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Weather and Climate Inventory
National Park Service
Appalachian Highlands Network

Natural Resource Technical Report NPS/APHN/NRTR—2007/008

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Blue Ridge Parkway
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Acronyms

AASC	American Association of State Climatologists
ACIS	Applied Climate Information System
APHN	Appalachian Highlands Inventory and Monitoring Network
APPA	Appalachian National Scenic Trail
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
BISO	Big South Fork National River and Recreational Area
BLM	Bureau of Land Management
BLRI	Blue Ridge Parkway
CASTNet	Clean Air Status and Trends Network
COOP	Cooperative Observer Program
CRN	Climate Reference Network
CWOP	Citizen Weather Observer Program
DFIR	Double-Fence Intercomparison Reference
DST	daylight savings time
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FIPS	Federal Information Processing Standards
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GPMP	Gaseous Pollutant Monitoring Program
GPS	Global Positioning System
GRSM	Great Smoky Mountains National Park
I&M	NPS Inventory and Monitoring Program
LST	local standard time
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
NETN	Northeast Temperate Network
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
OBRI	Obed Wild and Scenic River
POMS	Portable Ozone Monitoring System
PRISM	Parameter Regression on Independent Slopes Model
RAWS	Remote Automated Weather Station network
RCC	regional climate center
SAO	Surface Airways Observation network
SCAN	Soil Climate Analysis Network

SOD	Summary Of the Day
Surfrad	Surface Radiation Budget network
SNOTEL	Snowfall Telemetry 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 Appalachian Highlands Inventory and Monitoring Network (APHN). 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. The APHN is distinguished by steep moisture and temperature gradients resulting in substantially different environments over short distances. Annual precipitation in the southern Appalachian Mountains is second in North America only to the Pacific Northwest in annual rainfall and is a major driver in both terrestrial and aquatic systems of the APHN. Considerable local variations in precipitation are imposed by orography and rain shadow effects. Climate changes are directly affecting APHN ecosystems, altering natural ecosystem disturbance regimes (including fire), and facilitating exotic species invasions. Effects of these climate changes are likely amplified at the higher elevations of the APHN, where relict boreal communities contain unique and important resources that may be adversely impacted by significant climate warming trends. Because of its influence on the ecology of APHN park units and the surrounding areas, climate was identified as a high-priority vital sign for APHN and is 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 APHN park units.
- Inventory of weather and climate station locations in and near APHN 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 APHN are influenced both by the southern Appalachian Mountains, and the interactions of these mountains with air flows from the Atlantic Ocean and the Gulf of Mexico. Mean annual precipitation varies from northeast to southwest and as a function of elevation in the APHN, ranging from under 800 millimeters (mm) along northern portions of the Blue Ridge Parkway (BLRI) to well over 2000 mm along the southern BLRI and higher elevations of Great Smoky Mountains National Park (GRSM). Precipitation is common throughout the year in the APHN. Mean annual temperatures in the APHN range from 6°C in the higher elevations of BLRI and GRSM to over 12°C for lower elevations of APHN park units. Local topography drives much of the spatial temperature variability in APHN throughout the year, although coast-interior gradients are also important, particularly in the winter months. Some increases in precipitation have been observed over the last century in portions of the APHN. Temperature trends are not readily apparent. The North Atlantic Oscillation – Arctic Oscillation (NAO-AO) and the El Niño-Southern Oscillation (ENSO) influence interannual climate variability in the APHN. NAO-AO variations occur on time scales on the order of a couple decades and influence the wintertime temperature characteristics of the APHN. Warm

ENSO phases (El Niño events) occur every 3-7 years and tend to bring cooler and wetter winter conditions to the APHN. The number and severity of storm events in the APHN varies greatly from year to year, including nor'easters, ice storms, and tropical systems.

Through a search of national databases and inquiries to NPS staff, we have identified 37 meteorological stations within APHN park units. The vast majority of these stations are in GRSM, where 31 stations were identified. Many of these are associated with the National Weather Service Cooperative Observer Program (COOP). The APHN has compiled much preliminary station metadata that has been particularly useful for the completion of this report. We also looked for meteorological stations within a specified buffer distance of APHN park units (10 km for BLRI; 30 km for all other park units) and identified over 330 such stations.

