National Park Service
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Natural Resource Program Center
Fort Collins, Colorado

Weather and Climate Inventory
National Park Service
Cumberland Piedmont Network

Natural Resource Technical Report NPS/CUPN/NRTR—2007/009

ON THE COVER
Carl Sandburg Home National Historic Site

Weather and Climate Inventory
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Natural Resource Technical Report NPS/CUPN/NRTR—2007/009
WRCC Report 2007-05

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NPS/CUPN/NRTR—2007/009, April 2007

Contents

Contents (continued)

Page

Figures

Page

Tables

Page

Appendixes

Acronyms

AASC	American Association of State Climatologists
ABLI	Abraham Lincoln Birthplace National Historic Site
ACIS	Applied Climate Information System
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
BLM	Bureau of Land Management
CARL	Carl Sandburg Home National Historic Site
CASTNet	Clean Air Status and Trends Network
CHCH	Chickamauga and Chattanooga National Military Park
COOP	Cooperative Observer Program
COWP	Cowpens National Battlefield
CUGA	Cumberland Gap National Historical Park
CUPN	Cumberland Piedmont Inventory and Monitoring Network
DFIR	Double-Fence Intercomparison Reference
DST	daylight savings time
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FODO	Fort Donelson National Battlefield
FIPS	Federal Information Processing Standards
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
GUCO	Guilford Courthouse National Military Park
I&M	NPS Inventory and Monitoring Program
KIMO	Kings Mountain National Military Park
LEO	Low Earth Orbit
LIRI	Little River Canyon National Preserve
LST	local standard time
MACA	Mammoth Cave National Park
MDN	Mercury Deposition Network
NADP	National Atmospheric Deposition Program
NAO-AO	North Atlantic Oscillation – Arctic Oscillation
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NetCDF	Network Common Data Form
NISI	Ninety Six National Historic Site
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
POMS	Portable Ozone Monitoring System

PRISM	Parameter Regression on Independent Slopes Model
RAWS	Remote Automated Weather Station network
RCC	regional climate center
RUCA	Russell Cave National Monument
SAO	Surface Airways Observation network
SHIL	Shiloh National Military Park
SNOTEL	Snowfall Telemetry network
SOD	Summary Of the Day
STRI	Stones River National Battlefield
Surfrad	Surface Radiation Budget network
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
WBAN	Weather Bureau Army Navy
WMO	World Meteorological Organization
WRCC	Western Regional Climate Center
WX4U	Weather For You network

Executive Summary

Climate is a dominant factor driving the physical and ecologic processes affecting the Cumberland Piedmont Inventory and Monitoring Network (CUPN). Climate variations are responsible for short- and long-term changes in ecosystem fluxes of energy and matter and have profound effects on underlying geomorphic and biogeochemical processes. Climate characteristics of the CUPN drive water and water quality, which are a vital component of the terrestrial, aquatic, and cave ecosystems in the CUPN. Climate also influences levels of atmospheric pollutants and the spread of invasive plant species, both of which are significant anthropogenic threats to native plant species in the CUPN. The relationship between climate and land-use patterns in the CUPN is also important, as land use changes in the CUPN region introduce local microclimate and regional climate changes that in turn lead to further local- and regional-scale changes in CUPN ecosystems. Climate has been identified as one of the 12 basic inventories to be completed for all National Park Service (NPS) Inventory and Monitoring Program (I&M) networks.

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 CUPN park units.
- Inventory of weather and climate station locations in and near CUPN park units relevant to the 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 characteristics of the CUPN park units are influenced primarily by latitude and their proximity to either the Atlantic Ocean or the Gulf of Mexico. Precipitation increases generally from northeast to southwest across the CUPN. Superimposed on this background gradient is a sharp precipitation maximum over the southern Appalachian Mountains. Mean annual precipitation in the CUPN park units ranges from under 1200 mm at Guilford Courthouse National Military Park (GUCO) to almost 1600 mm at Carl Sandburg Home National Historic Site (CARL). Distinct seasonal variations in precipitation are evident throughout the CUPN. In western portions of the network, winter and early spring is the wettest time of the year, while to the east, summer tends to be the wettest time of the year. All areas within the CUPN generally see their driest conditions during the fall months. Mean annual temperatures in the CUPN are influenced both by proximity to oceans and by elevation, ranging from 11°C in Cumberland Gap National Historical Park (CUGA) up to 15°C in Ninety Six National Historic Site (NISI). In the winter months, latitudinal temperature gradients become very apparent, with the coldest conditions in northern park units. Temperatures in these northern park units have occasionally dropped to -25°C or lower. In the summer, however, topography plays a more important role in defining temperature characteristics for the CUPN. Both the Cumberland Plateau (eastern Kentucky and central Tennessee) and the Appalachian Mountains exhibit cooler summer temperatures compared to their surroundings. Although mean maximum temperatures in July

typically range between 28-32°C, some lower-elevation park units like NISI have observed summer maximum temperatures between 40-45°C.

Through a search of national databases and inquiries to NPS staff, we have identified 29 weather and climate stations within CUPN park units. Mammoth Cave National Park (MACA) has the most stations within its boundaries (5).

The CUPN network has collected some preliminary weather/climate station metadata for CARL and MACA. These metadata were helpful particularly in the initial stages of the CUPN weather/climate station inventory described in this report.

For a handful of the CUPN park units, including MACA, coverage of both real-time weather/climate stations and long-term climate stations is satisfactory both within park boundaries and in adjacent regions. Otherwise, many of the park units in the CUPN have limited coverage of both near-real-time stations and long-term stations within and near the parks. It is therefore important that NPS work with local agencies to ensure that any active near-real-time and long-term weather/climate stations be retained in order to continue their valuable contributions for weather and climate monitoring in the CUPN.

Two park units in the CUPN have potential long-term climate records that are comprised of records from two separate stations we identified. With both park units, it is likely that only one station is really under consideration but has gone by different names during its period of record. At CUGA, the COOP stations “Baxter” and “Harlan” are actually the same station. This station went by the name “Harlan” from 1918-1952 but then went by the name “Baxter” from 1952 until present. Since these are the only long-term records identified for CUGA, these combined records should be utilized. At Cowpens National Battlefield (COWP), the COOP station “Chesnee 7 WSW” has also been identified as “Rainbow Lake” at various times throughout its history. Other reliable records are available around COWP besides the record at “Chesnee 7 WSW.”

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 Cumberland Piedmont Inventory and Monitoring Network. Particular thanks are extended to Teresa Leibfried, Bobby Carson, and Johnathan Jernigan. We also thank John Gross, Margaret Beer, Grant Kelly, Greg McCurdy, and Heather Angeloff for all their help. 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 NOAA Western Regional Climate Center.

1.0. Introduction

Weather and climate are key drivers in ecosystem structure and function. 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. Secondary constraints are realized from the intensity and duration of individual weather events and, additionally, from seasonality and inter-annual climate variability. These constraints influence the fundamental properties of ecologic systems, such as soil–water relationships, plant–soil processes, and nutrient cycling, as well as disturbance rates and intensity. These properties, in turn, influence the life-history strategies supported by a climatic regime (Neilson 1987; Leibfried 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 Cumberland Piedmont Inventory and Monitoring Network (CUPN) have an effective climate-monitoring system in place to track climate changes and to aid in management decisions relating to these changes. The purpose of this report is to determine the current status of weather and climate monitoring within the CUPN (Table 1.1; Figure 1.1). In this report, we provide the following informational elements:

- Overview of broad-scale climatic factors and zones important to CUPN park units.
- Inventory of locations for all weather stations in and near CUPN 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.

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 A 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 operated 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 additional 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 (RAWS) network 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.

Table 1.1. Park units in the Cumberland Piedmont Network.

Acronym	Name
ABLI	Abraham Lincoln Birthplace National Historic Site
CARL	Carl Sandburg Home National Historic Site
CHCH	Chickamauga and Chattanooga National Military Park
COWP	Cowpens National Battlefield
CUGA	Cumberland Gap National Historical Park
FODO	Fort Donelson National Battlefield
GUCO	Guilford Courthouse National Military Park
KIMO	Kings Mountain National Military Park
LIRI	Little River Canyon National Preserve
MACA	Mammoth Cave National Park
NISI	Ninety Six National Historic Site
RUCA	Russell Cave National Monument
SHIL	Shiloh National Military Park
STRI	Stones River National Battlefield

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

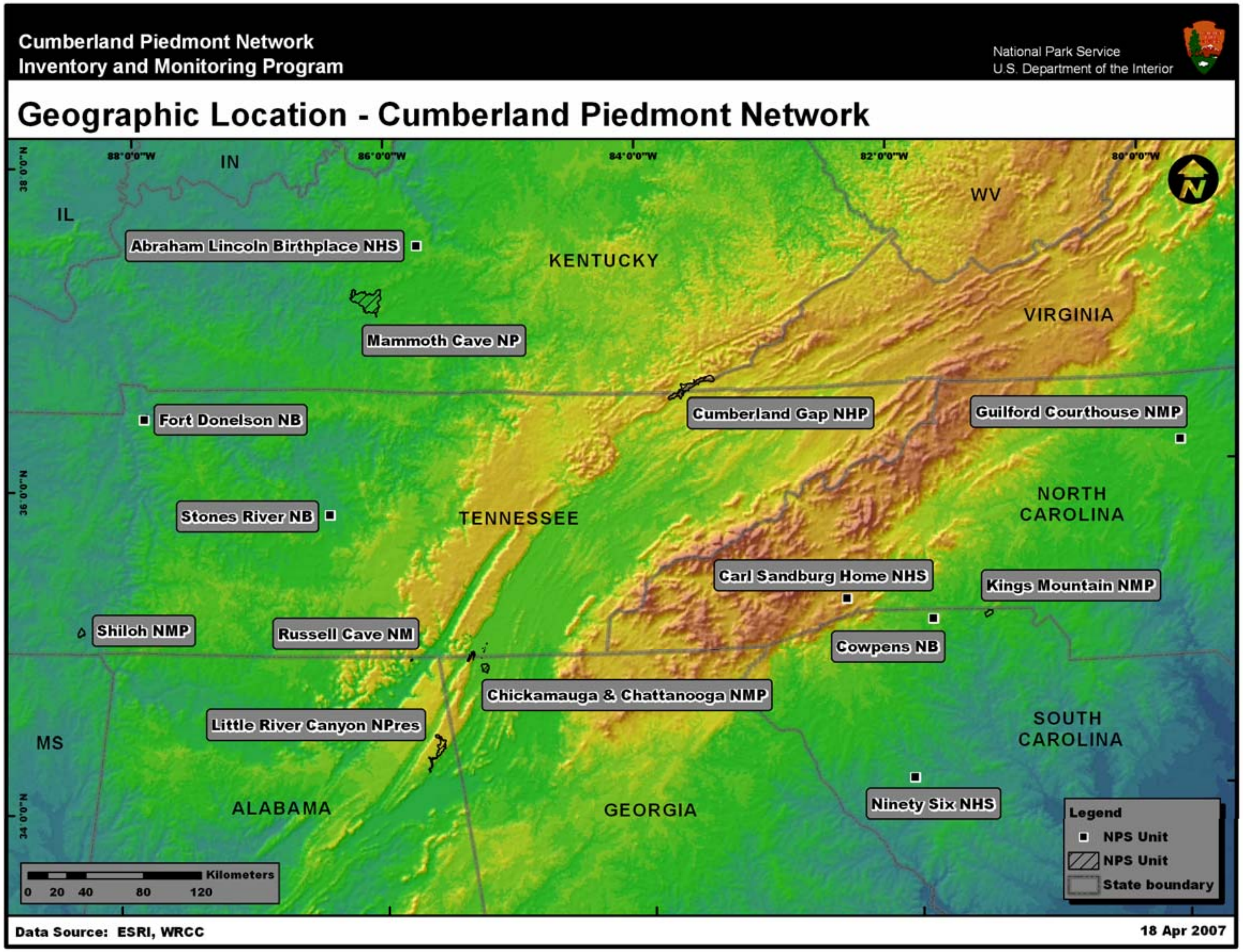


Figure 1.1. Map of the Cumberland Piedmont Network.

spatial properties of atmospheric behavior (see Appendix A). Climate and weather phenomena shade gradually into each other and are ultimately inseparable.

1.3. Purpose of Measurements

Climate inventory and monitoring climate activities should be based on a set of guiding fundamental principles. Any evaluation of 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.

Weather and climate data and information constitute a prominent and widely requested component of the NPS I&M networks (I&M 2006). 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 while they are 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.
- Consistently monitor climate 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 CUPN 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. 1996a; NRC 2001). These principals are presented in Appendix B, 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 D.

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 over 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 greatly underappreciated and is 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 soon after 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 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 at the major national networks are $1500–2500 per station per year but these costs still can vary greatly depending on the kind of automated site.

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. Quality-control 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, since good data are absolutely crucial for interpreting climate records properly, 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 in 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. These lands are largely protected from human development and other land changes that can impact observed climate records. 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

The vital signs monitoring objectives of the CUPN are centered around the three major ecosystem types in the CUPN: aquatic, cave, and terrestrial ecosystems (Leibfreid et al. 2005). Processes in each of these ecosystem types are governed by climate characteristics. Temporal variations in temperature and precipitation, in particular, can have significant influences on the health of each of these ecosystem types, affecting things such as water quality, subterranean water and nutrient transport, and trends in visibility and air pollution.

It is essential that the CUPN park units have an effective climate monitoring system to track climate changes and to aid in management decisions relating to these changes. These efforts are needed in order to support current vital sign monitoring activities within the park units of the CUPN. In order to do this, however, it is essential to understand the climate characteristics of the CUPN, as discussed in this chapter.

2.1. Climate and the CUPN Environment

Climate characteristics of the CUPN drive water and water quality, which are a vital component of the terrestrial, aquatic, and cave ecosystems in the CUPN (Leibfreid et al. 2005). Furthermore, water serves to tie the CUPN ecosystems together into a functional whole through the transport of nutrients, provision of natural habitats, and conveyance and distribution of chemical and physical threats and stressors. For some parks, surface waters support diverse vertebrate and invertebrate fauna. In other CUPN parks, groundwater flowing through karst aquifers is very important, as these karst aquifers are directly linked to surface waters in the form of recharge, typically via sinkholes and sinking streams. Climate variations, particularly those associated with precipitation, have direct impacts on the quantity and quality of the water in the CUPN ecosystems.

Climate also influences levels of atmospheric pollutants, which are a significant anthropogenic threat to park natural resources across the southeastern U.S. (NAST 2001), including the CUPN (Leibfreid et al. 2005). Many native plant species in the CUPN, including several known threatened and endangered species, are already showing signs of stress from increased pollution levels.

In addition to the stresses from air pollution, native plants communities in the CUPN are also being compromised by the introduction of invasive plant species (Leibfreid et al. 2005). Climate variations will have a direct influence on the rates of spread of these invasive species, and the abilities of native plant communities to respond to the introduction of non-native species.

The relationship between climate and land-use patterns in the CUPN is also important. In addition to introducing habitat fragmentation and decreasing biodiversity in the CUPN (Leibfreid et al. 2005), land use changes in the CUPN region also introduce local microclimate and regional climate changes that in turn lead to further local- and regional-scale changes in CUPN ecosystems.

2.2. Spatial Variability

The climate characteristics of the CUPN park units are influenced primarily by latitude and their proximity to either the Atlantic Ocean or the Gulf of Mexico, although the presence of the Appalachian Mountains in eastern CUPN also plays a role. Mean annual precipitation increases generally from northeast to southwest across the CUPN (Figure 2.1), directly related to the proximity to moist air flows from the Gulf of Mexico. Superimposed on this background gradient is a sharp precipitation maximum over the southern Appalachian Mountains. Mean annual precipitation in the CUPN park units ranges from under 1200 mm in the driest park units (e.g., GUCO) to almost 1600 mm in the wettest park units (e.g., CARL). Distinct seasonal variations in precipitation are evident throughout the CUPN (Figure 2.2). In western portions of the network (e.g., Figure 2.2a), winter and early spring is the wettest time of the year. To the east, closer to the Appalachian Mountains (e.g., Figure 2.2c), convective precipitation becomes more important and summer tends to be the wettest time of the year. All areas within the CUPN generally see their driest conditions during the fall months.

