/USDA SNOTEL system works in climates that measure up to 3000 cm of snow in a winter. (See http://www.wcc.nrcs.usda.gov/publications for publications or http://www.wcc.nrcs.usda.gov/factpub/aib536.html for a specific description.) No precipitation is lost this way. A thin layer of oil is used to suppress evaporation, and anti-freeze ensures that frozen precipitation melts. When initially recharged, the sum of the oil and starting antifreeze solution is treated as the zero point. The anti-freeze usually is not sufficiently environmentally friendly to discharge to the ground and thus must be hauled into the area and then back out. Other weighing gauges are capable of measuring to the 0.25-mm (0.01-in.) resolution but do not have as much capacity and must be emptied more often. Day/night and storm-related thermal expansion and contraction and sometimes wind shaking can cause fluid pressure from accumulated totals to go up and down in SNOTEL gauges by small increments (commonly 0.3-3 cm, or 0.01–0.10 ft) leading to “negative precipitation” followed by similarly non-real light precipitation when, in fact, no change took place in the amount of accumulated precipitation.

E.1.12. Time

Time should always be in local standard time (LST), and daylight savings time (DST) should never be used under any circumstances with automated equipment and timers. Using DST leads to one duplicate hour, one missing hour, and a season of displaced values, as well as needless confusion and a data-management nightmare. Absolute time, such as Greenwich Mean Time (GMT) or Coordinated Universal Time (UTC), also can be used because these formats are unambiguously translatable. Since measurements only provide information about what already *has* occurred or *is* occurring and not what *will* occur, they should always be assigned to the *ending time* of the associated interval with hour 24 marking the end of the last hour of the day. In this system, midnight always represents the end of the day, not the start. To demonstrate the importance of this differentiation, we have encountered situations where police officers seeking corroborating weather data could not recall whether the time on their crime report from a year ago was the starting midnight or the ending midnight! Station positions should be known to within a few meters, easily accomplished with GPS, so that time zones and solar angles can be determined accurately.

E.1.13. Automated versus Manual

Most of this report has addressed automated measurements. Historically, most measurements are manual and typically collected once a day. In many cases, manual measurements continue because of habit, usefulness, and desire for continuity over time. Manual measurements are extremely useful and when possible should be encouraged. However, automated measurements are becoming more common. For either, it is important to record time in a logically consistent manner.

It should not be automatically assumed that newer data and measurements are "better" than older data or that manual data are "worse" than automated data. Older or simpler manual measurements are often of very high quality even if they sometimes are not in the most convenient digital format.

There is widespread desire to use automated systems to reduce human involvement. This is admirable and understandable, but every automated weather/climate station or network requires significant human attention and maintenance. A telling example concerns the Oklahoma Mesonet (see Brock et al. 1995, and bibliography at http://www.mesonet.ou.edu), a network of about 115 high–quality, automated meteorological stations spread over Oklahoma, where about 80 percent of the annual ($2–3M) budget is nonetheless allocated to humans with only about 20 percent allocated to equipment.

E.1.14. Manual Conventions

Manual measurements typically are made once a day. Elements usually consist of maximum and minimum temperature, temperature at observation time, precipitation, snowfall, snow depth, and sometimes evaporation, wind, or other information. Since it is not actually known when extremes occurred, the only logical approach, and the nationwide convention, is to ascribe the entire measurement to the time-interval date and to enter it on the form in that way. For morning observers (for example, 8 am to 8 am), this means that the maximum temperature written for today often is from yesterday afternoon and sometimes the minimum temperature for the 24-hr period actually occurred yesterday morning. However, this is understood and expected. It is often a surprise to observers to see how many maximum temperatures do not occur in the afternoon and how many minimum temperatures do not occur in the predawn hours. This is especially true in environments that are colder, higher, northerly, cloudy, mountainous, or coastal. As long as this convention is strictly followed every day, it has been shown that truly excellent climate records can result (Redmond 1992). Manual observers should reset equipment only one time per day at the official observing time. Making more than one measurement a day is discouraged strongly; this practice results in a hybrid record that is too difficult to interpret. The only exception is for total daily snowfall. New snowfall can be measured up to four times per day with no observations closer than six hours. It is well known that more frequent measurement of snow increases the annual total because compaction is a continuous process.

Two main purposes for climate observations are to establish the long-term averages for given locations and to track variations in climate. Broadly speaking, these purposes address topics of absolute and relative climate behavior. Once absolute behavior has been "established" (a task that is never finished because long-term averages continue to vary in time)—temporal variability quickly becomes the item of most interest.

E.2. Representativeness

Having discussed important factors to consider when new sites are installed, we now turn our attention to site "representativeness." In popular usage, we often encounter the notion that a site is "representative" of another site if it receives the same annual precipitation or records the same annual temperature or if some other element-specific, long-term average has a similar value. This notion of representativeness has a certain limited validity, but there are other aspects of this idea that need to be considered.

A climate monitoring site also can be said to be representative if climate records from that site show sufficiently strong temporal correlations with a large number of locations over a sufficiently large area. If station A receives 20 cm a year and station B receives 200 cm a year, these climates obviously receive quite differing amounts of precipitation. However, if their monthly, seasonal, or annual correlations are high (for example, 0.80 or higher for a particular time scale), one site can be used as a surrogate for estimating values at the other if measurements for a particular month, season, or year are missing. That is, a wet or dry month at one station is also a wet or dry month (relative to its own mean) at the comparison station. Note that high correlations on one time scale do not imply automatically that high correlations will occur on other time scales.

Likewise, two stations having similar mean climates (for example, similar annual precipitation) might not co-vary in close synchrony (for example, coastal versus interior). This may be considered a matter of climate "affiliation" for a particular location.

Thus, the representativeness of a site can refer either to the basic climatic averages for a given duration (or time window within the annual cycle) or to the extent that the site co-varies in time with respect to all surrounding locations. One site can be representative of another in the first sense but not the second, or vice versa, or neither, or both—all combinations are possible.

If two sites are perfectly correlated then, in a sense, they are "redundant." However, redundancy has value because all sites will experience missing data especially with automated equipment in rugged environments and harsh climates where outages and other problems nearly can be guaranteed. In many cases, those outages are caused by the weather, particularly by unusual weather and the very conditions we most wish to know about. Methods for filling in those values will require proxy information from this or other nearby networks. Thus, redundancy is a virtue rather than a vice.

In general, the cooperative stations managed by the NWS have produced much longer records than automated stations like RAWS or SNOTEL stations. The RAWS stations often have problems with precipitation, especially in winter, or with missing data, so that low correlations may be data problems rather than climatic dissimilarity. The RAWS records also are relatively short, so correlations should be interpreted with care. In performing and interpreting such analyses, however, we must remember that there are physical climate reasons and observational reasons why stations within a short distance (even a few tens or hundreds of meters) may not correlate well.