Coverage of long-term climate stations in and near the APHN park units is sufficient for monitoring overall climate change characteristics in the APHN region, particularly at lower elevations. Unfortunately, the current coverage is not yet sufficient for understanding the characteristics of APHN climate changes at finer spatial scales and at higher elevations. It is important that any active longer-term climate stations continue operating in order to continue their valuable contributions for weather and climate monitoring in the APHN.

Steps could be considered for expanding the coverage of near-real-time sites in APHN parks as well. Various monitoring efforts in the highly-variable topography of the APHN park units underscore the need for near-real-time weather observations at denser spatial scales. New installations are needed in Obed Wild and Scenic River (OBRI), where no near-real-time stations are currently available. In Big South Fork National River and Recreational Area (BISO), the existing POMS and RAWS sites in southern BISO would be complimented by new installations in northern BISO, allowing the APHN to monitor climate gradients along the Big South watershed. Initial efforts to improve near-real-time station coverage in GRSM may focus on maintaining automated stations at a few key high points along the Appalachian Crest, along with installing at least one station in each of the larger watersheds in the park unit (e.g., Cataloochee, Prong). Any existing ranger stations in these watersheds would serve as useful locations for such installations. As resources allow, this coverage may then be expanded to include smaller-scale drainage basins. Precipitation measurements at existing air quality monitoring sites in GRSM, such as Elkmont, could be augmented with additional sensors measuring temperature, relative humidity, and wind. Alternatively, near-real-time sites devoted to weather observations, such as RAWS (Remote Automated Weather Station) sites, could be installed at these air-quality monitoring sites. Transects along significant elevation gradients, especially in GRSM, would provide useful meteorological data, particularly for attempts to monitor plant and animal community responses to climate changes. Suitable candidates for such transects include U.S. Highway 441 through the center of GRSM, with stations present about every 300 meters (1000 feet) in elevation. Additional resources could go towards finer sampling along existing transects or setting up additional transects at other readily-accessible locations such as Cades Cove.

Several reliable weather and climate stations have been identified along the length of BLRI. These stations provide an excellent opportunity for documenting latitudinal gradients of current weather conditions and long-term climate changes across the APHN.

Acknowledgements

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1.0. Introduction

Weather and climate are key drivers in ecosystem structure and function. Global- and regional-scale climate variations 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; Emmott 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 Appalachian Highlands Inventory and Monitoring Network (APHN) 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 APHN (Table 1.1; Figure 1.1). The Appalachian National Scenic Trail (APPA) is discussed in a similar report for the Northeast Temperate Network (NETN; Davey et al. 2006). In this report, we provide the following informational elements:

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

Some of the primary objectives for climate- and weather-monitoring in the APHN are as follows (Emmott et al. 2005):

A. Determine variability and long-term trends in climate for APHN parks through monthly and annual summaries of descriptive statistics for selected weather parameters, including air temperature, precipitation, cloud cover, wind speed and direction, solar radiation, fog and cloud immersion time, and how these affect other resources being monitored.
B. Determine how annual rainfall/snowfall and temperature in a given year compare to historic averages.

C. Determine how many storm events and of what magnitude occur each year.
D. Determine relationships between weather patterns and other resources of concern including timing/success of reproduction in selected species, outbreaks of forest insect pests and pathogens, and distribution of exotic invasive species.

Table 1.1. Park units in the Appalachian Highlands Network.

Acronym	Name
BISO	Big South Fork National River and Recreational Area
BLRI	Blue Ridge Parkway
GRSM	Great Smoky Mountains National Park
OBRI	Obed Wild and Scenic River

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 network (RAWS) and the U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS) Snowfall Telemetry (SNOTEL) and snowcourse networks. Usually a single agency, but sometimes a consortium of interested parties, will jointly support a particular weather/climate network.