Mean annual temperatures in the CUPN (Figure 2.3) are influenced both by proximity to oceans and by elevation. These temperatures range from 11°C in CUGA up to 15°C and greater in NISI. In the winter months, latitudinal temperature gradients become apparent (Figure 2.4). In Kentucky park units, winter temperatures commonly get down to -6°C, and in some cases have dropped below -25°C. Warmer park units in the CUPN, such as NISI in South Carolina, generally reach -2°C, with temperatures occasionally dropping below -10°C. In the summer, topography plays a more important role in defining temperature characteristics for the CUPN. Both the Cumberland Plateau (eastern Kentucky and central Tennessee) and the Appalachian Mountains exhibit cooler summer temperatures compared to their surroundings. For example, CARL is located in the southern Appalachian Mountains of North Carolina and has mean July maximum temperatures under 28°C (Figure 2.5). In contrast to this, lower-elevation park units such as NISI in South Carolina have mean July maximum temperatures that almost reach 32°C. The hottest observed temperatures at both NISI and SHIL (southern Tennessee) have been between 40-45°C.

2.3. Temporal Variability

Some studies indicate that precipitation has increased slightly over the last century for much of the eastern U.S. (Karl et al. 1996b; Karl and Knight 1998; NAST 2001). This pattern is somewhat apparent in portions of Tennessee and Kentucky (Figure 2.6a; 2.6b) but is not apparent across the Piedmont of North Carolina (Figure 2.6c). Temperature patterns for the CUPN (Figure 2.7) do not show any clear trend. The warmest temperatures on record in the CUPN generally occurred during the 1940s and 1950s. After a cooling in the 1960s, temperatures in the CUPN commenced a gradual warming trend that continues to this day. These patterns highlight the emphasis on measurement consistency that is needed in order to properly detect long-term climatic changes.

The El Niño-Southern Oscillation (ENSO) influences interannual climate variability in the CUPN. Warm ENSO phases (El Niño events) tend to bring cooler and wetter winter conditions across the southeastern U.S. (NAST 2001), particularly in the southern portions of the CUPN. Increased occurrences of severe thunderstorms are also evident in the CUPN during warm ENSO phases.

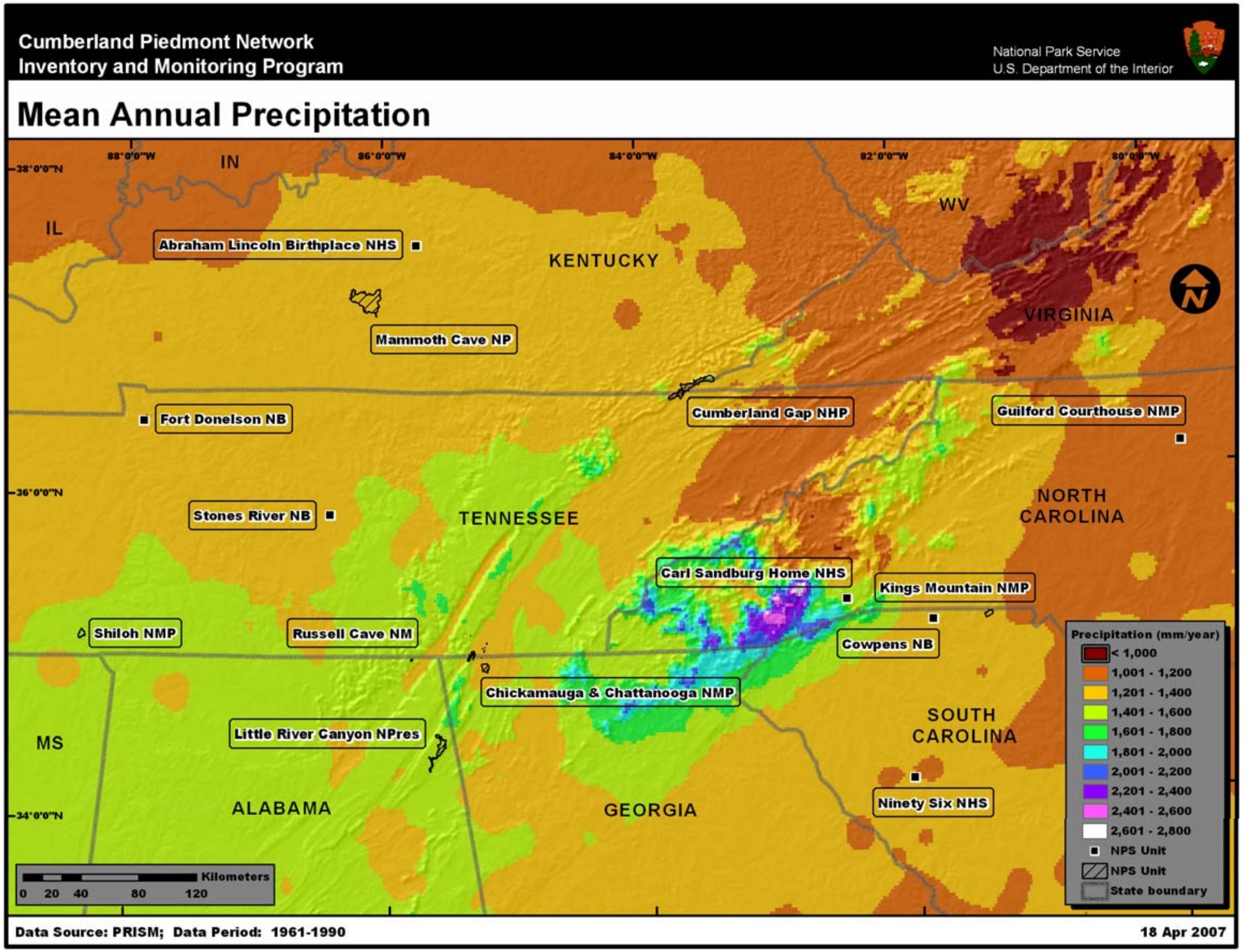
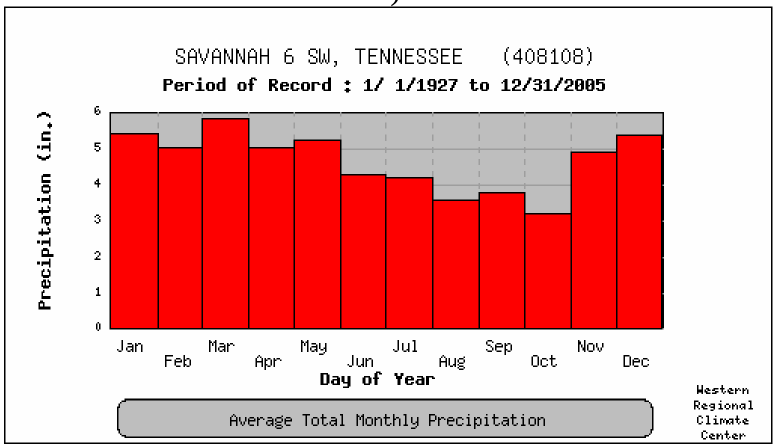
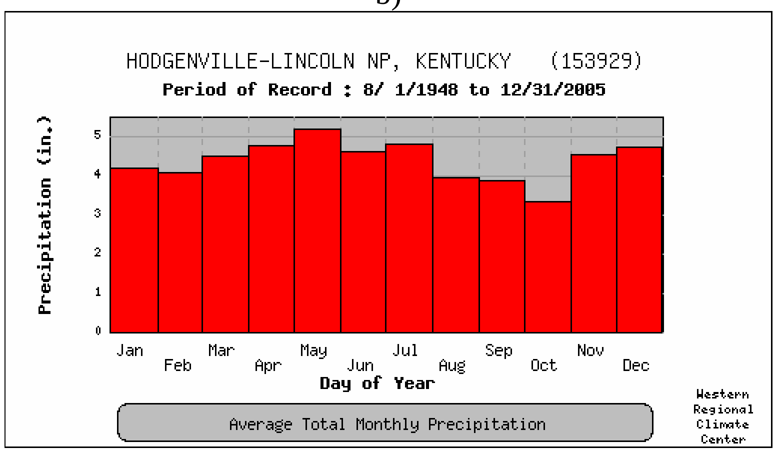


Figure 2.1. Mean annual precipitation, 1961-1990, for the CUPN.

a)



b)



c)

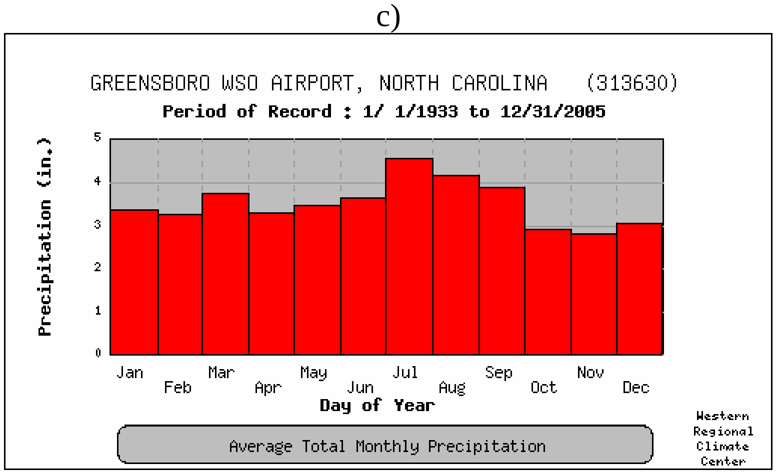


Figure 2.2. Mean monthly precipitation at selected stations in the CUPN. Savannah 6 SW (a) is in SHIL, Hodgenville-Lincoln NP (b) is in ABLI, and Greensboro WSO Airport (c) is near GUCO.

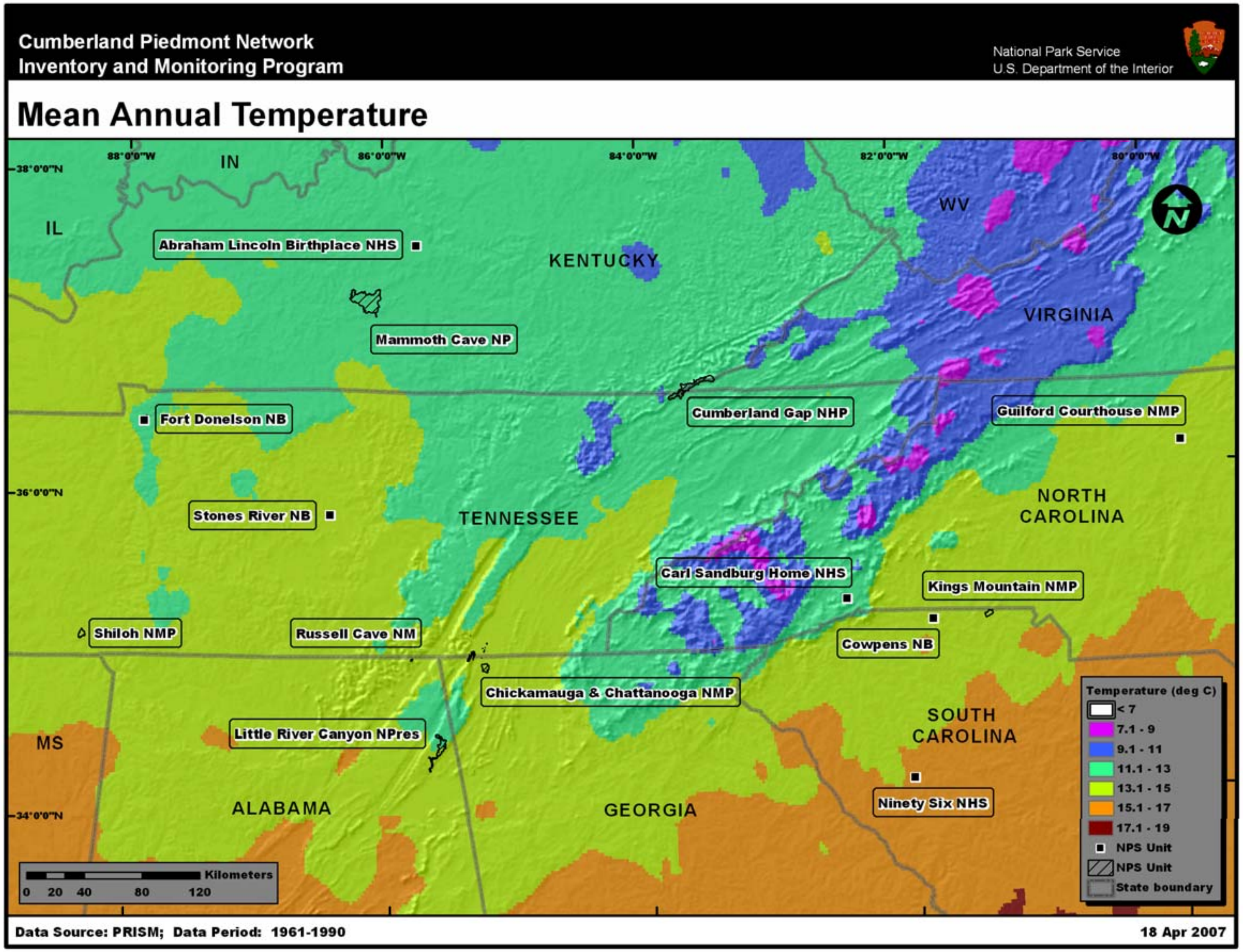


Figure 2.3. Mean annual temperature, 1961-1990, for the CUPN.

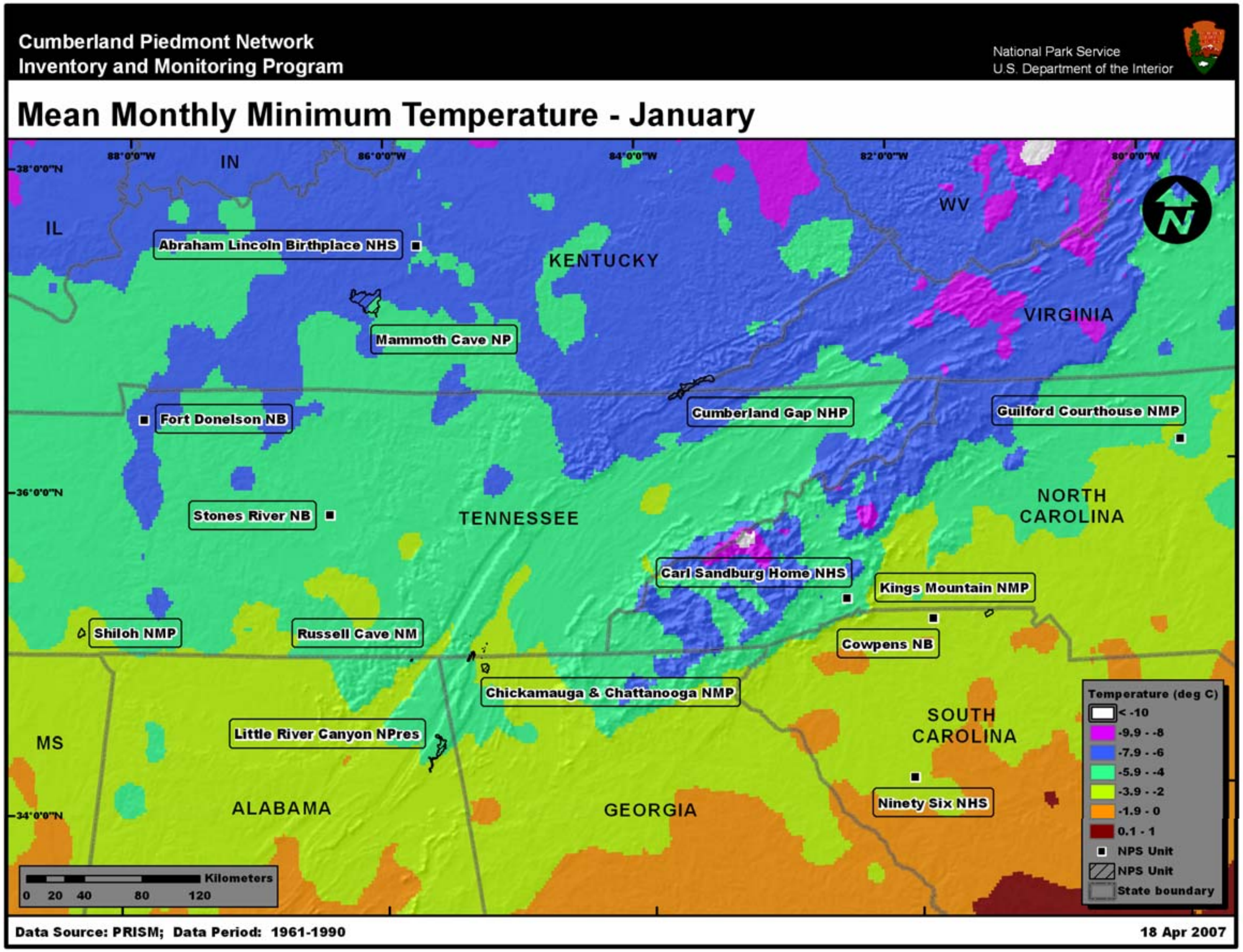


Figure 2.4. Mean January minimum temperature, 1961-1990, for the CUPN.