E.2.1. Temporal Behavior

It is possible that high correlations will occur between station pairs during certain portions of the year (i.e., January) but low correlations may occur during other portions of the year (e.g., September or October). The relative contributions of these seasons to the annual total (for precipitation) or average (for temperature) and the correlations for each month are both factors in the correlation of an aggregated time window of longer duration that encompasses those seasons (e.g., one of the year definitions such as calendar year or water year). A complete and careful evaluation ideally would include such a correlation analysis but requires more resources and data. Note that it also is possible and frequently is observed that temperatures are highly correlated while precipitation is not or vice versa, and these relations can change according to the time of year. If two stations are well correlated for all climate elements for all portions of the year, then they can be considered redundant.

With scarce resources, the initial strategy should be to try to identify locations that do not correlate particularly well, so that each new site measures something new that cannot be guessed easily from the behavior of surrounding sites. (An important caveat here is that lack of such correlation could be a result of physical climate behavior and not a result of faults with the actual measuring process; i.e., by unrepresentative or simply poor-quality data. Unfortunately, we seldom have perfect climate data.) As additional sites are added, we usually wish for some combination of unique and redundant sites to meet what amounts to essentially orthogonal constraints: new information and more reliably-furnished information.

A common consideration is whether to observe on a ridge or in a valley, given the resources to place a single station within a particular area of a few square kilometers. Ridge and valley stations will correlate very well for temperatures when lapse conditions prevail, particularly summer daytime temperatures. In summer at night or winter at daylight, the picture will be more mixed and correlations will be lower. In winter at night when inversions are common and even the rule, correlations may be zero or even negative and perhaps even more divergent as the two sites are on opposite sides of the inversion. If we had the luxury of locating stations everywhere, we would find that ridge tops generally correlate very well with other ridge tops and similarly valleys with other valleys, but ridge tops correlate well with valleys only under certain circumstances. Beyond this, valleys and ridges having similar orientations usually will correlate better with each other than those with perpendicular orientations, depending on their orientation with respect to large-scale wind flow and solar angles.

Unfortunately, we do not have stations everywhere, so we are forced to use the few comparisons that we have and include a large dose of intelligent reasoning, using what we have observed elsewhere. In performing and interpreting such analyses, we must remember that there are physical climatic reasons and observational reasons why stations within a short distance (even a few tens or hundreds of meters) may not correlate well.

Examples of correlation analyses include those for the Channel Islands and for southwest Alaska, which can be found in Redmond and McCurdy (2005) and Redmond et al. (2005). These examples illustrate what can be learned from correlation analyses. Spatial correlations generally vary by time of year. Thus, results should be displayed in the form of annual correlation cycles—for monthly mean temperature and monthly total precipitation and perhaps other climate elements like wind or humidity—between station pairs selected for climatic setting and data availability and quality.

In general, the COOP stations managed by the NWS have produced much longer records than have automated stations like RAWS or SNOTEL stations. The RAWS stations also often have problems with precipitation, especially in winter or with missing data, so that low correlations may be data problems rather than climate dissimilarity. The RAWS records are much shorter, so correlations should be interpreted with care, but these stations are more likely to be in places of interest for remote or under-sampled regions.

E.2.2. Spatial Behavior

A number of techniques exist to interpolate from isolated point values to a spatial domain. For example, a common technique is simple inverse distance weighting. Critical to the success of the simplest of such techniques is that some other property of the spatial domain, one that is influential for the mapped element, does not vary significantly. Topography greatly influences precipitation, temperature, wind, humidity, and most other meteorological elements. Thus, this criterion clearly is not met in any region having extreme topographic diversity. In such circumstances, simple Cartesian distance may have little to do with how rapidly correlation deteriorates from one site to the next, and in fact, the correlations can decrease readily from a mountain to a valley and then increase again on the next mountain. Such structure in the fields of spatial correlation is not seen in the relatively (statistically) well-behaved flat areas like those in the eastern United States.

To account for dominating effects such as topography and inland–coastal differences that exist in certain regions, some kind of additional knowledge must be brought to bear to produce meaningful, physically plausible, and observationally based interpolations. Historically, this has proven to be an extremely difficult problem, especially to perform objective and repeatable analyses. An analysis performed for southwest Alaska (Redmond et al. 2005) concluded that the PRISM (Parameter Regression on Independent Slopes Model) maps (Daly et al. 1994; 2002; Gibson et al. 2002; Doggett et al. 2004) were probably the best available. An analysis by Simpson et al. (2005) further discussed many issues in the mapping of Alaska's climate and resulted in the same conclusion about PRISM.

E.2.3. Climate-Change Detection

Although general purpose climate stations should be situated to address all aspects of climate variability, it is desirable that they also be in locations that are more sensitive to climate change from natural or anthropogenic influences should it begin to occur. The question here is how well we know such sensitivities. The polar regions and especially the North Pole are generally regarded as being more sensitive to changes in radiative forcing of climate because of positive feedbacks. The climate-change issue is quite complex because it encompasses more than just greenhouse gases.

Sites that are in locations or climates particularly vulnerable to climate change should be favored. How this vulnerability is determined is a considerably challenging research issue. Candidate locations or situations are those that lie on the border between two major biomes or just inside the edge of one or the other. In these cases, a slight movement of the boundary in anticipated direction (toward "warmer," for example) would be much easier to detect as the boundary moves past the site and a different set of biota begin to be established. Such a vegetative or ecologic response would be more visible and would take less time to establish as a real change than would a smaller change in the center of the distribution range of a marker or key species.

E.2.4. Element-Specific Differences

The various climate elements (temperature, precipitation, cloudiness, snowfall, humidity, wind speed and direction, solar radiation) do not vary through time in the same sequence or manner nor should they necessarily be expected to vary in this manner. The spatial patterns of variability should not be expected to be the same for all elements. These patterns also should not be expected to be similar for all months or seasons. The suitability of individual sites for measurement also varies from one element to another. A site that has a favorable exposure for temperature or wind may not have a favorable exposure for precipitation or snowfall. A site that experiences proper air movement may be situated in a topographic channel, such as a river valley or a pass, which restricts the range of wind directions and affects the distribution of speed-direction categories.

E.2.5. Logistics and Practical Factors

Even with the most advanced scientific rationale, sites in some remote or climatically challenging settings may not be suitable because of the difficulty in servicing and maintaining equipment. Contributing to these challenges are scheduling difficulties, animal behavior, snow burial, icing, snow behavior, access and logistical problems, and the weather itself. Remote and elevated sites usually require far more attention and expense than a rain-dominated, easily accessible valley location.

For climate purposes, station exposure and the local environment should be maintained in their original state (vegetation especially), so that changes seen are the result of regional climate variations and not of trees growing up, bushes crowding a site, surface albedo changing, fire clearing, etc. Repeat photography has shown many examples of slow environmental change in the vicinity of a station in rather short time frames (5–20 years), and this technique should be employed routinely and frequently at all locations. In the end, logistics, maintenance, and other practical factors almost always determine the success of weather- and climate-monitoring activities.