1.1.2. NPS I&M Networks

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

1.2. Weather versus Climate Definitions

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

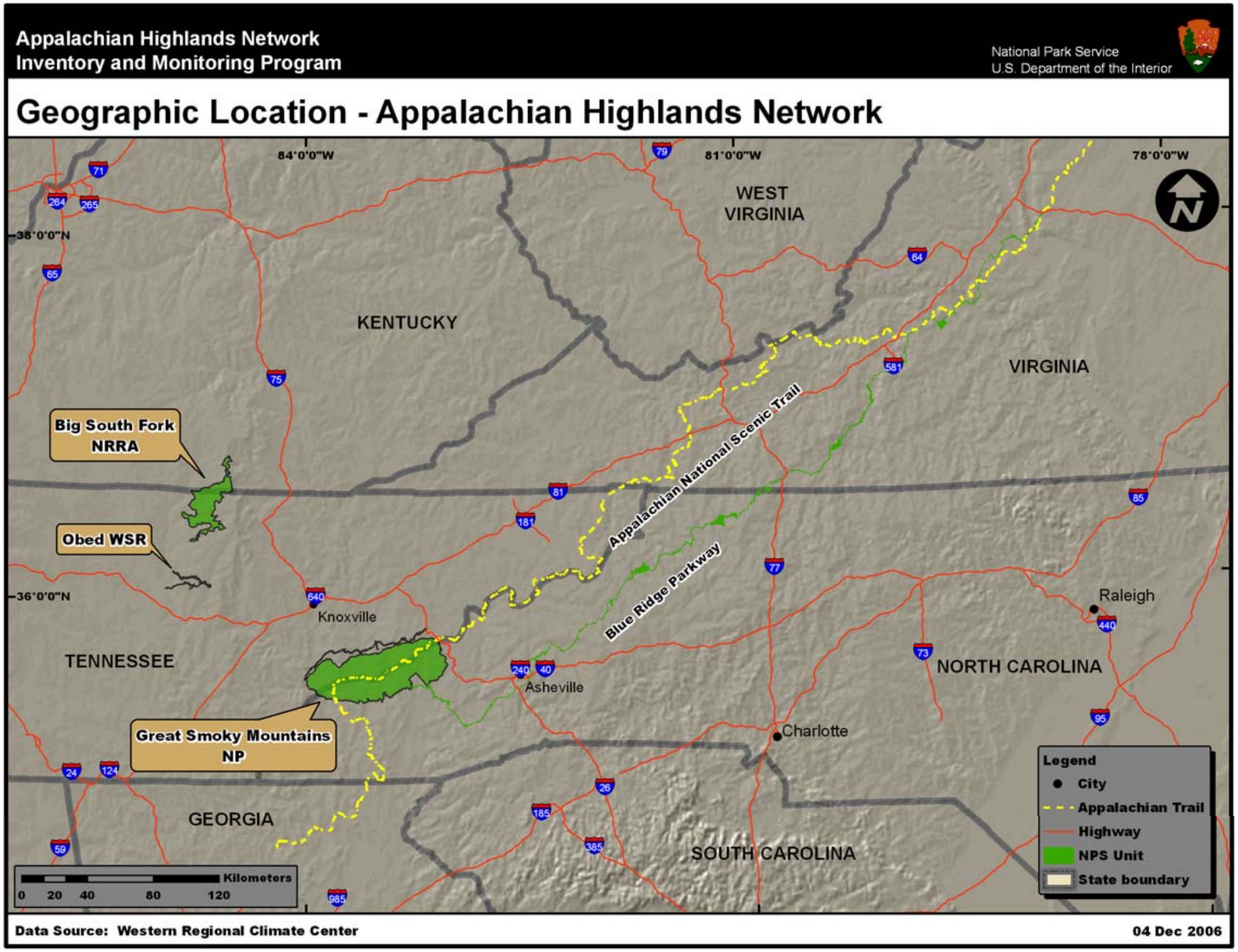


Figure 1.1. Map of the Appalachian Highlands Network.

Some climate networks can be considered hybrids of weather/climate networks. These hybrid climate networks can supply information on a short-term “weather” time scale and a longer-term “climate” time scale.

In this report, “weather” generally refers to current (or near-real-time) atmospheric conditions, while “climate” is defined as the complete ensemble of statistical descriptors for temporal and spatial properties of atmospheric behavior (see Appendix 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 measurements for use in atmospheric modeling (e.g., performance, evaluation, simulation, and prediction).
- 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.
- Provide useful information related to air quality measurements and air quality forecasting.
- 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.
- 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 APHN 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 are $1500–2500 per station per year but 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. Any NPS 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

Climate operates as a driver in every ecosystem modeled, across all parks in the APHN network (Emmott et al. 2005). The magnitude and timing of temperature changes and precipitation have a major influence on all ecosystems, dictating patterns of distribution and species composition. Climate/weather also drives ecosystems at various geographic scales including sites (microclimates), landscapes (topographic position), and regional physiography (e.g., mountainous terrain) (Stohlgren et al. 1997). As indicators of ecosystem health, weather measures are highly important because of their direct implications for the health of regional biota, and because of their value as supporting information for determining the possible causes of ecosystem changes (Emmott et al. 2005). Climate-monitoring efforts in APHN park units are critical in order 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 APHN. In order to do this, however, it is essential to understand the climate characteristics of the APHN, as discussed in this chapter.