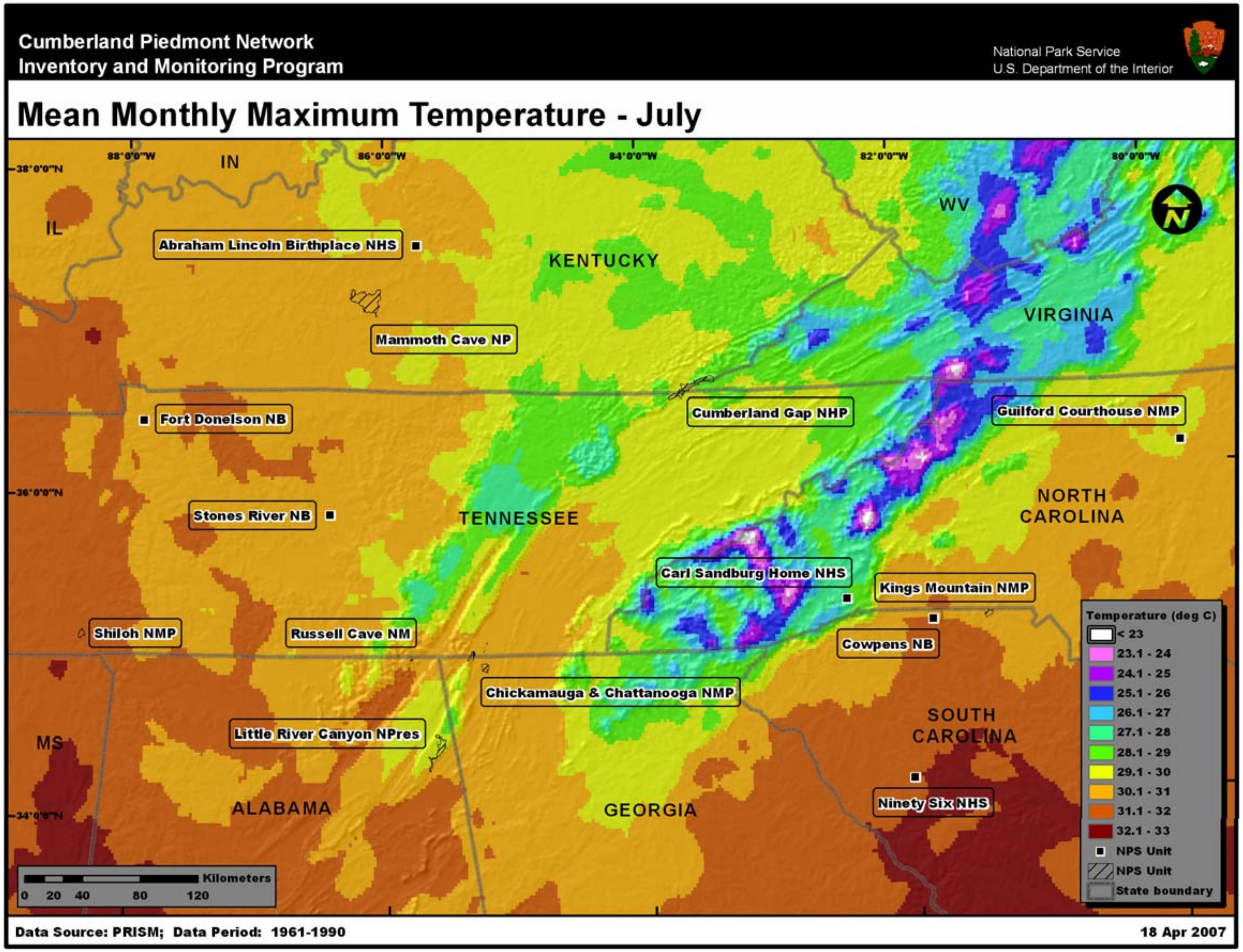
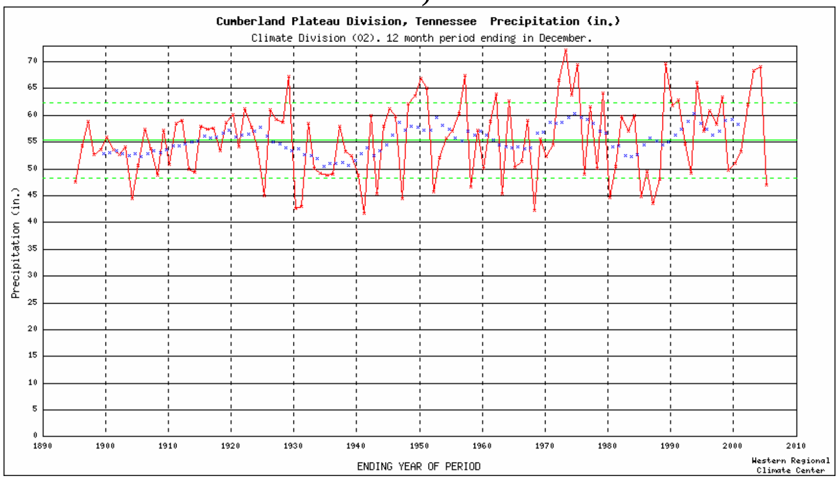
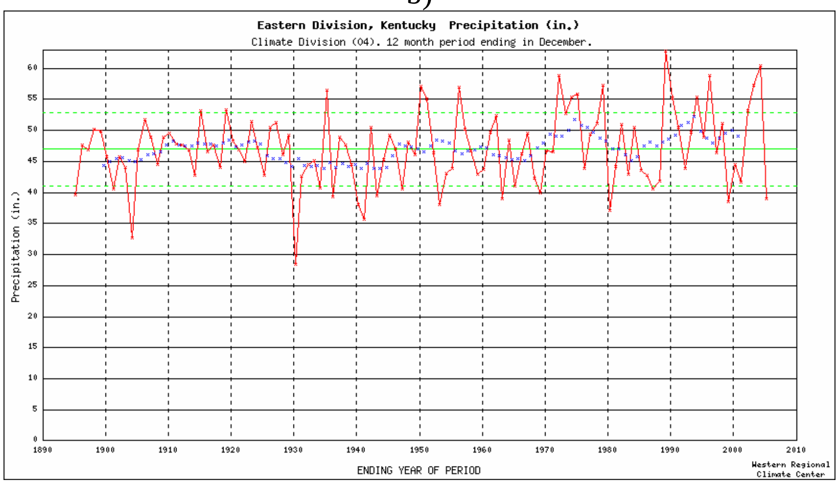


Figure 2.5. Mean July maximum temperature, 1961-1990, for the CUPN.

a)



b)



c)

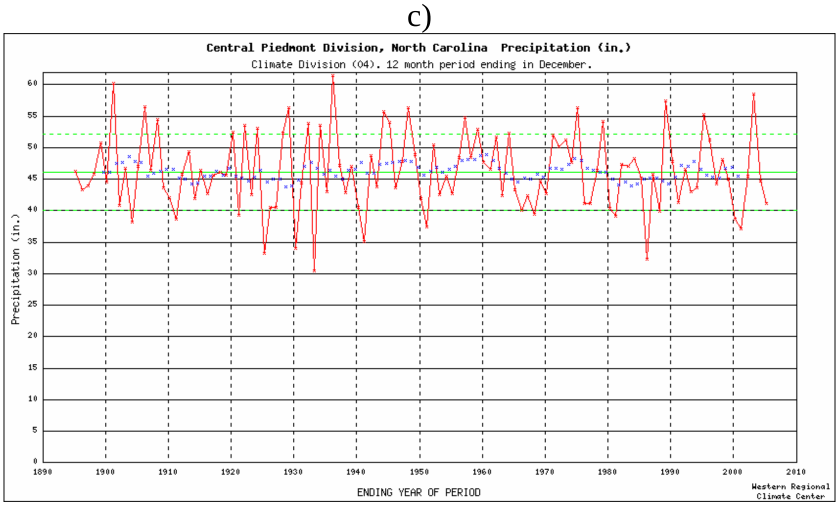
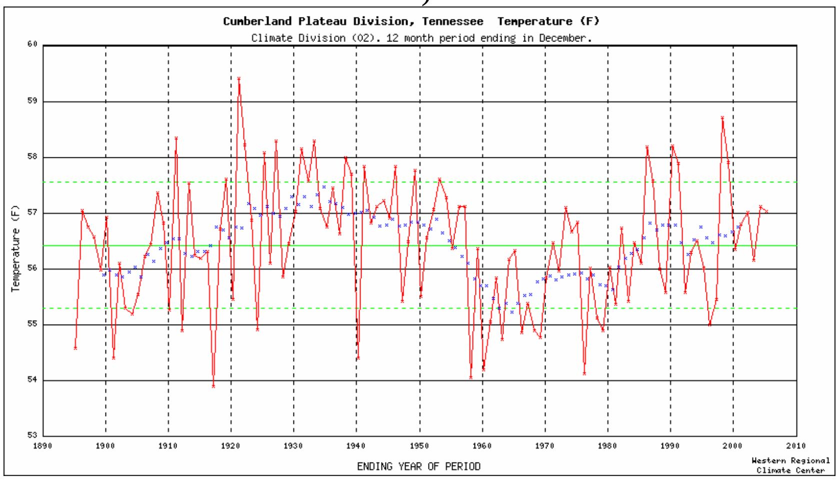
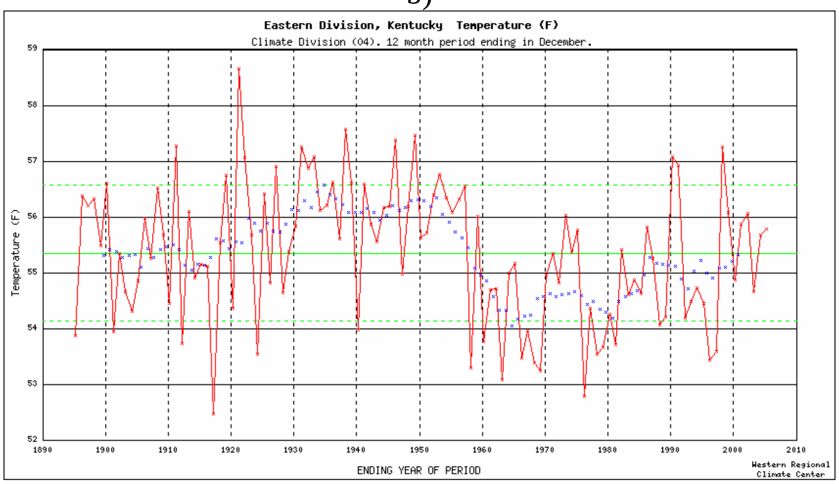


Figure 2.6. Precipitation time series, 1895-2005, for selected regions in the CUPN. These include twelve-month precipitation (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include the Cumberland Plateau of Tennessee (a), eastern Kentucky (b), and the central Piedmont of North Carolina (c).

a)



b)



c)

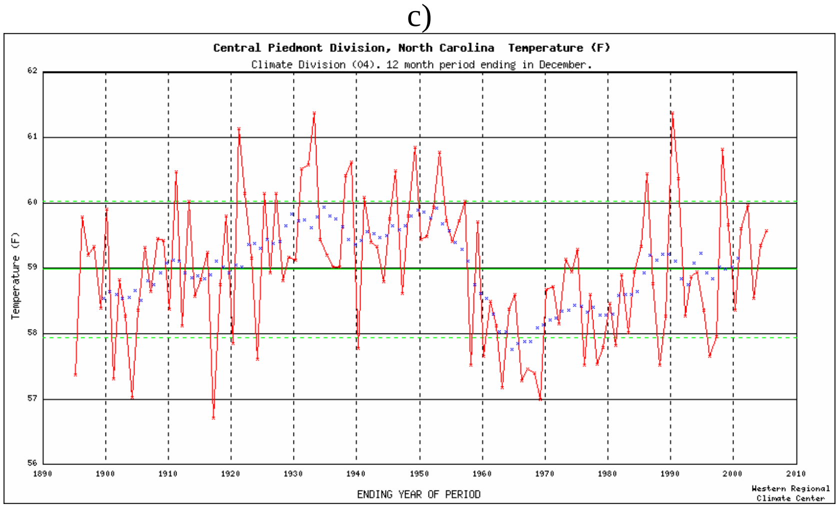


Figure 2.7. Temperature time series, 1895-2005, for selected regions in the CUPN. These include twelve-month average temperature (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include the Cumberland Plateau of Tennessee (a), eastern Kentucky (b), and the central Piedmont of North Carolina (c).

2.4. Parameter Regression on Independent Slopes Model

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 U.S. (Daly et al. 1994; 2002; Gibson et al. 2002; Doggett et al. 2004). The maps produced through PRISM have undergone rigorous evaluation in the U.S. This model was developed originally to provide climate information at scales matching available land-cover maps to assist in ecologic modeling. The PRISM technique accounts for the scale-dependent effects of topography on mean values of climate elements. Elevation provides the first-order constraint for the mapped climate fields, with slope and orientation (aspect) providing second-order constraints. 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 cell. The model relies on observed surface and upper-air measurements to estimate spatial climate fields.

3.0. Methods

Having discussed the climatic characteristics of the CUPN, we now present the procedures that were used to obtain information for weather/climate stations within the CUPN. 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 (Table 3.1) generally consist of a series of vignettes that apply to time intervals and, therefore, constitute a *history* rather than a single snapshot. An expanded list of relevant metadata fields for this inventory is provided in Appendix E. 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.

The initial metadata sources for this report were stored at WRCC. This regional climate center (RCC) acts as a working repository of many western climate records, including the main networks outlined in this section. The WRCC conducts live and periodic data collection (ingests) from all major national and western weather/climate networks. These networks include the COOP network, the Surface Airways Observation network (SAO) operated by NWS and the Federal Aviation Administration (FAA), the interagency RAWS 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.

The primary source of metadata at WRCC is the Applied Climate Information System (ACIS), a joint effort among RCCs and other NOAA entities. Metadata for CUPN weather/climate stations identified from the ACIS database are available in file “CUPN_from_ACIS.tar.gz” (see Appendix F). Historic metadata pertaining to major climate- and weather-observing systems in the U.S. 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. Metadata and data for 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 but in most cases the actual data have not yet 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 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.