E.2.6. Personnel Factors

Many past experiences (almost exclusively negative) strongly support the necessity to place primary responsibility for station deployment and maintenance in the hands of seasoned, highly qualified, trained, and meticulously careful personnel, the more experienced the better. Over time, even in “benign” climates but especially where harsher conditions prevail, every conceivable problem will occur and both the usual and unusual should be anticipated: weather, animals, plants, salt, sensor and communication failure, windblown debris, corrosion, power failures, vibrations, avalanches, snow loading and creep, corruption of the data logger program, etc. An ability to anticipate and forestall such problems, a knack for innovation and improvisation, knowledge of electronics, practical and organizational skills, and presence of mind to bring the various small but vital parts, spares, tools, and diagnostic troubleshooting equipment are highly valued qualities. Especially when logistics are so expensive, a premium should be placed on using experienced personnel, since the slightest and seemingly most minor mistake can render a station useless or, even worse, uncertain. Exclusive reliance on individuals without this background can be costly and almost always will result eventually in unnecessary loss of data. Skilled labor and an apprenticeship system to develop new skilled labor will greatly reduce (but not eliminate) the types of problems that can occur in operating a climate network.

E.3. Site Selection

In addition to considerations identified previously in this appendix, various factors need to be considered in selecting sites for new or augmented instrumentation.

E.3.1. Equipment and Exposure Factors

E.3.1.1. Measurement Suite: All sites should measure temperature, humidity, wind, solar radiation, and snow depth. Precipitation measurements are more difficult but probably should be attempted with the understanding that winter measurements may be of limited or no value unless an all-weather gauge has been installed. Even if an all-weather gauge has been installed, it is desirable to have a second gauge present that operates on a different principle–for example, a fluid-based system like those used in the SNOTEL stations in tandem with a higher–resolution, tipping bucket gauge for summertime. Without heating, a tipping bucket gauge usually is of use only when temperatures are above freezing and when temperatures have not been below freezing for some time, so that accumulated ice and snow is not melting and being recorded as present precipitation. Gauge undercatch is a significant issue in snowy climates, so shielding should be considered for all gauges designed to work over the winter months. It is very important to note the presence or absence of shielding, the type of shielding, and the dates of installation or removal of the shielding.

E.3.1.2. Overall Exposure: The ideal, general all-purpose site has gentle slopes, is open to the sun and the wind, has a natural vegetative cover, avoids strong local (less than 200 m) influences, and represents a reasonable compromise among all climate elements. The best temperature sites are not the best precipitation sites, and the same is true for other elements. Steep topography in the immediate vicinity should be avoided unless settings where precipitation is affected by steep topography are being deliberately sought or a mountaintop or ridgeline is the desired location. The potential for disturbance should be considered: fire and flood risk, earth movement, wind-borne debris, volcanic deposits or lahars, vandalism, animal tampering, and general human encroachment are all factors.

E.3.1.3. Elevation: Mountain climates do not vary in time in exactly the same manner as adjoining valley climates. This concept is emphasized when temperature inversions are present to a greater degree and during precipitation when winds rise up the slopes at the same angle. There is considerable concern that mountain climates will be (or already are) changing and perhaps changing differently than lowland climates, which has direct and indirect consequences for plant and animal life in the more extreme zones. Elevations of special significance are those that are near the mean rain/snow line for winter, near the tree line, and near the mean annual freezing level (all of these may not be quite the same). Because the lapse rates in wet climates often are nearly moist-adiabatic during the main precipitation seasons, measurements at one elevation may be extrapolated to nearby elevations. In drier climates and in the winter, temperature and to a lesser extent wind will show various elevation profiles.

E.3.1.4. Transects: The concept of observing transects that span climatic gradients is sound. This is not always straightforward in topographically uneven terrain, but these transects could still be arranged by setting up station(s) along the coast; in or near passes atop the main coastal interior drainage divide; and inland at one, two, or three distances into the interior lowlands. Transects need not—and by dint of topographic constraints probably cannot—be straight lines, but the closer that a line can be approximated the better. The main point is to systematically sample the key points of a behavioral transition without deviating too radically from linearity.

E.3.1.5. Other Topographic Considerations: There are various considerations with respect to local topography. Local topography can influence wind (channeling, upslope/downslope, etc.), precipitation (orographic enhancement, downslope evaporation, catch efficiency, etc.), and temperature (frost pockets, hilltops, aspect, mixing or decoupling from the overlying atmosphere, bowls, radiative effects, etc.), to different degrees at differing scales. In general, for measurements to be areally representative, it is better to avoid these local effects to the extent that they can be identified before station deployment (once deployed, it is desirable not to move a station). The primary purpose of a climate-monitoring network should be to serve as an infrastructure in the form of a set of benchmark stations for comparing other stations. Sometimes, however, it is exactly these local phenomena that we want to capture. Living organisms, especially plants, are affected by their immediate environment, whether it is representative of a larger setting or not. Specific measurements of limited scope and duration made for these purposes then can be tied to the main benchmarks. This experience is useful also in determining the complexity needed in the benchmark monitoring process in order to capture particular phenomena at particular space and time scales.

Sites that drain (cold air) well generally are better than sites that allow cold air to pool. Slightly sloped areas (1 degree is fine) or small benches from tens to hundreds of meters above streams are often favorable locations. Furthermore, these sites often tend to be out of the path of hazards (like floods) and to have rocky outcroppings where controlling vegetation will not be a major concern. Benches or wide spots on the rise between two forks of a river system are often the only flat areas and sometimes jut out to give greater exposure to winds from more directions.

E.3.1.6. Prior History: The starting point in designing a program is to determine what kinds of observations have been collected over time, by whom, in what manner, and if these observation are continuing to the present time. It also may be of value to “re-occupy” the former site of a station that is now inactive to provide some measure of continuity or a reference point from the past. This can be of value even if continuous observations were not made during the entire intervening period.

E.3.2. Element-Specific Factors

E.3.2.1. Temperature: An open exposure with uninhibited air movement is the preferred setting. The most common measurement is made at approximately eye level, 1.5–2.0 m. In snowy locations sensors should be at least one meter higher than the deepest snowpack expected in the next 50 years or perhaps 2–3 times the depth of the average maximum annual depth. Sensors should be shielded above and below from solar radiation (bouncing off snow), from sunrise/sunset horizontal input, and from vertical rock faces. Sensors should be clamped tightly, so that they do not swivel away from level stacks of radiation plates. Nearby vegetation should be kept away from the sensors (several meters). Growing vegetation should be cut to original conditions. Small hollows and swales can cool tremendously at night, and it is best avoid these areas. Side slopes of perhaps a degree or two of angle facilitate air movement and drainage and, in effect, sample a large area during nighttime hours. The very bottom of a valley should be avoided. Temperature can change substantially from moves of only a few meters. Situations have been observed where flat and seemingly uniform conditions (like airport runways) appear to demonstrate different climate behaviors over short distances of a few tens or hundreds of meters (differences of 5–10°C). When snow is on the ground, these microclimatic differences can be stronger, and differences of 2–5°C can occur in the short distance between the thermometer and the snow surface on calm evenings.