2.1. Climate and the APHN Environment

The Southern Appalachians, like many mountainous areas, are distinguished by steep moisture and temperature gradients resulting in substantially different environments over short distances. In the Great Smoky Mountains, for example, cool and moist forests of spruce and fir grow on mountaintops within sight of significantly hotter, drier ridge and valley forests, each of which has a significantly different species composition.

Annual precipitation in the Southern Appalachian Mountains is generally the highest of the eastern U.S. The region is second in North America only to the Pacific Northwest in annual rainfall (Emmott et al. 2005). This precipitation is a major driver in both terrestrial and aquatic systems of the APHN, influencing soil and fuel moisture (and thereby, fire regimes), primary production, stream flow, pollutant concentrations, and oxygen carrying capacity in riparian systems. Considerable local variations in precipitation are imposed by orography and rain shadow effects. This precipitation occasionally drives flood events in the region. In particular, heavy rainfall associated with severe summer thunderstorms can cause flash flooding events that are instrumental in some APHN riparian communities for control of succession by woody species and for nutrient input. Extended drought profoundly affects succession patterns in bogs and other wetlands, as well as forest composition on thin-soiled sites that are prone to desiccation.

Climate changes such as rising seasonal temperatures, altered dates for first and last frost, increased drought occurrences, increased storm/flooding severity and frequency, and other changes in weather patterns are directly affecting APHN ecosystems. These changes may also alter natural ecosystem disturbance regimes (including fire), and can facilitate exotic species invasions.

Effects of these climate changes are likely amplified at the higher elevations of the APHN, especially where relict boreal communities occupy mountaintop sites. High elevation boreal communities and associated rare species in the Southern Appalachian Mountains are unique and important resources that may be adversely impacted by significant climate warming trends.

Other issues relate to changes in weather events, hydrology, avian nesting success, growing season changes, and aspects of natural disturbance regimes that alter natural communities and cause changes in species/habitat distributions (Melillo et al. 2001; Burkett et al. 2001).

2.2. Spatial Variability

The climate characteristics of the APHN are influenced by the interactions of the regional topography with air flows from both the Atlantic Ocean and the Gulf of Mexico. Mean annual precipitation varies from northeast to southwest and as a function of elevation in the APHN (Figure 2.1). Mean annual precipitation in the APHN ranges from under 800 mm along northern portions of BLRI to well over 2000 mm along the southern BLRI and higher elevations of GRSM. Precipitation is common throughout the year in the APHN, although higher elevations in North Carolina see a slight maximum in precipitation during the summer months (Figure 2.2).

Mean annual temperatures in the APHN also vary largely as a function of elevation, although proximity to the coast is also a factor. Mean annual temperatures in the APHN (Figure 2.3) range from 6°C in the higher elevations of BLRI and GRSM to over 12°C for lower elevations of APHN park units. The annually-averaged temperature dependence on elevation appears to be influenced largely by warm-season temperature characteristics. For instance, July maximum temperatures (Figure 2.4) vary sharply as a function of elevation, ranging from just under 23°C in portions of BLRI and GRSM to just over 29°C at lower elevations of the APHN park units. Heading into the winter months, these elevational temperature gradients relax, with coast-interior gradients becoming much more prominent for the APHN. However, the coldest winter temperatures in the APHN are still seen at higher elevations where, for instance, mean January minimum temperatures get down to -11°C (Figure 2.5). Mean January minimum temperatures across much of the APHN are generally between -5°C and -8°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), including the APHN. This pattern is not apparent across the Appalachian Mountains in southwestern North Carolina (Figure 2.6a) but is somewhat apparent in eastern Tennessee and in southwestern Virginia (Figure 2.6b; 2.6c).