Table 3.1. Primary metadata fields for CUPN weather/climate stations. Explanations are provided 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.

In addition to obtaining CUPN weather/climate station metadata from ACIS, metadata were obtained from NPS staff at the CUPN office in Asheville, North Carolina. The metadata provided from the CUPN office are available in file "CUPN_NPS.tar.gz." Most of the stations noted by CUPN staff are already accounted for in ACIS. We have also relied on information supplied at various times in the past by the BLM, NPS, NCDC, and NWS.

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

- Station inventories: Information about observational 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 completeness, seasonality, data gaps, representation of missing data, flagging systems, how special circumstances in the data record are denoted, 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 the CUPN, we selected all weather and climate stations, past and present, which were located inside CUPN park units or within 30 km of a CUPN park-unit boundary. We selected a 30-km buffer in order to ensure the inclusion of a sufficient number of both manual and automated stations in and near the park units in the CUPN, while at the same time keeping the number of identified stations down to a reasonable number.

The station locator maps presented in Chapter 4 were designed to show clearly the spatial distributions of all major weather/climate station networks in CUPN. 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 CUPN region in relation to the boundaries of the NPS park units within the CUPN. 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 CUPN region are associated with at least one of 12 major weather/climate networks (Table 4.1). Brief descriptions of each weather/climate network are provided below (see Appendix G for greater detail).

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

Acronym	Name
CASTNet	Clean Air Status and Trends Network
COOP	NWS Cooperative Observer Program
CRN	NOAA Climate Reference Network
CWOP	Citizen Weather Observer Program
GPMP	Gaseous Pollutant Monitoring Program
GPS-MET	NOAA ground-based GPS meteorology network
NADP	National Atmospheric Deposition Program
POMS	Portable Ozone Monitoring System network
RAWS	Remote Automated Weather Station network
SAO	NWS/FAA Surface Airways Observation network
SCAN	Soil Climate Analysis Network
WX4U	Weather For You network

4.1.1. Clean Air Status and Trends Network (CASTNet)

CASTNet is primarily an air-quality monitoring network managed by the EPA. Standard 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.

4.1.2. NWS Cooperative Observer Program (COOP)

The COOP network has been a foundation of the U.S. climate program for decades and continues to play an important role. 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.

4.1.3. 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. Standard meteorological elements are measured. CRN data are used in operational climate-monitoring activities and to place current climate patterns in historic perspective.

4.1.4. 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.

4.1.5. 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.

4.1.6. NOAA Ground-Based GPS Meteorology (GPS-MET) Network
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.

4.1.7. National Atmospheric Deposition Program (NADP)
The purpose of the NADP network is to monitor primarily wet deposition at selected sites around the U.S. and its territories. The network is a collaborative effort among several agencies including the U.S. Geological Survey (USGS) and USDA. The NADP network includes sites from the Mercury Deposition Network (MDN). Precipitation is the primary climate parameter measured at NADP sites.

4.1.8. Portable Ozone Monitoring System (POMS) network
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.

4.1.9. Remote Automated Weather Station (RAWS) Network
The RAWS network is administered through many land 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.

4.1.10. NWS/FAA Surface Airways Observation (SAO) Network
These stations are located usually at major airports and military bases. 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 high quality.

4.1.11. USDA/NRCS Soil Climate Analysis Network (SCAN)
The SCAN network is administered by NRCS and is intended to be a comprehensive nationwide soil moisture and climate information system to be used in supporting natural resource assessments and other conservation activities. These stations are usually located in the agricultural areas of the U.S. All SCAN sites are automated. The parameters measured at these sites include air temperature, precipitation, humidity, wind, pressure, solar radiation, snow depth, and snow water content.

4.1.12. 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.

4.1.13. Weather Bureau Army Navy (WBAN)
This is a station identification system rather than a true weather/climate network. Stations identified with WBAN are largely historical stations that reported meteorological observations on the WBAN weather observation forms that were common during the early and middle parts of the twentieth century. The use of WBAN numbers to identify stations was one of the first attempts in the U.S. to use a coordinated station numbering scheme between several weather station networks, such as the SAO and COOP networks.

4.1.14. Other Networks
In addition to the major networks mentioned above, there are various networks that are operated for specific purposes by specific organizations or governmental agencies or scientific research projects, which could be present within APHN 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
- U.S. Department of Energy Surface Radiation Budget Network (Surfrad)
- USGS hydrologic stations
- Park-specific-monitoring networks and stations
- Other research or project networks having many possible owners

4.2. Station Locations

The major weather/climate networks in the CUPN (discussed in Section 4.1) have at most a few stations that are inside each park unit (Table 4.2). Mammoth Cave National Park (MACA) has the greatest number of stations inside park boundaries (five).

Table 4.2. Number of stations within or nearby CUPN park units. Numbers are listed by park unit and by weather/climate network. Figures in parentheses indicate the numbers of stations within park boundaries.

Network	ABLI	CARL	CHCH	COWP	CUGA	FODO	GUCO
CASTNet	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)
COOP	**13**(1)	**28**(0)	**33**(3)	**18**(0)	**29**(1)	**8**(1)	**6**(0)
CRN	**0**(0)	**2**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
CWOP	**1**(0)	**10**(0)	**8**(0)	**3**(0)	**1**(0)	**1**(0)	**13**(0)
GPMP	**0**(0)	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**0**(0)
GPS-MET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(0)
NADP	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)
POMS	**2**(2)	**1**(1)	**1**(1)	**0**(0)	**2**(2)	**1**(1)	**0**(0)
RAWS	**0**(0)	**3**(0)	**2**(0)	**0**(0)	**2**(1)	**0**(0)	**0**(0)
SAO	**0**(0)	**1**(0)	**2**(0)	**2**(0)	**0**(0)	**0**(0)	**1**(0)
SCAN	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
WX4U	**0**(0)	**0**(0)	**1**(0)	**2**(0)	**0**(0)	**0**(0)	**3**(0)
Other	**0**(0)	**1**(0)	**2**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)
Total	**16**(3)	**46**(1)	**49**(4)	**27**(1)	**36**(4)	**10**(2)	**25**(0)
Network	**KIMO**	**LIRI**	**MACA**	**NISI**	**RUCA**	**SHIL**	**STRI**
CASTNet	**0**(0)	**1**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
COOP	**10**(0)	**17**(0)	**21**(1)	**5**(0)	**12**(0)	**13**(1)	**12**(0)
CRN	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
CWOP	**2**(0)	**6**(0)	**0**(0)	**0**(0)	**2**(0)	**2**(0)	**0**(0)
GPMP	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
GPS-MET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
NADP	**0**(0)	**1**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
POMS	**1**(1)	**1**(1)	**4**(2)	**1**(1)	**1**(1)	**1**(1)	**1**(1)
RAWS	**1**(1)	**1**(1)	**2**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)
SAO	**2**(0)	**1**(0)	**1**(0)	**1**(0)	**1**(0)	**0**(0)	**2**(0)
SCAN	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
WX4U	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)
Other	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)
Total	**17**(2)	**28**(2)	**33**(5)	**7**(1)	**16**(1)	**17**(2)	**17**(1)

Lists of stations have been compiled for the CUPN. 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 also significant questions, whose answers can vary according to application, type of element, period of record, procedural or methodological observation conventions, and the like.

Three stations were identified within ABLI (Table 4.3). One is a COOP station (Hodgenville-Lincoln) which has a data record starting in 1948. The data record is quite complete since 1965. There was a gap in precipitation measurements from October 1951 to October 1965. Other data gaps (both precipitation and temperature) occurred in April-June 1988 and in July-September 1992. The other two stations are POMS stations. One of these sites is currently located near the visitor center. This station has been operating since March 2006. The other POMS station, "Knob Creek," operated briefly during the summer of 2005.

Out of the 12 COOP stations identified within 30 km of the outer boundary of ABLI, six are currently active (Table 4.3). The longest record among these active COOP stations, going back to 1948, is found at "Boston No. 2." This station is 26 km north of ABLI (Figure 4.1). "Glendale" is another COOP station near ABLI having a data record over 50 years in length. This station measures only precipitation. The data record at "Glendale" starts in 1951, with significant data gaps occurring for January-June 1980 and from September 1983 to October 1984. Unfortunately, these are the longest records available within 30 km of ABLI. The COOP station "Munfordville 5 NW" had a very long record going back to 1893 but it recently stopped taking measurements (2004).

The only source for near-real-time weather data within 30 km of ABLI is a CWOP station, "CW3227 Elizabethtown" (Table 4.3). This station is 28 km northwest of ABLI (Figure 4.1). As best as can be determined, no airport sites, RAWS sites, or similarly-reliable sources of near-real-time weather information are available around ABLI.

One station was identified within CARL (Table 4.3). This is a POMS station (Carl Sandburg) that was active in July and August of 2005. The visitor center also hosts an offline weather station.

Outside of CARL, we identified 28 COOP stations within 30 km of the park unit boundary. Twelve of these stations are currently active (Table 4.3). The closest active COOP station to CARL is "East Flat Rock 3 SE," which is 6 km southeast of CARL (Figure 4.1). However, the COOP station "Hendersonville 1 NE" is just slightly further away from CARL (6 km northwest) and has a very reliable data record starting in 1898. This data record is the longest of any of the COOP stations we have identified in this report for CARL. Another very reliable data record going back to 1917 is found at the COOP station "Tryon," which is 19 km southeast of CARL. The COOP station "Brevard," 23 km west of CARL, also has a very long data record, but this record contains several significant data gaps. The most notable gap occurred from February 1989 to February 1994. Other reliable long-term COOP records are found at "Asheville Regl. Arpt.," which is located 19 km northwest of CARL and has been active since 1940; "Bent Creek," which is located 29 km northwest of CARL and has been active since 1949; and "Pisgah Forest 3 NE," which is located 17 km west of CARL and has been active since 1935.

Several reliable stations within 30 km of CARL provide near-real-time data for the park unit. Two CRN sites, "Asheville 13 S" and "Asheville 8 SSW," are located 18 km and 28 km west of

CARL, respectively (Figure 4.1). These stations have been operating since November 2000 (Table 4.3). The elevations of these two CRN stations are comparable to the elevations at CARL. Three active RAWS stations are located within 30 km of CARL. The closest RAWS station, “Guion Farm,” is 13 km southwest of CARL and also has the longest record of these RAWS stations (1999-present). These stations are generally located a few hundred meters higher in elevation than CARL. The only SAO station we identified for CARL is “Asheville Regl. Arpt.” In addition to these, there are 10 CWOP stations within 30 km of CARL that provide near-real-time weather data.

Table 4.3. Weather/climate stations for the CUPN. Stations inside park units and within 30 km of the park unit boundaries are included. Missing entries are indicated by “M”.