E.3.2.2. Precipitation (liquid): Calm locations with vegetative or artificial shielding are preferred. Wind will adversely impact readings; therefore, the less the better. Wind effects on precipitation are far less for rain than for snow. Devices that “save” precipitation present advantages, but most gauges are built to dump precipitation as it falls or to empty periodically. Automated gauges give both the amount and the timing. Simple backups that record only the total precipitation since the last visit have a certain advantage (for example, storage gauges or lengths of PVC pipe perhaps with bladders on the bottom). The following question should be asked: Does the total precipitation from an automated gauge add up to the measured total in a simple bucket (evaporation is prevented with an appropriate substance such as mineral oil)? Drip from overhanging foliage and trees can augment precipitation totals.

E.3.2.3. Precipitation (frozen): Calm locations or shielding are a must. Undercatch for rain is only about 5 percent, but with winds of only 2–4 m/s, gauges may catch only 30–70 percent of the actual snow falling depending on density of the flakes. To catch 100 percent of the snow, the standard configuration for shielding is employed by the CRN (Climate Reference Network): the DFIR (Double-Fence Intercomparison Reference) shield with 2.4-m (8-ft.) vertical, wooden slatted fences in two concentric octagons with diameters of 8 m and 4 m (26 ft and 13 ft, respectively) and an inner Alter shield (flapping vanes). Numerous tests have shown this is the only way to achieve complete catch of snowfall (e.g., Yang et al. 1998; 2001). The DFIR shield is large and bulky; it is recommended that all precipitation gauges have at least Alter shields on them.

Near the ocean, much snow is heavy and falls more vertically. In colder locations or storms, light flakes frequently will fly in and then out of the gauge. Clearings in forests are usually excellent sites. Snow blowing from trees that are too close can augment actual precipitation totals. Artificial shielding (vanes, etc.) placed around gauges in snowy locales always should be used if accurate totals are desired. Moving parts tend to freeze up. Capping of gauges during heavy snowfall events is a common occurrence. When the cap becomes pointed, snow falls off to the ground and is not recorded. Caps and plugs often will not fall into the tube until hours, days, or even weeks have passed, typically during an extended period of freezing temperature or above or when sunlight finally occurs. Liquid-based measurements (e.g., SNOTEL "rocket" gauges) do not have the resolution (usually 0.3 cm [0.1 in.] rather than 0.03 cm [0.01 in.]) that tipping bucket and other gauges have but are known to be reasonably accurate in very snowy climates. Light snowfall events might not be recorded until enough of them add up to the next reporting increment. More expensive gauges like Geonors can be considered and could do quite well in snowy settings; however, they need to be emptied every 40 cm (15 in.) or so (capacity of 51 cm [20 in.]) until the new 91-cm (36-in.) capacity gauge is offered for sale. Recently, the NWS has been trying out the new (and very expensive) Ott all-weather gauge. Riming can be an issue in windy foggy environments below freezing. Rime, dew, and other forms of atmospheric condensation are not real precipitation, since they are caused by the gauge.

E.3.2.4. Snow Depth: Windswept areas tend to be blown clear of snow. Conversely, certain types of vegetation can act as a snow fence and cause artificial drifts. However, some amount of vegetation in the vicinity generally can help slow down the wind. The two most common types of snow-depth gauges are the Judd Snow Depth Sensor, produced by Judd Communications, and the snow depth gauge produced by Campbell Scientific, Inc. Opinions vary on which one is better. These gauges use ultrasound and look downward in a cone about 22 degrees in diameter. The ground should be relatively clear of vegetation and maintained in a manner so that the zero point on the calibration scale does not change.

E.3.2.5. Snow Water Equivalent: This is determined by the weight of snow on fluid-filled pads about the size of a desktop set up sometimes in groups of four or in larger hexagons several meters in diameter. These pads require flat ground some distance from nearby sources of windblown snow and shielding that is "just right": not too close to the shielding to act as a kind of snow fence and not too far from the shielding so that blowing and drifting become a factor. Generally, these pads require fluids that possess antifreeze-like properties, as well as handling and replacement protocols.

E.3.2.6. Wind: Open exposures are needed for wind measurements. Small prominences or benches without blockage from certain sectors are preferred. A typical rule for trees is to site stations back 10 tree-heights from all tree obstructions. Sites in long, narrow valleys can obviously only exhibit two main wind directions. Gently-rounded eminences are more favored. Any kind of topographic steering should be avoided to the extent possible. Avoiding major mountain chains or single isolated mountains or ridges is usually a favorable approach, if there is a choice. Sustained wind speed and the highest gusts (1-second) should be recorded. Averaging methodologies for both sustained winds and gusts can affect climate trends and should be recorded as metadata with all changes noted. Vegetation growth affects the vertical wind profile, and growth over a few years can lead to changes in mean wind speed even if the "real" wind does not change, so vegetation near the site (perhaps out to 50 m) should be maintained in a quasi-permanent status (same height and spatial distribution). Wind devices can rime up and freeze or spin out of balance. In severely rimed or windy climates, rugged anemometers, such as those made by Taylor, are worth considering. These anemometers are expensive but durable and can withstand substantial abuse. In exposed locations, personnel should plan for winds to be at least 50 m/s and be able to measure these wind speeds. At a minimum, anemometers should be rated to 75 m/s.

E.3.2.7. Humidity: Humidity is a relatively straightforward climate element. Close proximity to lakes or other water features can affect readings. Humidity readings typically are less accurate near 100 percent and at low humidities in cold weather.

E.3.2.8. Solar Radiation: A site with an unobstructed horizon obviously is the most desirable. This generally implies a flat plateau or summit. However, in most locations trees or mountains will obstruct the sun for part of the day.

E.3.2.9. Soil Temperature: It is desirable to measure soil temperature at locations where soil is present. If soil temperature is recorded at only a single depth, the most preferred depth is 10 cm. Other common depths include 25 cm, 50 cm, 2 cm, and 100 cm. Biological activity in the soil will be proportional to temperature with important threshold effects occurring near freezing.

E.3.2.10. Soil Moisture: Soil-moisture gauges are somewhat temperamental and require care to install. The soil should be characterized by a soil expert during installation of the gauge. The readings may require a certain level of experience to interpret correctly. If accurate, readings of soil moisture are especially useful.

E.3.2.11. Distributed Observations: It can be seen readily that compromises must be struck among the considerations described in the preceding paragraphs because some are mutually exclusive.

How large can a "site" be? Generally, the equipment footprint should be kept as small as practical with all components placed next to each other (within less than 10–20 m or so). Readings from one instrument frequently are used to aid in interpreting readings from the remaining instruments.

What is a tolerable degree of separation? Some consideration may be given to locating a precipitation gauge or snow pillow among protective vegetation, while the associated temperature, wind, and humidity readings would be collected more effectively in an open and exposed location within 20–50 m. Ideally, it is advantageous to know the wind measurement precisely at the precipitation gauge, but a compromise involving a short split, and in effect a "distributed observation," could be considered. There are no definitive rules governing this decision, but it is suggested that the site footprint be kept within approximately 50 m. There also are constraints imposed by engineering and electrical factors that affect cable lengths, signal strength, and line noise; therefore, the shorter the cable the better. Practical issues include the need to trench a channel to outlying instruments or to allow lines to lie atop the ground and associated problems with animals, humans, weathering, etc. Separating a precipitation gauge up to 100 m or so from an instrument mast may be an acceptable compromise if other factors are not limiting.