Although temporal temperature patterns for the APHN (Figure 2.7) show a slight warming for each record as a whole, the warmest temperatures occurred during the 1940s and 1950s. Temperatures in the APHN became abruptly cooler in the 1960s and commenced a gradual warming trend that continues to this day. It is not clear how much of this observed pattern may be due to discontinuities in temperature records at individual stations, caused by artificial changes such as stations moves. These patterns highlight the emphasis on measurement consistency that is needed in order to properly detect long-term climatic changes.

The North Atlantic Oscillation – Arctic Oscillation (NAO-AO) is a major source of interannual climate variability in eastern North America (Hurrell 1995; Hurrell and van Loon 1997; Thompson and Wallace 1998; Wettstein and Mearns 2002), with NAO-AO variations occurring on the order of a couple decades. The NAO-AO influences heavily the wintertime temperature characteristics of the northeastern U.S. but also has some influence on the APHN. Warmer

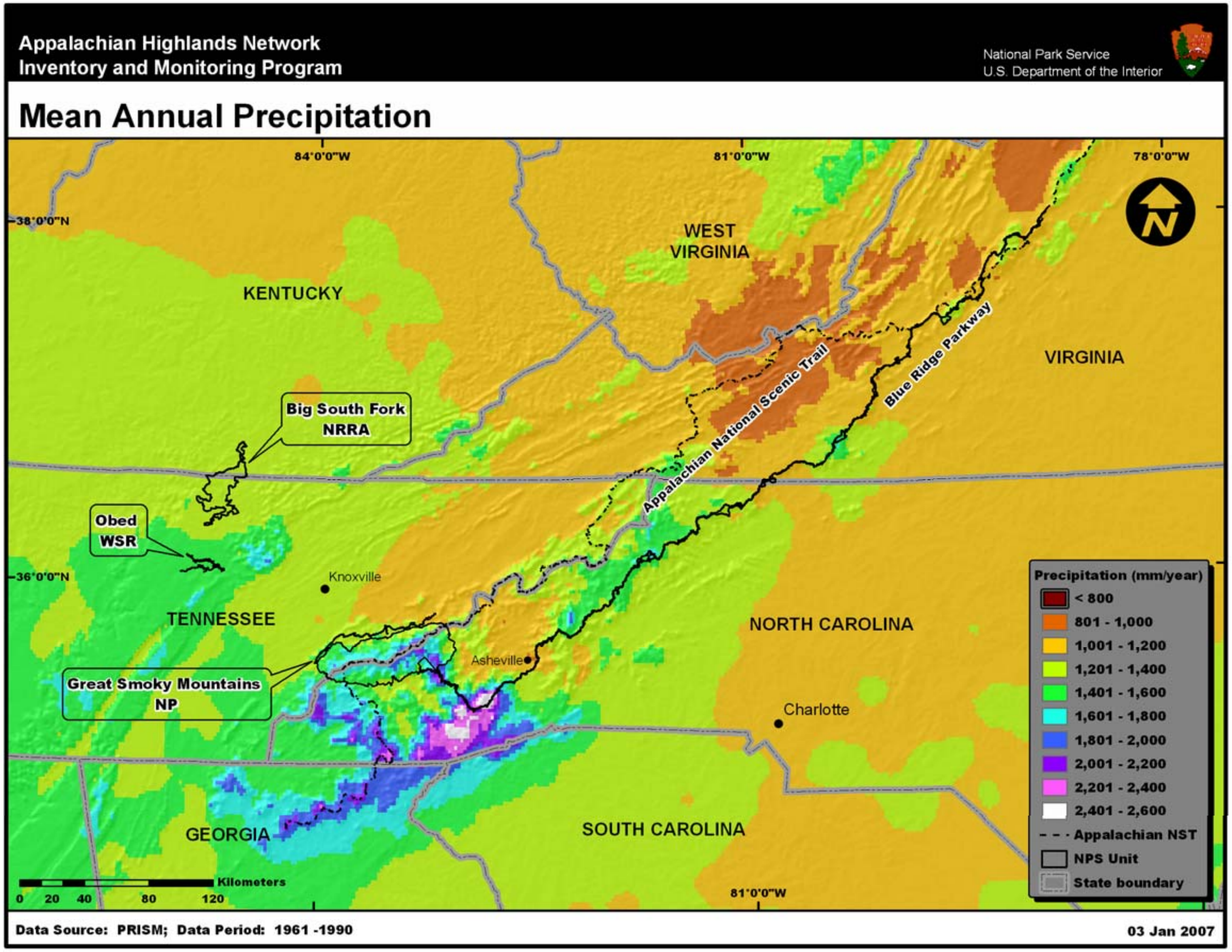


Figure 2.1. Mean annual precipitation, 1961-1990, for the APHN.