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Abraham Lincoln Birthplace National Historic Site – ABLI							
Hodgenville-Lincoln	37.532	-85.735	240	COOP	8/1/1948	Present	Yes
ABLI Visitor Center	M	M	M	POMS	3/1/2006	Present	Yes
Knob Creek	37.609	-85.644	240	POMS	7/13/2005	8/3/2005	Yes
Bonnieville 4 N	37.433	-85.900	223	COOP	4/1/1956	10/5/1966	No
Boston 6 SW	37.744	-85.748	250	COOP	5/1/1970	Present	No
Boston No 2	37.766	-85.704	122	COOP	11/1/1948	Present	No
Cecilia 2 SE	37.667	-85.933	221	COOP	3/1/1960	8/31/1984	No
Elizabethtown	37.683	-85.867	226	COOP	11/1/1893	12/1/1967	No
Elizabethtown KSP P4	37.712	-85.831	238	COOP	12/1/1982	Present	No
Elizabethtown WP C S	37.679	-85.878	209	COOP	3/1/1989	Present	No
Glendale	37.601	-85.907	216	COOP	11/15/1951	Present	No
Millerstown	37.450	-86.050	183	COOP	4/18/1940	6/30/1987	No
Munfordville 5 NW	37.335	-85.950	207	COOP	4/1/1893	3/15/2004	No
Raywick	37.550	-85.433	M	COOP	8/1/1948	3/31/1949	No
St. John Bethlehem AC	37.700	-85.983	238	COOP	3/1/1896	3/31/1960	No
CW3227 Elizabethtown	37.754	-85.882	268	CWOP	M	Present	No
Carl Sandburg Home National Historic Site – CARL							
Carl Sandburg	35.265	-82.451	M	POMS	7/1/2005	8/31/2005	Yes
Asheville Regl. Arpt.	35.432	-82.538	645	COOP	11/1/1940	Present	No
Bent Creek	35.504	-82.596	643	COOP	1/1/1949	Present	No
Blantyre	35.300	-82.617	634	COOP	M	11/30/1971	No
Blantyre 2	35.304	-82.631	655	COOP	M	Present	No
Blue Ridge Post Office	35.350	-82.367	695	COOP	9/1/1948	7/26/1972	No
Brevard	35.216	-82.705	674	COOP	1/1/1902	Present	No
Buck Forest	35.183	-82.617	767	COOP	1/1/1959	1/1/1992	No
Caesars Head	35.117	-82.633	952	COOP	12/1/1924	8/7/1967	No
Caesars Head	35.107	-82.626	975	COOP	6/9/1966	Present	No
Cedar Mountain	35.150	-82.633	839	COOP	9/1/1948	4/30/1981	No
Cleveland 3 S	35.034	-82.515	341	COOP	6/1/1943	Present	No
East Flat Rock 3 SE	35.246	-82.389	563	COOP	7/1/1972	Present	No
Edneyville	35.417	-82.333	683	COOP	6/1/1951	11/30/1954	No
Fletcher 2 NE	35.450	-82.483	668	COOP	10/1/1956	8/16/1995	No
Fletcher 3 W	35.426	-82.557	631	COOP	11/1/1959	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Garren Creek	35.517	-82.333	799	COOP	1/1/1949	3/31/1962	No
Hendersonville 1 NE	35.330	-82.449	658	COOP	6/1/1898	Present	No
Hendersonville 8 WNW	35.383	-82.567	628	COOP	5/1/1954	11/30/1959	No
Hendersonville TVA	35.317	-82.483	668	COOP	1/1/1949	12/31/1966	No
Hogback Mountain	35.167	-82.283	985	COOP	3/1/1966	4/1/1992	No
Lake Lure	35.400	-82.200	369	COOP	11/1/1973	9/30/1983	No
Lake Lure 2	35.421	-82.188	317	COOP	9/1/1948	Present	No
Landrum 1 NE	35.183	-82.183	305	COOP	1/1/1915	12/31/1974	No
Mills River	35.383	-82.567	656	COOP	9/1/1950	3/31/1962	No
Pisgah Forest 3 NE	35.272	-82.648	668	COOP	10/1/1939	Present	No
Rush Mountain	35.250	-82.467	900	COOP	1/1/1949	3/31/1962	No
Tigerville 6 E	35.067	-82.267	317	COOP	10/1/1985	6/1/1993	No
Tryon	35.206	-82.252	366	COOP	1/1/1917	Present	No
Asheville 13 S	35.419	-82.557	641	CRN	11/14/2000	Present	No
Asheville 8 SSW	35.494	-82.614	656	CRN	11/14/2000	Present	No
AF4NQ Taylors	35.015	-82.361	294	CWOP	M	Present	No
AI4GR Hendersonville	35.319	-82.461	680	CWOP	M	Present	No
CW1203 Saluda	35.200	-82.366	723	CWOP	M	Present	No
CW1531 Saluda	35.250	-82.385	577	CWOP	M	Present	No
CW2100 Brevard	35.234	-82.734	680	CWOP	M	Present	No
CW3151 Flat Rock	35.267	-82.446	716	CWOP	M	Present	No
CW5363 Brevard	35.255	-82.735	763	CWOP	M	Present	No
CW5631 Hendersonville	35.302	-82.464	655	CWOP	M	Present	No
N4JVU Tigerville	35.133	-82.330	472	CWOP	M	Present	No
W4DK Etowah	35.336	-82.616	724	CWOP	M	Present	No
Davidson River	35.351	-82.779	975	RAWS	1/1/2004	Present	No
Guion Farm	35.213	-82.590	792	RAWS	10/1/1999	Present	No
Jackson County	35.317	-82.200	853	RAWS	7/1/2002	Present	No
Asheville Regl. Arpt.	35.432	-82.538	645	SAO	11/1/1940	Present	No
Hendersonville AAF	35.433	-82.467	639	WBAN	8/1/1943	1/31/1946	No
Chickamauga and Chattanooga National Military Park – CHCH							
Chickamauga Park	34.900	-85.272	226	COOP	8/1/1948	Present	Yes
Chickamauga Park LARC	34.903	-85.271	236	COOP	2/1/1974	Present	Yes
Lookout Mountain	35.010	-85.345	655	COOP	11/1/1995	Present	Yes
Chickamanga Chattanooga	34.918	-85.270	237	POMS	8/3/2005	8/24/2005	Yes
Beaverdale 1 E	34.919	-84.832	226	COOP	6/17/1940	10/1/1999	No
Chattanooga	35.050	-85.300	189	COOP	7/1/1962	5/1/1992	No
Chattanooga Lovell Field Arpt.	35.031	-85.201	210	COOP	1/1/1928	Present	No
Chattanooga WB City	35.067	-85.300	210	COOP	1/1/1927	12/31/1950	No
Chickamauga Dam	35.100	-85.233	214	COOP	9/1/1948	3/31/1962	No
Dalton	34.770	-84.887	244	COOP	9/16/1935	4/1/2005	No
Dunlap	35.367	-85.383	220	COOP	8/1/1909	3/31/1962	No
Flintstone	34.933	-85.350	217	COOP	3/1/1943	11/30/1955	No
Friendship School	35.267	-85.083	232	COOP	1/1/1949	3/31/1962	No
Hales Bar	35.050	-85.550	204	COOP	2/1/1940	10/31/1949	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Hales Bar Dam	35.050	-85.533	198	COOP	1/1/1949	3/31/1962	No
Jasper	35.067	-85.617	198	COOP	1/1/1949	7/31/1955	No
Kensington	34.783	-85.367	262	COOP	8/1/1952	12/31/1981	No
La Fayette 1 SE	34.683	-85.267	253	COOP	M	3/31/1962	No
Lafayette 2	34.700	-85.267	244	COOP	11/1/1971	4/30/1972	No
Lafayette 5 SW	34.664	-85.320	274	COOP	4/10/1892	Present	No
Lewis Chapel	35.333	-85.300	564	COOP	1/1/1949	3/31/1962	No
Lockhart Tower	35.267	-85.533	680	COOP	1/1/1949	3/31/1962	No
Lookout Mountain	34.983	-85.350	601	COOP	11/1/1913	3/31/1962	No
Nickajack Gap	34.817	-85.133	390	COOP	1/1/1959	3/31/1962	No
Ooltewah	35.083	-85.067	244	COOP	1/1/1949	3/31/1962	No
Point Park Lookout Mt.	35.000	-85.367	610	COOP	9/1/1948	10/31/1955	No
Ringgold 2 SE	34.900	-85.067	235	COOP	8/1/1952	Present	No
Rising Fawn	34.750	-85.533	250	COOP	1/1/1949	3/31/1962	No
Signal Mountain	35.117	-85.350	525	COOP	1/1/1949	3/31/1962	No
S. Chickamauga Creek	35.014	-85.210	196	COOP	1/1/1975	Present	No
Soddy Daisy Mowbray Mt.	35.280	-85.241	518	COOP	10/1/1997	Present	No
Trenton 3 E	34.884	-85.452	606	COOP	8/25/2000	12/5/2001	No
Tunnel Hill	34.867	-85.033	268	COOP	1/1/1949	3/31/1962	No
Whitwell Sequatchie Valley	35.290	-85.474	311	COOP	5/1/2000	Present	No
CW0019 Soddy Daisy	35.292	-85.114	210	CWOP	M	Present	No
CW2104 Hixson	35.184	-85.170	210	CWOP	M	Present	No
CW2440 Georgetown	35.256	-85.010	271	CWOP	M	Present	No
CW3331 Ringgold	34.900	-85.200	275	CWOP	M	Present	No
CW3732 Trenton	34.892	-85.570	485	CWOP	M	Present	No
CW5013 Chattanooga	35.000	-85.117	264	CWOP	M	Present	No
CW5352 Soddy Daisy	35.212	-85.117	300	CWOP	M	Present	No
N4DRV Hixson	35.133	-85.200	299	CWOP	M	Present	No
Armuchee #1	34.695	-85.174	351	RAWS	9/1/2001	Present	No
Prentice Cooper SF	35.130	-85.428	585	RAWS	10/1/2003	Present	No
Chattanooga Lovell Field Arpt.	35.031	-85.201	210	SAO	1/1/1928	Present	No
Dalton Muni. Arpt.	34.722	-84.869	216	SAO	3/1/1990	Present	No
Chattanooga Aero. Che.	35.050	-85.300	209	WBAN	M	Present	No
Chattanooga WBO	35.067	-85.233	232	WBAN	1/1/1879	12/31/1940	No
WDEF Studios Chattanooga	35.050	-85.310	209	WX4U	M	Present	No
Cowpens National Battlefield – COWP							
Cowpens	35.130	-81.816	296	GPMP	4/1/1988	9/30/1993	Yes
Caroleen	35.283	-81.800	247	COOP	1/1/1900	6/13/1974	No
Chesnee 7 WSW	35.132	-81.968	228	COOP	2/1/1928	Present	No
Converse	34.983	-81.833	214	COOP	4/1/1966	7/31/1973	No
Cowpens 2 NW	35.050	-81.783	262	COOP	3/1/1966	9/30/1968	No
Forest City 6 SW	35.265	-81.931	302	COOP	6/1/1974	1/1/2005	No
Forest City 8 W	35.313	-81.989	259	COOP	1/12/2005	Present	No
Gaffney 6 E	35.092	-81.576	198	COOP	12/1/1893	Present	No
Gaston Shoals	35.138	-81.596	183	COOP	11/7/1912	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Gramling 1 S	35.050	-82.133	323	COOP	2/14/1963	10/2/1985	No
Ninety Nine Islands	35.065	-81.505	152	COOP	12/1/1940	Present	No
Pacolet	34.895	-81.759	229	COOP	8/20/1974	5/1/1997	No
Shelby 2	35.267	-81.550	238	COOP	9/1/1948	3/18/1992	No
Shelby Ag. 2 S	35.300	-81.550	274	COOP	10/15/1992	1/1/1994	No
Spartanburg	34.983	-81.883	256	COOP	2/1/1973	1/1/1983	No
Spartanburg	34.917	-81.950	248	COOP	6/1/1930	Present	No
Spartanburg	34.950	-81.900	242	COOP	1/1/1963	Present	No
Spartanburg 3 SSE	34.908	-81.914	186	COOP	7/1/1983	Present	No
Spindale	35.350	-81.917	332	COOP	10/1/1965	12/31/1974	No
CW3484 Gaffney	35.104	-81.774	270	CWOP	M	Present	No
CW5471 Blacksburg	35.143	-81.565	234	CWOP	M	Present	No
K4XP Spartanburg	34.954	-82.010	265	CWOP	M	Present	No
Shelby Muni. Arpt.	35.256	-81.601	258	SAO	12/23/2003	Present	No
Spartanburg	34.917	-81.950	248	SAO	6/1/1930	Present	No
Spartanburg Natl. Guard	34.967	-82.000	251	WBAN	7/1/1963	8/31/1963	No
Spartanburg	34.910	-82.000	296	WX4U	M	Present	No
WeatherSource Shelby	35.280	-81.680	244	WX4U	M	Present	No
Cumberland Gap National Historical Park – CUGA							
Cumberland Gap Park	36.600	-83.683	354	COOP	4/1/1966	3/29/2002	Yes
Cumberland Gap Pinnacles	36.606	-83.665	749	POMS	6/1/2005	6/22/2005	Yes
Cumberland Gap	M	M	M	POMS	M	Present	Yes
Yellow Creek	36.604	-83.696	332	RAWS	2/1/2002	Present	Yes
Speedwell	36.470	-83.827	361	CASTNet	6/1/1989	Present	No
Ages	36.867	-83.250	149	COOP	3/1/1920	12/31/1923	No
Arthur	36.550	-83.633	326	COOP	1/1/1949	3/31/1962	No
Barbourville No. 2	36.850	-83.883	287	COOP	11/1/1977	Present	No
Baxter	36.858	-83.330	355	COOP	8/1/1948	Present	No
Big Sycamore	36.517	-83.333	619	COOP	9/1/1948	10/1/1975	No
Big Sycamore 2	36.500	-83.333	479	COOP	10/1/1975	10/31/1980	No
Blackmont	36.783	-83.517	347	COOP	2/1/1980	Present	No
Bledsoe 2 SSE	36.900	-83.333	570	COOP	8/1/1957	6/30/1959	No
Ferndale	36.700	-83.700	381	COOP	5/1/1994	6/30/1994	No
Fourmile Ky. Util. Prk.	36.783	-83.750	306	COOP	2/1/1962	3/29/2002	No
Harlan	36.833	-83.317	366	COOP	9/1/1918	2/28/1952	No
Harlan KSP Post 10	36.817	-83.317	366	COOP	9/1/1982	Present	No
Jonesville	36.683	-83.100	427	COOP	1/1/1949	7/31/1951	No
Jonesville 2 SSE	36.667	-83.100	421	COOP	1/1/1949	3/31/1962	No
Middlesboro 2 N	36.633	-83.733	360	COOP	12/1/1892	11/30/1994	No
Middlesboro Radio WM	36.633	-83.717	351	COOP	3/1/1964	10/1/1983	No
Middlesboro Sewage Plant	36.617	-83.717	345	COOP	8/1/1948	10/7/1964	No
New Tazewell	36.450	-83.567	451	COOP	3/1/1962	4/1/1966	No
Pineville	36.765	-83.710	306	COOP	3/1/1940	9/16/1999	No
Rose Hill	36.667	-83.367	436	COOP	1/1/1946	3/31/1962	No
Saxton	36.633	-84.117	295	COOP	11/16/1983	Present	No
Tazewell	36.465	-83.560	416	COOP	5/1/1966	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Tazewell 2 SE	36.417	-83.550	406	COOP	12/1/1897	3/31/1962	No
Walkers Ford	36.333	-83.700	390	COOP	1/1/1949	3/31/1962	No
Well Spring	36.417	-84.000	323	COOP	1/1/1949	3/31/1962	No
Westbourne	36.500	-84.033	439	COOP	9/1/1948	3/31/1962	No
White Hollow	36.367	-83.900	458	COOP	9/1/1948	8/24/1977	No
White Hollow 2	36.367	-83.900	500	COOP	8/1/1977	10/31/1980	No
CW4613 Barbourville	36.875	-83.780	325	CWOP	M	Present	No
Speedwell	36.469	-83.827	361	NADP	1/26/1999	Present	No
Chuck Swan SF	36.369	-83.899	505	RAWS	10/1/2003	Present	No
Fort Donelson National Battlefield – FODO							
Dover 1 W	36.482	-87.863	145	COOP	12/1/1897	Present	Yes
Fort Donelson NB	36.483	-87.862	172	POMS	8/24/2005	9/14/2005	Yes
Canton 3 S	36.747	-87.947	106	COOP	8/1/1896	Present	No
Cumberland City	36.383	-87.633	107	COOP	11/1/1965	11/10/1970	No
Dover	36.493	-87.841	122	COOP	11/1/1965	1/1/2006	No
Dover Fire Tower	36.383	-87.933	125	COOP	1/1/1949	3/31/1962	No
L C Cumberland River	36.433	-87.567	116	COOP	2/20/1940	12/1/1965	No
La Fayette	36.667	-87.65	M	COOP	3/1/1940	11/23/1942	No
Tennessee Ridge	36.325	-87.789	220	COOP	4/1/1999	Present	No
KD4MPL Dover	36.486	-87.808	143	CWOP	M	Present	No
Guilford Courthouse National Military Park – GUCO							
Greensboro Piedmont Triad Intl.	36.098	-79.944	273	COOP	1/1/1903	Present	No
Greensboro Pump Stn.	36.083	-79.800	235	COOP	11/1/1948	12/31/1980	No
High Point	35.967	-79.972	274	COOP	7/1/1921	Present	No
McLeansville Ag. 2 SW	36.083	-79.683	226	COOP	10/15/1993	12/1/1995	No
Reidsville	36.350	-79.633	253	COOP	11/1/1901	8/31/1963	No
Reidsville 2 NW	36.383	-79.695	271	COOP	2/1/1962	Present	No
CW1352 Greensboro	36.070	-79.768	253	CWOP	M	Present	No
CW2923 Kernersville	36.030	-80.073	285	CWOP	M	Present	No
CW3435 Jamestown	36.032	-79.926	282	CWOP	M	Present	No
CW5377 Summerfield	36.190	-79.869	250	CWOP	M	Present	No
KE4FCW Greensboro	36.145	-79.845	250	CWOP	M	Present	No
KE4IAF Vandalia	36.017	-79.770	235	CWOP	M	Present	No
KE4IAM Sedgefield	36.038	-79.883	263	CWOP	M	Present	No
KE4MOJ Oak Ridge	36.150	-79.932	282	CWOP	M	Present	No
N1OD Oak Ridge	36.165	-79.880	247	CWOP	M	Present	No
N4BYU Pleasant Garden	35.962	-79.720	223	CWOP	M	Present	No
N4GVK Greensboro	36.025	-79.896	269	CWOP	M	Present	No
N9VP Greensboro	36.108	-79.850	277	CWOP	M	Present	No
WX4GSO-2 Guilford	36.065	-79.883	266	CWOP	M	Present	No
Greensboro	36.070	-79.740	246	GPS-MET	M	Present	No
High Point	35.970	-80.010	298	GPS-MET	M	Present	No
Greensboro Piedmont Triad Intl.	36.098	-79.944	273	SAO	1/1/1903	Present	No
Greensboro	36.114	-79.831	271	WX4U	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Greensboro	36.040	-79.870	265	WX4U	M	Present	No
Piedmont Triad Greensboro	36.130	-79.800	281	WX4U	M	Present	No
Kings Mountain National Military Park – KIMO							
Reservoir Hill	35.138	-81.387	325	POMS	6/1/2005	6/22/2005	Yes
Kings Mountain	35.146	-81.402	250	RAWS	1/1/2004	Present	Yes
Gaffney 6 E	35.092	-81.576	198	COOP	12/1/1893	Present	No
Gaston Shoals	35.138	-81.596	183	COOP	11/7/1912	Present	No
Gastonia	35.266	-81.143	213	COOP	1/1/1890	Present	No
McAdenville	35.263	-81.078	186	COOP	1/1/1972	Present	No
Ninety Nine Islands	35.065	-81.505	152	COOP	12/1/1940	Present	No
Shelby 2	35.267	-81.550	238	COOP	9/1/1948	3/18/1992	No
Shelby 2 NNE	35.314	-81.534	280	COOP	2/8/1893	Present	No
Shelby Ag. 2 S	35.300	-81.550	274	COOP	10/15/1992	1/1/1994	No
York 1 W	34.983	-81.250	204	COOP	6/1/1963	8/31/1966	No
York 4 S	34.939	-81.225	221	COOP	8/1/1966	Present	No
CW5471 Blacksburg	35.143	-81.565	234	CWOP	M	Present	No
K1CY Gastonia	35.253	-81.142	238	CWOP	M	Present	No
Gastonia Muni. Arpt.	35.197	-81.156	243	SAO	1/20/1999	Present	No
Shelby Muni. Arpt.	35.256	-81.601	258	SAO	12/23/2003	Present	No
WeatherSource Shelby	35.280	-81.680	244	WX4U	M	Present	No
Little River Canyon National Preserve – LIRI							
Little River Canyon Rim	34.460	-85.597	441	POMS	7/13/2004	8/18/2004	Yes
Liri	34.498	-85.629	366	RAWS	1/1/1997	Present	Yes
Sand Mountain	34.289	-85.970	352	CASTNet	12/1/1988	Present	No
Centre	34.150	-85.702	183	COOP	11/1/2001	Present	No
Centre 4 SW	34.117	-85.733	188	COOP	2/1/1956	10/31/1986	No
Collinsville	34.250	-85.883	229	COOP	3/1/1938	10/31/1977	No
Flat Rock	34.767	-85.683	427	COOP	8/1/1938	3/31/1962	No
Fort Payne	34.441	-85.724	280	COOP	7/15/1935	Present	No
Gadsden 19 N	34.285	-85.962	351	COOP	4/14/2005	Present	No
Ider	34.717	-85.683	467	COOP	1/1/1956	3/31/1962	No
Lafayette 5 SW	34.664	-85.320	274	COOP	4/10/1892	Present	No
Leesburg	34.183	-85.767	180	COOP	1/24/1900	9/30/1981	No
Maple Grove	34.200	-85.800	189	COOP	1/1/1893	1/31/1939	No
Rainsville	34.500	-85.867	403	COOP	12/1/1955	3/31/1962	No
Rising Fawn	34.750	-85.533	250	COOP	1/1/1949	3/31/1962	No
Sand Mt. Substation	34.288	-85.968	363	COOP	1/1/1949	Present	No
Summerville	34.471	-85.361	232	COOP	6/1/1937	Present	No
Sylvania	34.567	-85.817	427	COOP	8/1/1938	3/31/1962	No
Valley Head	34.567	-85.613	324	COOP	1/1/1893	Present	No
Weiss Dam	34.133	-85.800	180	COOP	10/1/1981	Present	No
AC4CS Collinsville	34.277	-85.914	293	CWOP	M	Present	No
KB4BSA-8 Mentone	34.523	-85.624	538	CWOP	M	Present	No
KE4SXD Ft. Payne	34.455	-85.703	309	CWOP	M	Present	No
KE4YGK Fort Payne	34.443	-85.813	390	CWOP	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
W4OZK-7 Mentone	34.540	-85.612	561	CWOP	M	Present	No
W4OZK-8 Collinsville	34.268	-85.801	366	CWOP	M	Present	No
Sand Mountain R&E Center	34.289	-85.970	349	NADP	10/2/1984	Present	No
Fort Payne Isbell Field	34.474	-85.721	267	SAO	3/5/2004	Present	No
Mammoth Cave National Park – MACA							
Mammoth Cave	37.183	-86.087	241	COOP	7/1/1934	Present	Yes
Bowling Green 21 NNE	37.250	-86.233	213	CRN	5/19/2004	Present	Yes
Great Onyx Meadow	37.218	-86.074	219	GPMP	12/1/1984	7/1/1997	Yes
Great Onyx Job Corps	37.250	-86.233	234	POMS	9/14/2005	10/26/2005	Yes
Great Onyx Meadow	37.218	-86.074	219	POMS	9/14/2005	10/26/2005	Yes
Houchin Meadow	37.132	-86.148	243	CASTNet	8/1/1997	Present	No
Barren River Lake	36.898	-86.125	189	COOP	7/1/1963	Present	No
Bonnieville 4 N	37.433	-85.900	223	COOP	4/1/1956	10/5/1966	No
Bowling Green	36.998	-86.428	147	COOP	8/1/1896	Present	No
Bowling Green College	36.983	-86.450	171	COOP	1/19/1934	5/15/1957	No
Bowling Green Substn.	37.017	-86.433	143	COOP	1/1/1949	3/31/1962	No
Bowling Green Warren Co. Arpt.	36.965	-86.424	161	COOP	1/1/1893	Present	No
Brownsville	37.200	-86.267	177	COOP	1/15/1917	12/31/1989	No
Caneyville 1 W	37.418	-86.501	177	COOP	11/1/1957	Present	No
Cave City 1 E	37.141	-85.951	213	COOP	9/1/1984	9/1/2002	No
Chalybeate	37.133	-86.217	192	COOP	6/1/1991	2/1/1998	No
Glasgow	36.983	-85.900	207	COOP	3/1/1921	8/31/1985	No
Glasgow	37.001	-85.907	235	COOP	4/1/1953	Present	No
Greencastle	37.083	-86.500	M	COOP	6/1/1933	8/31/1936	No
Leitchfield 2 N	37.511	-86.289	189	COOP	10/1/1895	Present	No
Lucas	36.883	-86.033	226	COOP	4/9/1941	4/30/1978	No
Millerstown	37.450	-86.050	183	COOP	4/18/1940	6/30/1987	No
Munfordville 2	37.267	-85.883	189	COOP	M	1/31/1965	No
Munfordville 5 NW	37.335	-85.950	207	COOP	4/1/1893	3/15/2004	No
Nolin River Lake	37.279	-86.249	207	COOP	1/1/1964	Present	No
Smiths Grove	37.067	-86.200	195	COOP	7/1/1931	12/7/1944	No
Mammoth Cave NP-Houchin Meadow	37.132	-86.148	236	NADP	8/27/2002	Present	No
Houchin Meadow	37.132	-86.148	243	POMS	2/13/2005	Present	No
Mammoth Cave Biogarden	37.186	-86.041	258	POMS	4/1/2004	10/26/2005	No
Houchin Meadow	37.132	-86.148	236	RAWS	12/1/2004	Present	No
Maca 2	37.131	-86.148	236	RAWS	2/1/2003	4/30/2005	No
Bowling Green Warren Co. Arpt.	36.965	-86.424	161	SAO	1/1/1893	Present	No
Mammoth Cave	37.190	-86.040	244	SCAN	M	Present	No
Ninety Six National Historic Site – NISI							
Bumble Bee Hill	34.148	-82.013	151	POMS	6/22/2005	7/14/2005	Yes
Chappells 2 NNW	34.214	-81.885	145	COOP	7/1/1905	Present	No
Greenwood	34.200	-82.171	187	COOP	5/1/1894	Present	No
Lake Greenwood	34.168	-81.905	152	COOP	6/22/1981	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
McCormick 9 E	33.924	-82.144	151	COOP	5/1/1893	5/1/1999	No
Saluda	33.998	-81.775	146	COOP	4/1/1902	Present	No
Greenwood Co. Arpt.	34.249	-82.159	192	SAO	7/1/1949	Present	No
Russell Cave National Monument – RUCA							
Russell Cave	34.981	-85.810	215	POMS	8/18/2004	9/22/2004	Yes
Bridgeport 5 NW	34.979	-85.801	204	COOP	9/19/1896	Present	No
Flat Rock	34.767	-85.683	427	COOP	8/1/1938	3/31/1962	No
Hales Bar	35.050	-85.550	204	COOP	2/1/1940	10/31/1949	No
Hales Bar Dam	35.050	-85.533	198	COOP	1/1/1949	3/31/1962	No
Hytop	34.817	-86.117	494	COOP	5/1/1935	3/31/1962	No
Ider	34.717	-85.683	467	COOP	1/1/1956	3/31/1962	No
Jasper	35.067	-85.617	198	COOP	1/1/1949	7/31/1955	No
Monteagle	35.224	-85.842	564	COOP	11/1/1930	Present	No
Pleasant Grove Sch.	34.950	-85.917	192	COOP	5/1/1949	3/31/1962	No
Sewanee	35.203	-85.917	579	COOP	5/1/1895	Present	No
Smithtown	35.083	-85.733	204	COOP	1/1/1959	3/31/1962	No
Widows Ck. Stem Plant	34.883	-85.750	192	COOP	4/1/1950	3/31/1962	No
AF4JJ-9 Winchester	35.120	-86.065	315	CWOP	M	Present	No
CW3732 Trenton	34.892	-85.570	485	CWOP	M	Present	No
Monteagle	35.224	-85.842	564	SAO	11/1/1930	Present	No
Shiloh National Military Park – SHIL							
Savannah 6 SW	35.153	-88.321	128	COOP	3/1/1883	Present	Yes
Russian Tenant Field	35.157	-88.339	M	POMS	8/24/2005	9/14/2005	Yes
Acton	34.967	-88.433	156	COOP	7/1/1948	3/31/1962	No
Corinth Fire Stn.	34.950	-88.500	137	COOP	2/1/1952	6/2/1983	No
Eastport	34.917	-88.183	137	COOP	10/1/1943	12/31/1948	No
Enville	35.400	-88.433	165	COOP	1/1/1949	3/31/1962	No
Glens	34.883	-88.417	183	COOP	4/1/1959	3/31/1962	No
Lambs Chapel School	34.933	-88.317	195	COOP	6/1/1959	3/31/1962	No
Leapwood	35.267	-88.450	165	COOP	1/1/1949	3/31/1962	No
Olivehill	35.267	-88.033	165	COOP	12/1/1960	3/31/1962	No
Pickwick Landing Dam	35.067	-88.250	146	COOP	3/1/1938	3/31/1962	No
Savannah TVA	35.233	-88.217	131	COOP	9/1/1948	10/31/1980	No
Selmer	35.165	-88.599	143	COOP	10/1/1923	Present	No
Shiloh	35.150	-88.317	146	COOP	1/1/1949	3/31/1962	No
CW1849 Corinth	34.952	-88.503	143	CWOP	M	Present	No
WB5CON Corinth	34.932	-88.510	143	CWOP	M	Present	No
Shiloh NMP	35.155	-88.322	128	RAWS	10/1/2003	Present	No
Stones River National Battlefield – STRI							
South Chicago Bottom	35.879	-86.436	168	POMS	8/3/2005	8/24/2005	Yes
Beech Grove	35.633	-86.233	275	COOP	1/1/1949	3/31/1962	No
Christiana 5 W	35.705	-86.487	229	COOP	5/1/2004	Present	No
Donelson	36.067	-86.567	122	COOP	M	6/30/1971	No
Eagleville 1 SW	35.731	-86.662	312	COOP	1/12/2000	Present	No
Gladeville	36.113	-86.421	183	COOP	9/6/2001	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Halls Hill	35.867	-86.233	186	COOP	12/1/1902	9/30/1936	No
Lascassas 3 SW	35.917	-86.333	168	COOP	10/18/1957	10/30/1980	No
Murfreesboro 5 N	35.921	-86.379	168	COOP	5/1/1890	Present	No
Murfreesboro Substn.	35.833	-86.383	177	COOP	1/1/1949	3/31/1962	No
Smyrna 4 SE	35.933	-86.467	152	COOP	1/1/1985	2/21/2002	No
Smyrna 6 S	35.912	-86.558	168	COOP	2/5/1941	Present	No
Woodbury 1 WNW	35.843	-86.088	229	COOP	7/1/1954	Present	No
Murfreesboro	35.917	-86.467	183	SAO	8/1/1930	Present	No
Nashville Intl. Arpt.	36.119	-86.689	183	SAO	12/1/1928	Present	No
Sewart	36	-86.533	163	WBAN	7/1/1942	3/31/1970	No
Hendersonville	36.15	-86.35	128	WX4U	M	Present	No