E.3.2.12. Instrument Replacement Schedules: Instruments slowly degrade, and a plan for replacing them with new, refurbished, or recalibrated instruments should be in place. After approximately five years, a systematic change-out procedure should result in replacing most sensors in a network. Certain parts, such as solar radiation sensors, are candidates for annual calibration or change-out. Anemometers tend to degrade as bearings erode or electrical contacts become uneven. Noisy bearings are an indication, and a stethoscope might aid in hearing such noises. Increased internal friction affects the threshold starting speed; once spinning, they tend to function properly. Increases in starting threshold speeds can lead to more zero-wind measurements and thus reduce the reported mean wind speed with no real change in wind properties. A field calibration kit should be developed and taken on all site visits, routine or otherwise. Rain gauges can be tested with drip testers during field visits. Protective conduit and tight water seals can prevent abrasion and moisture problems with the equipment, although seals can keep moisture in as well as out. Bulletproof casings sometimes are employed in remote settings. A supply of spare parts, at least one of each and more for less-expensive or more-delicate sensors, should be maintained to allow replacement of worn or nonfunctional instruments during field visits. In addition, this approach allows instruments to be calibrated in the relative convenience of the operational home—the larger the network, the greater the need for a parts depot.

E.3.3. Long-Term Comparability and Consistency

E.3.3.1. Consistency: The emphasis here is to hold biases constant. Every site has biases, problems, and idiosyncrasies of one sort or another. The best rule to follow is simply to try to keep biases constant through time. Since the goal is to track climate through time, keeping sensors, methodologies, and exposure constant will ensure that only true climate change is being measured. This means leaving the site in its original state or performing maintenance to keep it that way. Once a site is installed, the goal should be to never move the site even by a few meters or to allow significant changes to occur within 100 m for the next several decades.

Sites in or near rock outcroppings likely will experience less vegetative disturbance or growth through the years and will not usually retain moisture, a factor that could speed corrosion. Sites that will remain locally similar for some time are usually preferable. However, in some cases the intent of a station might be to record the local climate effects of changes within a small-scale system (for example, glacier, recently burned area, or scene of some other disturbance) that is subject to a regional climate influence. In this example, the local changes might be much larger than the regional changes.

E.3.3.2. Metadata: Since the climate of every site is affected by features in the immediate vicinity, it is vital to record this information over time and to update the record repeatedly at each service visit. Distances, angles, heights of vegetation, fine-scale topography, condition of instruments, shielding discoloration, and other factors from within a meter to several kilometers should be noted. Systematic photography should be undertaken and updated at least once every one–two years.

Photographic documentation should be taken at each site in a standard manner and repeated every two–three years. Guidelines for methodology were developed by Redmond (2004) as a result of experience with the NOAA CRN and can be found on the WRCC NPS Web pages at http://www.wrcc.dri.edu/nps and at ftp://ftp.wrcc.dri.edu/nps/photodocumentation.pdf.

The main purpose for climate stations is to *track climatic conditions through time*. Anything that affects the interpretation of records through time must to be noted and recorded for posterity. The important factors should be clear to a person who has never visited the site, no matter how long ago the site was installed.

In regions with significant, climatic transition zones, transects are an efficient way to span several climates and make use of available resources. Discussions on this topic at greater detail can be found in Redmond and Simeral (2004) and in Redmond et al. (2005).

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Appendix F. Descriptions of weather/climate-monitoring networks.

F.1. Utah Division of Air Quality (AQ)

- Purpose of network: provide weather data in support of air quality monitoring activities in Utah.
- Data website: http://www.airmonitoring.utah.gov/.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Wind speed and direction.
- Sampling frequency: 15 minutes.
- Reporting frequency: 15 minutes.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
- Network weaknesses:
  - Network limited to Utah.

The Utah Division of Air Quality runs weather stations to support their efforts in air quality monitoring for the state of Utah. This network is primarily an air-quality monitoring network managed by the EPA.

F.2. The Arizona Meteorological Network (AZMET)

- Purpose of network: provide weather data to agricultural and horticultural interests in southern and central Arizona.
- Data website: http://ag.arizona.edu/azmet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Precipitation.
  - Wind speed and direction.
  - Solar radiation
  - Soil temperatures
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
  - High-quality data and metadata.
- Network weaknesses:
  - Limited geographic extent (southern and central Arizona).

The Arizona Meteorological Network (AZMET) provides near-real-time weather data that is used primarily for agricultural applications in southern and central Arizona. This network began operating stations in January, 1987. Meteorological measurements collected by AZMET include temperature (air and soil), humidity, solar radiation, wind (speed and direction), and precipitation.

F.3. Clean Air Status and Trends Network (CASTNet)

- Purpose of network: provide information for evaluating the effectiveness of national emission-control strategies.
- Primary management agency: EPA.
- Data website: http://epa.gov/castnet/.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed.
  - Wind direction.
  - Wind gust.
  - Gust direction.
  - Solar radiation.
  - Soil moisture and temperature.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: $13000.
- Network strengths:
  - High-quality data.
  - Sites are well maintained.
- Network weaknesses:
  - Density of station coverage is low.
  - Shorter periods of record for western U.S.

CASTNet primarily is an air-quality-monitoring network managed by the EPA. The elements shown here are intended to support interpretation of measured air-quality parameters such as ozone, nitrates, sulfides, etc., which also are measured at CASTNet sites.

F.4. Clark County (Nevada) Regional Flood Control District (CCRFCD)

- Purpose of network: provide weather data for flash flood monitoring activities in Clark County, Nevada.
- Data website: http://www.ccrfcd.org.
- Measured weather/climate elements:
  - Precipitation.
- Sampling frequency: unknown.
- Reporting frequency: twice daily.
- Estimated station cost: unknown.
- Network strengths:

- Network coverage is dense in Clark County, Nevada.
- Network weaknesses:
  - Limited spatial extent.

The Clark County Regional Flood Control District (CCRFCD) was created in 1985. The CCRFCD operates a set of weather stations whose primary purpose is to collect near-real-time precipitation measurements in support of efforts by the CCRFCD to manage and monitor potential flood conditions in the district.

F.5. NWS Cooperative Observer Program (COOP)

- Purpose of network:
  - Provide observational, meteorological data required to define U.S. climate and help measure long-term climate changes.
  - Provide observational, meteorological data in near real-time to support forecasting and warning mechanisms and other public service programs of the NWS.
- Primary management agency: NOAA (NWS).
- Data website: data are available from the NCDC (http://www.ncdc.noaa.gov), RCCs (e.g., WRCC, http://www.wrcc.dri.edu), and state climate offices.
- Measured weather/climate elements
  - Maximum, minimum, and observation-time temperature.
  - Precipitation, snowfall, snow depth.
  - Pan evaporation (some stations).
- Sampling frequency: daily.
- Reporting frequency: daily or monthly (station-dependent).
- Estimated station cost: $2000 with maintenance costs of $500–900/year.
- Network strengths:
  - Decade–century records at most sites.
  - Widespread national coverage (thousands of stations).
  - Excellent data quality when well maintained.
  - Relatively inexpensive; highly cost effective.
  - Manual measurements; not automated.
- Network weaknesses:
  - Uneven exposures; many are not well-maintained.
  - Dependence on schedules for volunteer observers.
  - Slow entry of data from many stations into national archives.
  - Data subject to observational methodology; not always documented.
  - Manual measurements; not automated and not hourly.

The COOP network has long served as the main climate observation network in the United States. Readings are usually made by volunteers using equipment supplied, installed, and maintained by the federal government. The observer in effect acts as a host for the data-gathering activities and supplies the labor; this is truly a “cooperative” effort. The SAO sites often are considered to be part of the cooperative network as well if they collect the previously mentioned types of weather/climate observations. Typical observation days are morning to morning, evening to evening, or midnight to midnight. By convention, observations are ascribed to the date the instrument was reset at the end of the observational period. For this reason, midnight observations represent the end of a day. The Historical Climate Network is a subset of the cooperative network but contains longer and more complete records.

F.6. Colorado River Basin Forecast Center (CRBFC)

- Purpose of network: provide weather data for river forecasting efforts in Colorado River Basin.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
- Network weaknesses:
  - Instrumentation platforms do sometimes vary.

The CRBFC network has over 100 weather stations in the Colorado River Basin. The primary purpose of CRBFC stations is to collect meteorological data in support of efforts by the CRBFC to monitor potential flood conditions in the Colorado River Basin.

F.7. NOAA Climate Reference Network (CRN)

- Purpose of network: provide long-term homogeneous measurements of temperature and precipitation that can be coupled with long-term historic observations to monitor present and future climate change.
- Primary management agency: NOAA.
- Data website: http://www.ncdc.noaa.gov/crn/.
- Measured weather/climate elements:
  - Air temperature (triply redundant, aspirated).
  - Precipitation (three-wire Geonor gauge).
  - Wind speed.
  - Solar radiation.
  - Ground surface temperature.
- Sampling frequency: precipitation can be sampled either 5 or 15 minutes. Temperature sampled every 5 minutes. All other elements sampled every 15 minutes.
- Reporting frequency: hourly or every three hours.
- Estimated station cost: $30000 with maintenance costs around $2000/year.
- Network strengths:
  - Station siting is excellent (appropriate for long-term climate monitoring).
  - Data quality is excellent.
  - Site maintenance is excellent.
- Network weaknesses:
  - CRN network is still developing.

- Period of record is short compared to other automated networks. Earliest sites date from 2004.
- Station coverage is limited.
- Not intended for snowy climates.

Data from the CRN are used in operational climate-monitoring activities and are used to place current climate patterns into a historic perspective. The CRN is intended as a reference network for the United States that meets the requirements of the Global Climate Observing System. Up to 115 CRN sites are planned for installation, but the actual number of installed sites will depend on available funding.

F.8. Citizen Weather Observer Program (CWOP)

- Purpose of network: collect observations from private citizens and make these data available for homeland security and other weather applications, providing constant feedback to the observers to maintain high data quality.
- Primary management agency: NOAA MADIS program.
- Data Website: http://www.wxqa.com.
- Measured weather/climate elements:
  - Air temperature.
  - Dewpoint temperature.
  - Precipitation.
  - Wind speed and direction.
  - Barometric pressure.
- Sampling frequency: 15 minutes or less.
- Reporting frequency: 15 minutes.
- Estimated station cost: unknown.
- Network strengths:
  - Active partnership between public agencies and private citizens.
  - Large number of participant sites.
  - Regular communications between data providers and users, encouraging higher data quality.
- Network weaknesses:
  - Variable instrumentation platforms.
  - Metadata are sometimes limited.

The CWOP network is a public-private partnership with U.S. citizens and various agencies including NOAA, NASA (National Aeronautics and Space Administration), and various universities. There are over 4500 registered sites worldwide, with close to 3000 of these sites located in North America.

F.9. NPS Gaseous Pollutant Monitoring Program (GPMP)

- Purpose of network: measurement of ozone and related meteorological elements.
- Primary management agency: NPS.
- Data website: http://www2.nature.nps.gov/air/monitoring.
- Measured weather/climate elements:

- Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
  - Solar radiation.
  - Surface wetness.
- Sampling frequency: continuous.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Stations are located within NPS park units.
  - Data quality is excellent, with high data standards.
  - Provides unique measurements that are not available elsewhere.
  - Records are up to 2 decades in length.
  - Site maintenance is excellent.
  - Thermometers are aspirated.
- Network weaknesses:
  - Not easy to download the entire data set or to ingest live data.
  - Period of record is short compared to other automated networks. Earliest sites date from 2004.
  - Station spacing and coverage: station installation is episodic, driven by opportunistic situations.

The NPS web site indicates that there are 33 sites with continuous ozone analysis run by NPS, with records from a few to about 16-17 years. Of these stations, 12 are labeled as GPMP sites and the rest are labeled as CASTNet sites. All of these have standard meteorological measurements, including a 10-m mast. Another nine GPMP sites are located within NPS units but run by cooperating agencies. A number of other sites (1-2 dozen) ran for differing periods in the past, generally less than 5-10 years.

F.10. NOAA Ground-Based GPS Meteorology (GPS-MET)

- Purpose of network:
  - Measure atmospheric water vapor using ground-based GPS receivers.
  - Facilitate use of these data operational and in other research and applications.
  - Provides data for weather forecasting, atmospheric modeling and prediction, climate monitoring, calibrating and validation other observing systems including radiosondes and satellites, and research.
- Primary management agency: NOAA Earth System Research Laboratory.
- Data website: http://gpsmet.noaa.gov/jsp/index.jsp.
- Measurements:
  - Dual frequency carrier phase measurements every 30 seconds
- Ancillary weather/climate observations:
  - Air temperature.
  - Relative humidity.
  - Pressure.

- Reporting frequency: currently 30 min.
- Estimated station cost: $0-$10K, depending on approach. Data from dual frequency GPS receivers installed for conventional applications (e.g. high accuracy surveying) can be used without modification.
- Network strengths:
  - Frequent, high-quality measurements.
  - High reliability.
  - All-weather operability.
  - Many uses.
  - Highly leveraged.
  - Requires no calibration.
  - Measurement accuracy improves with time.
- Network weakness:
  - Point measurement.
  - Provides no direct information about the vertical distribution of water vapor.

The GPS-MET network is the first network of its kind dedicated to GPS meteorology (see Duan et al. 1996). The GPS-MET network was developed in response to the need for improved moisture observations to support weather forecasting, climate monitoring, and other research activities. GPS-MET is a collaboration between NOAA and several other governmental and university organizations and institutions.