Chickamauga and Chattanooga National Military Park (CHCH) has four weather/climate stations inside its park unit boundaries (Table 4.3). A POMS station was operated briefly in CHCH in August 2005. The other three stations we identified in CHCH are active currently and all of them are COOP stations. The longest data record comes from “Chickamauga Park,” which measures precipitation only. This station’s data record starts in 1948 and is largely complete, although scattered data gaps do exist. The most recent gaps for “Chickamauga Park” occurred in February 2002, October 2002, and February 2004. The other two COOP stations we have identified in CHCH (“Chickamauga Park LARC” and “Lookout Mountain”) provide both temperature and precipitation measurements.

Six active COOP stations are located within 30 km of CHCH (Table 4.3). The longest record of these stations comes from “Lafayette 5 SW,” which is 26 km south of CHCH (Figure 4.1) and started taking measurements in 1892. This station’s data record has occasional data gaps, with the most recent gaps occurring in September 2000, May-July 2001, November 2001, and February-March 2002. Another COOP station we have identified for CHCH with a long data record is “Chattanooga Lovell Field Arpt.” This station, 5 km north of CHCH, has been active since 1928 and has a reliable data record. “Ringgold 2 SE” is 4 km east of CHCH and is a COOP station which measures precipitation only. The data record at this station extends back to 1952 and is largely complete with the exception of occasional data gaps, most notably in October 2002 and in February 2004.

Several stations provide near-real-time data within 30 km of CHCH. The SAO station “Chattanooga Lovell Field Arpt.” is an excellent source of near-real-time observations for CHCH. “Dalton Muni. Arpt.” is an additional SAO station located 30 km southeast of CHCH (Figure 4.1). The RAWS stations “Armuchee #1” and “Prentice Cooper SF” are located 22 km south and 6 km northwest of CHCH, respectively. Other sources for near-real-time data around CHCH include eight CWOP stations and one WX4U station.

We identified one station within COWP (Table 4.3). This is a GPMP station (Cowpens) that is no longer active.

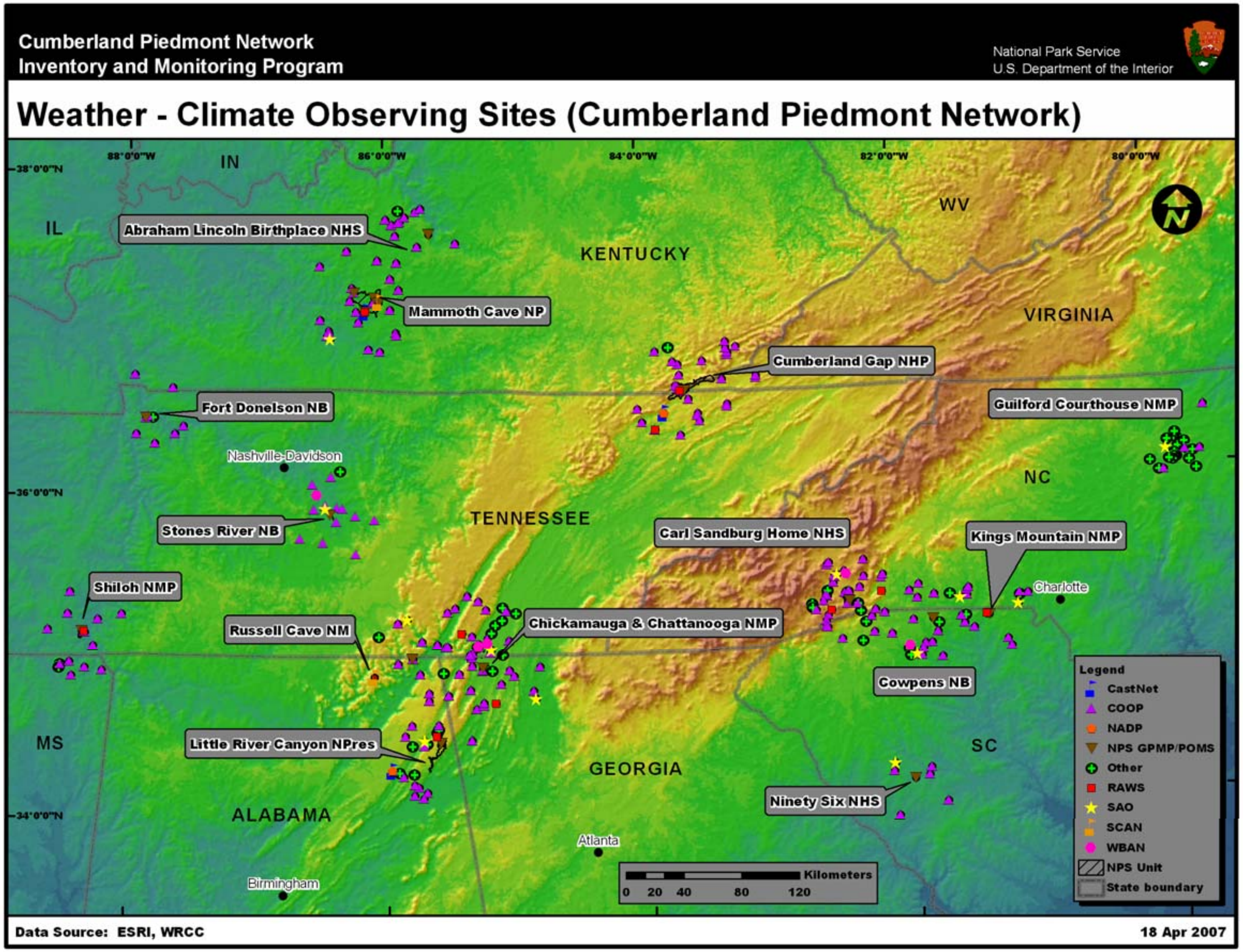


Figure 4.1. Station locations for the CUPN.