GPS meteorology utilizes the radio signals broadcast by the satellite Global Positioning System for atmospheric remote sensing. GPS meteorology applications have evolved along two paths: ground-based (Bevis et al. 1992) and space-based (Yuan et al. 1993). Both applications make the same fundamental measurement (the apparent delay in the arrival of radio signals caused by changes in the radio-refractivity of the atmosphere along the paths of the radio signals) but they do so from different perspectives.

In ground-based GPS meteorology, a GPS receiver and antenna are placed at a fixed location on the ground and the signals from all GPS satellites in view are continuously recorded. From this information, the exact position of the GPS antenna can be determined over time with high (millimeter-level) accuracy. Subsequent measurements of the antenna position are compared with the known position, and the differences can be attributed to changes in the temperature, pressure and water vapor in the atmosphere above the antenna. By making continuous measurements of temperature and pressure at the site, the total amount of water vapor in the atmosphere at this location can be estimated with high accuracy under all weather conditions. For more information on ground based GPS meteorology the reader is referred to http://gpsmet.noaa.gov.

In space-based GPS meteorology, GPS receivers and antennas are placed on satellites in Low Earth Orbit (LEO), and the signals transmitted by a GPS satellite are continuously recorded as a GPS satellite "rises" or "sets" behind the limb of the Earth. This process is called an occultation or a limb sounding. The GPS radio signals bend more as they encounter a thicker atmosphere and the bending (which causes an apparent increase in the length of the path of the radio signal) can be attributed to changes in temperature, pressure and water vapor along the path of the radio signal through the atmosphere that is nominally about 300 km long. The location of an occultation depends on the relative geometries of the GPS satellites in Mid Earth Orbit and the satellites in LEO. As a consequence, information about the vertical temperature, pressure and moisture structure of the Earth's atmosphere as a whole can be estimated with high accuracy, but not at any one particular place over time. The main difference between ground and space-based GPS meteorology is one of geometry. A space-based measurement can be thought of as a ground-based measurement turned on its side. For more information on space based GPS meteorology, the reader is referred to http://www.cosmic.ucar.edu/gpsmet/.

F.11. Grand Staircase – Escalante National Monument Network (GSE)

- Purpose of network: provide weather data for Grand Staircase – Escalante National Monument.
- Network website: http://www.ut.blm.gov/gse.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Precipitation.
  - Wind speed and direction.
  - Wind gust and direction.
  - Pressure.
  - Solar radiation.
  - Soil temperature.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
  - Dense station coverage in and near Grand Staircase – Escalante National Monument.
- Network weaknesses:
  - Spatial coverage is limited.

The GSE network is a local network of weather/climate stations operated by the Utah division of the Bureau of Land Management. The primary purpose of these stations is to provide local meteorological data for Grand Staircase-Escalante National Monument. These stations are primarily located to the west of Glen Canyon National Recreation Area.

F.12. Los Alamos National Laboratory (LANL)

- Purpose of network: provide weather data for local climate research activities around Los Alamos National Laboratory in Los Alamos, New Mexico.
- Data website: http://www.weather.lanl.gov.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Precipitation.

  - Wind speed and direction.
- Sampling frequency: 15 minutes.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
  - Data are usually of very high quality.
- Network weaknesses:
  - Limited areal extent (immediate vicinity of Los Alamos, New Mexico).

The Los Alamos National Laboratory (LANL) operates a set of weather/climate stations whose objective is to provide meteorological observations and climatological information for the Los Alamos area. Measured elements include temperature, precipitation, humidity, pressure, wind speed and direction, and solar radiation. These data are of high quality.

F.13. Portable Ozone Monitoring System (POMS)

- Purpose of network: provide seasonal, short-term (1-5 years) monitoring of near-surface atmospheric ozone levels in remote locations.
- Primary management agency: NPS.
- Data website: http://www2.nature.nps.gov/air/studies/portO3.htm.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed and direction.
  - Solar radiation.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: $20000 with operation and maintenance costs of up to $10000/year.
- Network strengths:
  - High-quality data.
  - Site maintenance is excellent.
- Network weaknesses:
  - No long-term sites, so not as useful for climate monitoring.
  - Sites are somewhat expensive to operate.

The POMS network is operated by the NPS Air Resources Division. Sites are intended primarily for summer, short-term (1-5 years) monitoring of near-surface atmospheric ozone levels in remote locations. Measured meteorological elements include temperature, precipitation, wind, relative humidity, and solar radiation.

F.14. Remote Automated Weather Station (RAWS)

- Purpose of network: provide near-real-time (hourly or near hourly) measurements of meteorological variables for use in fire weather forecasts and climatology. Data from RAWS also are used for natural resource management, flood forecasting, natural hazard management, and air-quality monitoring.
- Primary management agency: WRCC, National Interagency Fire Center.
- Data website: http://www.raws.dri.edu/index.html.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed.
  - Wind direction.
  - Wind gust.
  - Gust direction.
  - Solar radiation.
  - Soil moisture and temperature.
- Sampling frequency: 1 or 10 minutes, element-dependent.
- Reporting frequency: generally hourly. Some stations report every 15 or 30 minutes.
- Estimated station cost: $12000 with satellite telemetry ($8000 without satellite telemetry); maintenance costs are around $2000/year.
- Network strengths:
  - Metadata records are usually complete.
  - Sites are located in remote areas.
  - Sites are generally well-maintained.
  - Entire period of record available on-line.
- Network weaknesses:
  - RAWS network is focused largely on fire management needs (formerly focused only on fire needs).
  - Frozen precipitation is not measured reliably.
  - Station operation is not always continuous.
  - Data transmission is completed via one-way telemetry. Data are therefore recoverable either in real-time or not at all.

The RAWS network is used by many land-management agencies, such as the BLM, NPS, Fish and Wildlife Service, Bureau of Indian Affairs, Forest Service, and other agencies. The RAWS network was one of the first automated weather station networks to be installed in the United States. Most gauges do not have heaters, so hydrologic measurements are of little value when temperatures dip below freezing or reach freezing after frozen precipitation events. There are approximately 1100 real-time sites in this network and about 1800 historic sites (some are decommissioned or moved). The sites can transmit data all winter but may be in deep snow in some locations. The WRCC is the archive for this network and receives station data and metadata through a special connection to the National Interagency Fire Center in Boise, Idaho.

F.15. NWS/FAA Surface Airways Observation Network (SAO)

- Purpose of network: provide near-real-time (hourly or near hourly) measurements of meteorological variables and are used both for airport operations and weather forecasting.
- Primary management agency: NOAA, FAA.
- Data website: data are available from state climate offices, RCCs (e.g., WRCC, http://www.wrcc.dri.edu), and NCDC (http://www.ncdc.noaa.gov).
- Measured weather/climate elements:
  - Air temperature.
  - Dewpoint and/or relative humidity.
  - Wind speed.
  - Wind direction.
  - Wind gust.
  - Gust direction.
  - Barometric pressure.
  - Precipitation (not at many FAA sites).
  - Sky cover.
  - Ceiling (cloud height).
  - Visibility.
- Sampling frequency: element-dependent.
- Reporting frequency: element-dependent.
- Estimated station cost: $100000–$200000 with maintenance costs approximately $10000/year.
- Network strengths:
  - Records generally extend over several decades.
  - Consistent maintenance and station operations.
  - Data record is reasonably complete and usually high quality.
  - Hourly or sub-hourly data.
- Network weaknesses:
  - Nearly all sites are located at airports.
  - Data quality can be related to size of airport—smaller airports tend to have poorer datasets.
  - Influences from urbanization and other land-use changes.