The closest active COOP station to COWP is "Chesnee 7 WSW," located 13 km west of COWP (Figure 4.1). Of the 18 COOP stations we identified within 30 km of the boundaries of COWP, six are active currently (Table 4.3). The COOP station "Chesnee 7 WSW" also has a long and reliable data record, having been active since 1928. This station was known as "Rainbow Lake" during its first few decades of operation. The longest data record among the COOP stations we have identified around COWP is at "Gaffney 6 E," 20 km east of COWP. This station has been taking measurements since 1893. Although the data record at "Gaffney 6 E" is very complete, this station measures precipitation only. The COOP station "Gaston Shoals" is only 1-2 km west of "Gaffney 6 E" and has a data record starting in 1912. Like "Gaffney 6 E," this station measures precipitation only. The data record at "Gaston Shoals" is quite complete with the exception of a significant data gap from January 1959 to July 1960. The COOP station "Ninety Nine Islands" is 27 km east of COWP and has been active since 1940. The data record at this station is very complete, although temperature measurements did not begin until after 1960.

The SAO station "Shelby Muni. Arpt." is the primary source for near-real-time weather data within 30 km of COWP. This station is located 22 km northeast of COWP (Figure 4.1) and has been active since 2003 (Table 4.3). The SAO station at Spartanburg was only active from 1930 to 1963. In addition to the SAO station at the Shelby Municipal Airport, two CWOP stations and two WX4U stations also provide near-real-time weather data within 30 km of COWP.

Four weather/climate stations have been identified within CUGA. Two of these are active currently (Table 4.3). The RAWS station "Yellow Creek" is located in the extreme southern end of CUGA (Figure 4.1) and has provided near-real-time weather information since 2002. A POMS station in addition to "Cumberland Gap Pinnacles" (which is no longer active) has also been active in CUGA since spring 2006.

We have identified 28 COOP stations outside of CUGA that are within 30 km of the park unit. Six of these are active (Table 4.3). The closest active COOP station, "Blackmont," is 11 km north of the park unit (Figure 4.1). This station has been operating since 1980. The COOP station "Baxter" has the longest data record of these stations, starting in 1948, and the data record is very reliable. Temperatures were not measured at "Baxter" until 1952. The COOP station "Harlan" (1918-1952) was located very near "Baxter." When "Harlan" stopped taking measurements in 1952, "Baxter" took over the temperature measurements. The other primary source of longer climate records comes from the COOP station "Tazewell 2 SE," which provides a very reliable data record starting in 1966. This station is 16 km south of CUGA.

Two important weather stations are located around the town of Speedwell, Tennessee, 10 km south of CUGA. These include a CASTNet station (Speedwell) and a NADP station (also named "Speedwell"). The CASTNet station provides near-real-time weather for several parameters such as temperature, precipitation, wind, and humidity. Further south is the RAWS station "Chuck Swan SF," which also provides near-real-time data for CUGA.

Two weather/climate stations have been identified within FODO (Table 4.3). The POMS station we identified (Fort Donelson NB) is no longer active, while the COOP station (Dover 1 W) is active and contains a long data record going back to 1897. The data record at "Dover 1 W" has a lengthy gap from 1931 through 1947, with occasional gaps after 1947. The most recent gap occurred in January 2004. Only two active COOP stations, “Canton 3 S” and “Tennessee Ridge,” have been identified within 30 km of FODO. “Canton 3 S,” located 29 km north of FODO, has been active since 1896. This is a precipitation-only COOP station whose data record is unreliable before 1980. The COOP station “Tennessee Ridge” is located 18 km southeast of FODO and has been operating since 1999. One CWOP station, “KD4MPL Dover,” provides the only source of near-real-time weather data within 30 km of FODO.

We identified no weather/climate stations within GUCO (Table 4.3). The closest sources of reliable weather/climate information for GUCO are the COOP and SAO stations at Greensboro Piedmont Triad International Airport, located 9 km southwest of GUCO (Figure 4.1). These stations have reliable data records that start in 1903. In addition to this SAO station, near-real-time weather data are provided by 13 CWOP stations and two WX4U stations within 30 km of GUCO.

Three of the six COOP stations we identified within 30 km of GUCO are active currently, including the aforementioned COOP station at Greensboro Piedmont Triad International Airport. The COOP station “High Point,” located 21 km southwest of GUCO, also provides a reliable data record, beginning in 1921. “Reidsville 2 NW” is an active COOP station 30 km northeast of GUCO which has a reliable data record that starts in 1962.

Two weather stations have been identified within KIMO (Table 4.3). The POMS station we identified (Reservoir Hill) is no longer active, while the RAWS station (Kings Mountain) is active and provides near-real-time weather data for KIMO.

Seven of the 10 COOP stations we identified within 30 km of KIMO are active currently (Table 4.3). The closest COOP station to KIMO is “Ninety Nine Islands,” located 10 km southwest of the park unit (Figure 4.1). This station was discussed previously. The longest data record comes from the COOP station “Gastonia,” located 23 km northeast of KIMO. This station has been operating since 1890. The data record for “Gastonia” is largely complete, with a few data gaps; the most recent gap occurred in January 1996. The COOP station “Shelby 2 NNE,” 22 km northwest of KIMO, has been operating since 1893 but has a large data gap from January 1895 through July 1936. The data record has been very complete since 1936. Two other COOP stations that have been discussed previously, “Gaffney 6 E” and “Gaston Shoals,” are about 15 km southwest of KIMO and provide long-term climate records for the park unit.

The primary sources of near-real-time weather data outside of KIMO are two SAO stations. One station is at Gastonia Municipal Airport, 19 km northeast of KIMO, while the other SAO station is at Shelby Municipal Airport, 21 km northwest of KIMO (Figure 4.1). The data records at both of these stations are less than 10 years in length. Two CWOP stations and one WX4U station also provide near-real-time data within 30 km of KIMO.

We have identified two stations within LIRI (Table 4.3). The POMS station we identified (Little River Canyon Rim) is no longer active, while the RAWS station (Liri) is active and provides near-real-time weather data for LIRI.

We have identified several sources of near-real-time weather data within 30 km of LIRI. The CASTNet station "Sand Mountain" is located 25 km southwest of LIRI (Figure 4.1). A NADP station (Sand Mountain R&E Center) is co-located with the CASTNet station. The only SAO station we identified for LIRI is "Fort Payne Isbell Field," located 8 km west of LIRI. In addition to these stations, there are at least six CWOP stations within 30 km of LIRI providing near-real-time weather data.

Eight of the 17 COOP stations we identified within 30 km of LIRI are active currently (Table 4.3). The closest COOP station to LIRI is "Valley Head," located 6 km north of the park unit (Figure 4.1). This station has a very complete data record that starts in 1893. However, this isn't the longest data record around LIRI. The longest data record comes from the COOP station "Lafayette 5 SW" (1892-present), located 30 km northeast of LIRI. This station has been discussed previously. The COOP station "Fort Payne," 8 km west of LIRI, has been operating since 1935 and has a very complete data record; however, the station measures precipitation primarily. The COOP station "Summerville," 18 km east of LIRI, is a precipitation-only station that has been operating since 1937 and also has a very complete data record. "Sand Mt. Substation" is a COOP station that has a very complete data record (1949-present) and is located near the CASTNet and NADP stations at Sand Mountain, 25 km southwest of LIRI.

Mammoth Cave National Park (MACA) has five weather/climate stations inside its park unit boundaries (Table 4.3). Two of these stations are still active. The COOP station "Mammoth Cave" has been active since 1934 and is fairly complete, although the data record has occasional gaps. The most recent gaps occurred in March, June, and September of 2005. A CRN station (Bowling Green 21 NNE) has been active in MACA since 2004. A GPMP station (Great Onyx Meadow) was active between 1984 and 1997. Two POMS stations (Great Onyx Job Corps, Great Onyx Meadow) were operated briefly in MACA during 2005. The POMS station "Mammoth Cave Biogarden," located just outside of MACA, operated until October 2005 and was then moved to ABLI to begin taking observations in the spring of 2006.

Seven of the 20 COOP stations we identified within 30 km of MACA are active currently (Table 4.3). The longest data record comes from "Bowling Green Warren Co. Arpt.," a COOP station located almost 30 km southwest of MACA. This station has a data gap from January 1996 through February 1999 but has an otherwise complete data record. The best climate record, overall, may come from the COOP station "Leitchfield 2 N," which is located 27 km north of MACA and has a very complete record. The COOP station "Bowling Green" is a precipitation-only station located 27 km southwest of MACA that has a very complete data record starting in 1896.

Besides the CRN station inside MACA, we have identified a few other sources of near-real-time weather data within 30 km of MACA. Most of these stations are located just south of MACA (Figure 4.1). First, the CASTNet station "Houchin Meadow" has been operating since 1997 (Table 4.3). Second, the RAWS station "Houchin Meadow" has been taking measurements since December 2004. A third near-real-time station just south of MACA is the SCAN station "Mammoth Cave." There are also some NADP and POMS stations measuring select meteorological parameters just south of MACA. Bowling Green's Warren County Airport has a

SAO station in addition to its COOP station, providing near-real-time data 30 km southwest of MACA.

We identified one station within NISI. This is a POMS station (Bumble Bee Hill) that is no longer active, having operated briefly during the summer of 2005. Outside of NISI, we have identified five COOP stations and one SAO station located within 30 km of the park unit (Table 4.3). The SAO station “Greenwood Co. Arpt.,” located 16 km northwest of NISI (Figure 4.1), is the primary source of near-real-time weather data for the park unit. In addition, this site has a long data record going back to 1949, so this station’s record can also be used for climate analyses. The closest COOP station to NISI is “Lake Greenwood,” which is 9 km northeast of NISI. This station has been active since 1981. The longest data record comes from the COOP station “Greenwood,” which is 14 km west of NISI and has been active since 1894. This station’s data record is very complete. Two other long-term records are available within 30 km of NISI. The COOP station “Saluda” has been active since 1902 and has a very complete data record. This station is 27 km southeast of NISI. The COOP station “Chappells 2 NNW” is a precipitation-only station that has been active since 1905 and has a very complete data record. This station is 13 km northeast of NISI.

We identified one station within RUCA. This is a POMS station (Russell Cave) that is no longer active, having operated briefly during the late summer of 2005.

One SAO station (Monteagle) and two CWOP stations (“AF4JJ-9 Winchester” and “CW3732 Trenton”) provide near-real-time data within 30 km of RUCA. The SAO station “Monteagle” is 27 km north of RUCA and provides a lengthy data record (1930-present) that is suitable for climate-monitoring purposes.

Only three of the 12 COOP stations we identified within 30 km of RUCA are active currently (Table 4.3). The previously-discussed SAO station at Monteagle is also co-located with a COOP station (Monteagle) which has a very reliable data record (1930-present). The longest data record comes from the COOP station “Sewanee,” located 26 km northwest of RUCA. Unfortunately, this station’s data record is unreliable. The closest COOP station to RUCA is “Bridgeport 5 NW,” located just southeast of RUCA. This station had a significant gap in observations between April 1973 and September 1982 but has an otherwise complete data record.

Two weather/climate stations have been identified within SHIL (Table 4.3). The POMS station we identified (Russian Tenant Field) is no longer active, while the COOP station we identified (Savannah 6 SW) is active and contains a very complete data record going back to 1883. This is in fact the longest data record of any of the stations we have identified for SHIL. Another long-term record is available from the COOP station “Selmer,” located 22 km west of SHIL. This station has a very complete data record (1923-present), although temperatures have only been measured since July 1958. The best source of near-real-time weather data for SHIL comes from a RAWS station just west of SHIL (Shiloh NMP). Two CWOP stations in Corinth also provide near-real-time weather data for the park unit.

One weather/climate stations has been identified within STRI (Table 4.3). This is a POMS station (South Chicago Bottom) that is no longer active. Six active COOP stations were identified within 30 km of STRI. The longest record among these stations is at “Murfreesboro 5 N,” located 5 km east of STRI. This station has been active since 1890 and has a very complete record. Two other long-term records are found at the COOP stations “Smyrna 6 S” (1941-present; 11 km northwest of STRI) and “Woodbury 1 WNW” (1956-present; 29 km east of STRI). While “Woodbury 1 WNW” has a very complete data record, the record at “Smyrna 6 S” is less reliable, with a data gap from the 1950s until the late 1990s. The COOP station “Murfreesboro 5 N” is also the closest active COOP station to STRI. The best source of near-real-time weather data for STRI comes from the SAO station “Murfreesboro,” which has been operating since 1930. At only 4 km southeast of STRI, this station is the closest active station to STRI.

5.0. Conclusions and Recommendations

We have based our findings on an examination of available climate records within CUPN 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 CUPN.

5.1. Cumberland Piedmont Inventory and Monitoring Network

The CUPN network has collected some preliminary weather/climate station metadata for CARL and MACA (see Appendix F). These metadata were helpful particularly in the initial stages of the CUPN weather/climate station inventory described in this report.

For a handful of the CUPN park units, coverage of both real-time weather/climate stations and long-term climate stations is satisfactory for addressing the weather- and climate-monitoring objectives of the CUPN, both within park boundaries and in adjacent regions. These park units include CHCH and MACA. Otherwise, many of the park units in the CUPN have limited coverage of both near-real-time stations and long-term stations within and near the parks, including at least four CUPN park units that have no active weather/climate stations within their boundaries (COWP, GUCO, NISI, and RUCA). It is therefore important that NPS work with local agencies to ensure that any active near-real-time and long-term weather/climate stations be retained in order to continue their valuable contributions for weather and climate monitoring in the CUPN.

Two park units in the CUPN have potential long-term climate records that are comprised of records from two separate stations we identified. With both park units, it is likely that one station is really under consideration, with the only differences arising from the given station having been identified by different names during its period of record. For example, at CUGA, the COOP stations “Baxter” and “Harlan” are actually the same station. This station went by the name “Harlan” from 1918-1952 but then went by the name “Baxter” from 1952 until present. Another example of this situation is at COWP, where the COOP station “Chesnee 7 WSW” has also been identified as “Rainbow Lake” at various times throughout its history. For COWP, this is less of an issue for climate monitoring efforts, as other long-term climate records have been identified. However, for CUGA, the combined record of “Baxter” and “Harlan” provides the only climate record longer than 40 years. It is therefore more imperative that CUGA utilize these records, albeit with great care, for their climate monitoring efforts.

5.2. Spatial Variations in Mean Climate

Land-use heterogeneity, particularly land uses introduced by human settlement, influences heavily the park units within CUPN, leading to systematic spatial variations in mean surface climate. This is true at local scales in particular; with local variations over short horizontal distances, land use patterns introduce considerable fine-scale structure to mean climate (temperature and precipitation). Issues encountered in mapping mean climate are discussed in Appendix D 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 snow). This level of characterization generally requires that the stations should be distributed spatially in the major biomes of each park, located in those land uses/land covers that most truly represent the local area. 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 land use variations, particularly local wind patterns.

5.3. Climate Change Detection

There is much interest in the adaptation of CUPN ecosystems in response to possible future climate change. This particularly includes climate influences from land use changes, impacts on air quality and water quantity and quality, and the introduction of non-native plant and animal communities.

The desire for credible, accurate, complete, and long-term climate records—from any location—cannot be overemphasized. Thus, 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 consequence of diversity within CUPN in land use patterns.

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 CUPN 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 CUPN park units but also to climate-monitoring efforts for CUPN. 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

- The preliminary weather/climate station metadata for CARL and MACA collected by the CUPN network has been helpful in compiling the CUPN weather/climate station inventory described in this report.
- Only a few of the CUPN park units have satisfactory coverage of both real-time weather/climate stations and long-term climate stations, including CHCH and MACA. Otherwise, many of the park units in the CUPN have limited coverage of both near-real-time stations and long-term stations within and near the parks, highlighting the importance of maintaining those stations that are currently active.
- COWP and CUGA both have COOP stations that could likely be combined together to provide one long-term climate records. While other reliable records are available around COWP, the combined records at CUGA should be utilized, being the only long-term records identified for the park unit.

6.0. Literature Cited

American Association of State Climatologists. 1985. Heights and exposure standards for sensors on automated weather stations. The State Climatologist **9**.

Bevis, M., S. Businger, T. A. Herring, C. Rocken, R. A. Anthes, and R. H. Ware. 1992. GPS meteorology: remote sensing of the atmospheric water vapor using the global positioning system. Journal of Geophysical Research **97**:75–94.

Bonan, G. B. 2002. Ecological Climatology: Concepts and Applications. Cambridge University Press.

Bureau of Land Management. 1997. Remote Automatic Weather Station (RAWS) and Remote Environmental Monitoring Systems (REMS) standards. RAWS/REMS Support Facility, Boise, Idaho.

Chapin III, F. S., M. S. Torn, and M. Tateno. 1996. Principles of ecosystem sustainability. The American Naturalist **148**:1016-1037.

Daly, C., R. P. Neilson, and D. L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology **33**:140-158.

Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. Climate Research **22**:99-113.

Doggett, M., C. Daly, J. Smith, W. Gibson, G. Taylor, G. Johnson, and P. Pasteris. 2004. High-resolution 1971-2000 mean monthly temperature maps for the western United States. Fourteenth AMS Conf. on Applied Climatology, 84th AMS Annual Meeting. Seattle, Washington, American Meteorological Society, Boston, Massachusetts, January 2004, Paper 4.3, CD-ROM.

Duan, J., M. Bevis, P. Fang, Y. Bock, S. Chiswell, S. Businger, C. Rocken, F. Solheim, T. van Hove, R. Ware, and others. 1996. GPS meteorology: direct estimation of the absolute value of precipitable water. Journal of Applied Meteorology **35**:830-838.

Environmental Protection Agency. 1987. On-site meteorological program guidance for regulatory modeling applications. EPA-450/4-87-013. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

Finklin, A. I., and W. C. Fischer. 1990. Weather station handbook –an interagency guide for wildland managers. NFES No. 2140. National Wildfire Coordinating Group, Boise, Idaho.

Gibson, W. P., C. Daly, T. Kittel, D. Nychka, C. Johns, N. Rosenbloom, A. McNab, and G. Taylor. 2002. Development of a 103-year high-resolution climate data set for the conterminous United States. Thirteenth AMS Conf. on Applied Climatology. Portland, Oregon, American Meteorological Society, Boston, MA, May 2002:181-183.

I&M. 2006. I&M Inventories home page. http://science.nature.nps.gov/im/inventory/index.cfm.

Jacobson, M. C., R. J. Charlson, H. Rodhe, and G. H. Orians. 2000. Earth System Science: From Biogeochemical Cycles to Global Change. Academic Press, San Diego.

Karl, T. R., V. E. Derr, D. R. Easterling, C. K. Folland, D. J. Hoffman, S. Levitus, N. Nicholls, D. E. Parker, and G. W. Withee. 1996. Critical issues for long-term climate monitoring. Pages 55-92 *in* T. R. Karl, editor. Long Term Climate Monitoring by the Global Climate Observing System, Kluwer Publishing.

Karl, T. R., R. W. Knight, D. R. Easterling, and R. G. Quayle, 1996. Trends in U.S. climate during the twentieth century. Consequences **1**:2-12.

Karl, T. R., and R. W. Knight. 1998. Secular trends in precipitation amount, frequency, and intensity in the United States. Bull. Amer. Meteor. Soc. **79**:231-241.

Leibfreid, T. R., R. L. Woodman, and S. C. Thomas. 2005. Vital Signs Monitoring Plan for the Cumberland Piedmont Network and Mammoth Cave National Park Prototype Monitoring Program: July 2005. National Park Service, Mammoth Cave, Kentucky, USA. 125 pp. plus appendices.

National Assessment Synthesis Team. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, Report for the U.S. Global Change Research Program. Cambridge University Press, Cambridge, UK.

National Research Council. 2001. A Climate Services Vision: First Steps Toward the Future. National Academies Press, Washington, D.C.

National Wildfire Coordinating Group. 2004. National fire danger rating system weather station standards. Report PMS 426.3. National Wildfire Coordinating Group, Boise, Idaho.

Neilson, R. P. 1987. Biotic regionalization and climatic controls in western North America. Vegetatio **70**:135-147.

Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin **31**:1000-1003.

Redmond, K. T., D. B. Simeral, and G. D. McCurdy. 2005. Climate monitoring for southwest Alaska national parks: network design and site selection. Report 05-01. Western Regional Climate Center, Reno, Nevada.

Schlesinger, W. H. 1997. Biogeochemistry: An Analysis of Global Change. Academic Press, San Diego.

Tanner, B. D. 1990. Automated weather stations. Remote Sensing Reviews **5**:73-98.

World Meteorological Organization. 1983. Guide to meteorological instruments and methods of observation, No. 8, 5th edition, World Meteorological Organization, Geneva Switzerland.

World Meteorological Organization. 2005. Organization and planning of intercomparisons of rainfall intensity gauges. World Meteorological Organization, Geneva Switzerland.

Yuan, L. L., R. A. Anthes, R. H. Ware, C. Rocken, W. D. Bonner, M. G. Bevis, and S. Businger. 1993. Sensing climate change using the global positioning system. Journal of Geophysical Research **98**:14925-14937.

Appendix A. 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 B. 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.)

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

B.1.1. 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.1.2. Processing algorithms and changes in these algorithms must be well documented. Documentation should be carried with the data throughout the data-archiving process.

B.1.3. 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.

B.1.4. 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.

B.1.5. 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.

B.1.6. Where feasible, some level of "low-technology" backup to "high-technology" observing systems should be developed to safeguard against unexpected operational failures.

B.1.7. 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.

B.1.8. 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.

B.1.9. 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.

B.1.10. 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.

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

B.2.1. 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.2.2. 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)

B.2.3. 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)

B.2.4. 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)

B.2.5. 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)

B.2.6. Maintain long-term weather and climate stations.

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

B.2.7. 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)

B.2.8. 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)

B.2.9. Carefully consider the transition from research-observing system to long-term operation.

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

B.2.10. 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)

B.3. Literature Cited

Karl, T. R., V. E. Derr, D. R. Easterling, C. K. Folland, D. J. Hoffman, S. Levitus, N. Nicholls, D. E. Parker, and G. W. Withee. 1996. Critical Issues for Long-Term Climate Monitoring. Pages 55-92 *in* T. R. Karl, editor. Long Term Climate Monitoring by the Global Climate Observing System, Kluwer Publishing.

Global Climate Observing System. 2004. Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC. GCOS-92, WMO/TD No. 1219, World Meteorological Organization, Geneva, Switzerland.

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. 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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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").

D.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.

D.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.

D.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.

D.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* (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.

D.1.10. Frozen Precipitation

Frozen precipitation is more difficult to measure than liquid precipitation, especially with automated techniques. Sevruk and Harmon (1984), Goodison et al. (1998), 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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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 U.S.

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.

D.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 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 gasses.

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.

D.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.

D.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.

D.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.

D.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.

D.3.1. Equipment and Exposure Factors

D.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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.3.2. Element-Specific Factors

D.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.

D.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.

D.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: 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 coast, 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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.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.

D.3.3. Long-Term Comparability and Consistency

D.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.

D.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).

D.4. Literature Cited

American Association of State Climatologists. 1985. Heights and exposure standards for sensors on automated weather stations. The State Climatologist **9**.

Brock, F. V., K. C. Crawford, R. L. Elliott, G. W. Cuperus, S. J. Stadler, H. L. Johnson and M. D. Eilts. 1995. The Oklahoma Mesonet: A technical overview. Journal of Atmospheric and Oceanic Technology **12**:5-19.

Daly, C., R. P. Neilson, and D. L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology **33**:140-158.

Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. Climate Research **22**:99-113.

Doggett, M., C. Daly, J. Smith, W. Gibson, G. Taylor, G. Johnson, and P. Pasteris. 2004. High-resolution 1971-2000 mean monthly temperature maps for the western United States. Fourteenth AMS Conf. on Applied Climatology, 84^{th} AMS Annual Meeting. Seattle, WA, American Meteorological Society, Boston, MA, January 2004, Paper 4.3, CD-ROM.

Geiger, R., R. H. Aron, and P. E. Todhunter. 2003. The Climate Near the Ground. 6^{th} edition. Rowman & Littlefield Publishers, Inc., New York.

Gibson, W. P., C. Daly, T. Kittel, D. Nychka, C. Johns, N. Rosenbloom, A. McNab, and G. Taylor. 2002. Development of a 103-year high-resolution climate data set for the conterminous United States. Thirteenth AMS Conf. on Applied Climatology. Portland, OR, American Meteorological Society, Boston, MA, May 2002:181-183.

Goodison, B. E., P. Y. T. Louie, and D. Yang. 1998. WMO solid precipitation measurement intercomparison final report. WMO TD 982, World Meteorological Organization, Geneva, Switzerland.

National Research Council. 1998. Future of the National Weather Service Cooperative Weather Network. National Academies Press, Washington, D.C.

National Research Council. 2001. A Climate Services Vision: First Steps Toward the Future. National Academies Press, Washington, D.C.

Redmond, K. T. 1992. Effects of observation time on interpretation of climatic time series - A need for consistency. Eighth Annual Pacific Climate (PACLIM) Workshop. Pacific Grove, CA, March 1991:141-150.

Redmond, K. T. 2004. Photographic documentation of long-term climate stations. Available from ftp://ftp.wrcc.dri.edu/nps/photodocumentation.pdf. (accessed 15 August 2004)

Redmond, K. T. and D. B. Simeral. 2004. Climate monitoring comments: Central Alaska Network Inventory and Monitoring Program. Available from ftp://ftp.wrcc.dri.edu/nps/alaska/cakn/npscakncomments040406.pdf. (accessed 6 April 2004)

Redmond, K. T., D. B. Simeral, and G. D. McCurdy. 2005. Climate monitoring for southwest Alaska national parks: network design and site selection. Report 05-01. Western Regional Climate Center, Reno, Nevada.

Redmond, K. T., and G. D. McCurdy. 2005. Channel Islands National Park: Design considerations for weather and climate monitoring. Report 05-02. Western Regional Climate Center, Reno, Nevada.

Sevruk, B., and W. R. Hamon. 1984. International comparison of national precipitation gauges with a reference pit gauge. Instruments and Observing Methods, Report No 17, WMO/TD – 38, World Meteorological Organization, Geneva, Switzerland.

Simpson, J. J., Hufford, G. L., C. Daly, J. S. Berg, and M. D. Fleming. 2005. Comparing maps of mean monthly surface temperature and precipitation for Alaska and adjacent areas of Canada produced by two different methods. Arctic **58**:137-161.

Whiteman, C. D. 2000. Mountain Meteorology: Fundamentals and Applications. Oxford University Press, Oxford, UK.

Wilson, E. O. 1998. Consilience: The Unity of Knowledge. Knopf, New York.

World Meteorological Organization. 1983. Guide to meteorological instruments and methods of observation, No. 8, 5th edition, World Meteorological Organization, Geneva Switzerland.

World Meteorological Organization. 2005. Organization and planning of intercomparisons of rainfall intensity gauges. World Meteorological Organization, Geneva Switzerland.

Yang, D., B. E. Goodison, J. R. Metcalfe, V. S. Golubev, R. Bates, T. Pangburn, and C. Hanson. 1998. Accuracy of NWS 8” standard nonrecording precipitation gauge: results and application of WMO intercomparison. Journal of Atmospheric and Oceanic Technology **15**:54-68.

Yang, D., B. E. Goodison, J. R. Metcalfe, P. Louie, E. Elomaa, C. Hanson, V. Bolubev, T. Gunther, J. Milkovic, and M. Lapin. 2001. Compatibility evaluation of national precipitation gauge measurements. Journal of Geophysical Research **106**:1481-1491.

Appendix E. 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 F. Electronic supplements

F.1. ACIS metadata file for weather and climate stations associated with the APHN: http://www.wrcc.dri.edu/nps/pub/APHN/metadata/APHN_from_ACIS.tar.gz.

F.2. APHN metadata files for weather and climate stations associated with the APHN: http://www.wrcc.dri.edu/nps/pub/APHN/metadata/APHN_NPS.tar.gz.

Appendix G. Descriptions of weather/climate monitoring networks

G.1. 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 United States.

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.

G.2. 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 U.S. 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.

G.3. 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.
  - 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 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.

G.4. 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.

G.5. 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.

G.6. NOAA Ground-Based GPS Meteorology (GPS-MET) Network

- 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-$10000, 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/.

G.7. National Atmospheric Deposition Program (NADP)

- Purpose of network: measurement of precipitation chemistry and atmospheric deposition.
- Primary management agencies: USDA, but multiple collaborators.
- Data website: http://nadp.sws.uiuc.edu.
- Measured weather/climate elements:
  - Precipitation.
- Sampling frequency: daily.
- Reporting frequency: daily.
- Estimated station cost: unknown.
- Network strengths:
  - Data quality is excellent, with high data standards.
  - Site maintenance is excellent.
- Network weaknesses:
  - A very limited number of climate parameters are measured.

Stations within the NADP network monitor primarily wet deposition through precipitation chemistry at selected sites around the U.S. and its territories. The network is a collaborative effort among several agencies including USGS and USDA. Precipitation is the primary climate parameter measured at NADP sites. This network includes MDN sites.

G.8. 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.

G.9. Remote Automated Weather Station (RAWS) Network

- 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 U.S. 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.

G.10. NWS/FAA Surface Airways Observation (SAO) Network

- Purpose of network: provide near-real-time 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.

G.11. USDA/NRCS Soil Climate Analysis Network (SCAN)

- Purpose of network: comprehensive soil-climate network used in natural resource assessments and other conservation activities in the U.S.
- Primary management agency: USDA/NRCS.
- Data website: http://www.wcc.nrcs.usda.gov/scan/.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed.
  - Wind direction.
  - Barometric pressure.
  - Solar radiation.
  - Snow water content.
  - Snow depth.
  - 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: $25000, with maintenance costs approximately $1000/year.
- Network strengths:
  - Sites are well-maintained.
  - Data are of high quality and are largely complete.
  - Very reliable automated system.
- Network weaknesses:
  - Short data records.
  - Network is still in development.

The SCAN network is intended to be a comprehensive nationwide soil moisture and climate information system to be used in supporting natural resource assessments and other conservation activities. These stations are usually located in the agricultural areas of the U.S. All SCAN sites are automated. The parameters measured at these sites include air temperature, precipitation, humidity, wind, pressure, solar radiation, snow depth, and snow water content.

G.12. Weather For You Network (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.

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