These stations are managed by NOAA, U. S. Navy, U. S. Air Force, and FAA. These stations are located generally at major airports and military bases. The FAA stations often do not record precipitation, or they may provide precipitation records of reduced quality. Automated stations are typically ASOSs for the NWS or AWOSs for the FAA. Some sites only report episodically with observers paid per observation.

F.16. USDA/NRCS Snowfall Telemetry (SNOTEL) network

- Purpose of network: collect snowpack and related climate data to assist in forecasting water supply in the western United States.
- Primary management agency: NRCS.
- Data website: http://www.wcc.nrcs.usda.gov/snow/.
- Measured weather/climate elements:

- Air temperature.
  - Precipitation.
  - Snow water content.
  - Snow depth.
  - Relative humidity (enhanced sites only).
  - Wind speed (enhanced sites only).
  - Wind direction (enhanced sites only).
  - Solar radiation (enhanced sites only).
  - Soil moisture and temperature (enhanced sites only).
- Sampling frequency: 1-minute temperature; 1-hour precipitation, snow water content, and snow depth. Less than one minute for relative humidity, wind speed and direction, solar radiation, and soil moisture and temperature (all at enhanced site configurations only).
- Reporting frequency: reporting intervals are user-selectable. Commonly used intervals are every one, two, three, or six hours.
- Estimated station cost: $20K with maintenance costs approximately $2K/year.
- Network strengths:
  - Sites are located in high-altitude areas that typically do not have other weather or climate stations.
  - Data are of high quality and are largely complete.
  - Very reliable automated system.
- Network weaknesses:
  - Historically limited number of elements.
  - Remote so data gaps can be long.
  - Metadata sparse and not high quality; site histories are lacking.
  - Measurement and reporting frequencies vary.
  - Many hundreds of mountain ranges still not sampled.
  - Earliest stations were installed in the late 1970s; temperatures have only been recorded since the 1980s.

USDA/NRCS maintains a set of automated snow-monitoring stations known as the SNOTEL (snowfall telemetry) network. These stations are designed specifically for cold and snowy locations. Precipitation and snow water content measurements are intended for hydrologic applications and water-supply forecasting, so these measurements are measured generally to within 2.5 mm (0.1 in.). Snow depth is tracked to the nearest 25 mm (1 inch). These stations function year around.

F.17. USDA/NRCS Snowcourse Network (NRCS-SC)

- Purpose of network: collect snowpack and related climate data to assist in forecasting water supply in the western United States.
- Primary management agency: NRCS.
- Data website: http://www.wcc.nrcs.usda.gov/snowcourse/.
- Measured weather/climate elements:
  - Snow depth.
  - Snow water equivalent.
- Measurement, reporting frequency: monthly or seasonally.

- Estimated station cost: cost of man-hours needed to set up snowcourse and make measurements.
- Network strengths
  - Periods of record are generally long.
  - Large number of high-altitude sites.
- Network weaknesses
  - Measurement and reporting only occurs on monthly to seasonal basis.
  - Few weather/climate elements are measured.

USDA/NRCS maintains another network of snow-monitoring stations in addition to SNOTEL. These sites are known as snowcourses. Many of these sites have been in operation since the early part of the twentieth century. These are all manual sites where only snow depth and snow water content are measured.

F.18. USDA/USFS Avalanche Network (SNOWNET)

- Purpose of network: provide near-real-time weather data for monitoring of snow conditions.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Precipitation.
  - Wind speed and direction.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
  - Sites are located in areas that traditionally have sparse weather and climate station coverage.
- Network weaknesses:
  - Station operation can be seasonal (e.g. winter).
  - Data are sometimes of questionable quality.

The United States Forest Service (USFS) administers a collection of weather stations run by various state- and local-level avalanche centers throughout the western U.S. Measured meteorological elements include temperature, precipitation, wind, and humidity.

F.19. Weather For You (WX4U)

- Purpose of network: allow volunteer weather enthusiasts around the U.S. to observe and share weather data.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.

    - Precipitation.
    - Wind speed and direction.
    - Wind gust and direction.
    - Pressure.
- Sampling frequency: 10 minutes.
- Reporting frequency: 10 minutes.
- Estimated station cost: unknown.
- Network strengths:
    - Stations are located throughout the U.S.
    - Stations provide near-real-time observations.
- Network weaknesses:
    - Instrumentation platforms can be variable.
    - Data are sometimes of questionable quality.

The WX4U network is a nationwide collection of weather stations run by local observers. Meteorological elements that are measured usually include temperature, precipitation, wind, and humidity.

Appendix G. Electronic supplements.

G.1. ACIS metadata file for weather and climate stations associated with the SCPN: http://www.wrcc.dri.edu/nps/pub/scpn/metadata/SCPN_from_ACIS.tar.gz.

G.2. SCPN metadata files for weather and climate stations associated with the SCPN: http://www.wrcc.dri.edu/nps/pub/scpn/metadata/SCPN_NPS.tar.gz.

Appendix H. Additional weather/climate stations.

Name	Lat.	Lon.	Elev. (m)	Network	Start	End
Cerro	35.845	-106.403	M	NPS MISC	5/29/1996	Present
Firetower	35.779	-106.266	M	NPS MISC	8/19/1993	Present
Ponderosa	35.833	-106.358	M	NPS MISC	6/18/1996	Present
Frijolito	35.778	-106.279	M	NPS MISC	7/23/1993	Present
Bandalier	35.780	-106.266	M	IMPROVE	10/5/1988	Present
Rim Fire Tower	35.780	-106.266	M	NADP	6/22/1982	Present
Shabikeschee	36.017	-107.846	M	NPS MISC	4/1/1989	Present
Pueblo Bonito	36.060	-107.962	M	NPS MISC	4/1/1989	Present
Fajada Gap	36.021	-107.931	M	NPS MISC	4/1/1989	Present
Desert View Tower	36.044	-111.826	2290	IMPROVE	10/1/1979	2/28/1987
Hance Camp	35.973	-111.984	2235	IMPROVE	12/18/1997	Present
Hopi Point Fire Tower	36.072	-112.155	2152	NADP	8/1/1981	11/26/2002
Hopi Point Fire Tower	36.072	-112.155	2152	IMPROVE	8/1/1981	11/26/2002
Yavapai Museum	36.067	-112.118	2177	IMPROVE	12/13/1989	Present
Indian Gardens	36.078	-112.128	1166	IMPROVE	6/1/2004	Present
Grandview Point	35.996	-111.988	2256	IMPROVE	12/18/1986	Present
Mesa Verde National Park	37.275	-108.687	1821	CoAgMet	1/1/2002	5/31/2005
Mesa Verde National Park	37.198	-108.490	2172	NADP	4/28/1981	Present

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