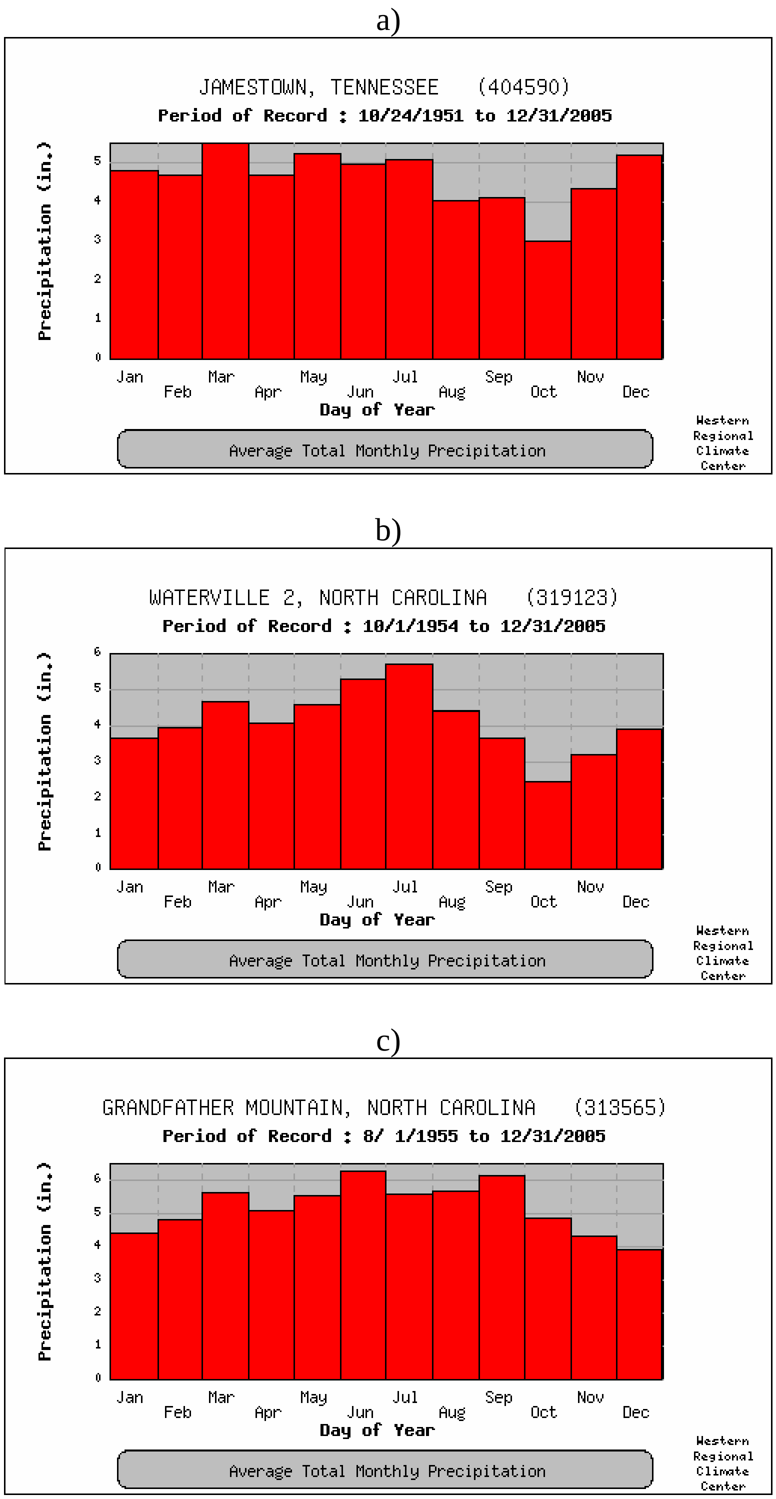


Figure 2.2. Mean monthly precipitation at selected locations in the APHN. Jamestown, Tennessee (a) is near BISO; Waterville 2 (b) is near GRSM; and Grandfather Mountain, North Carolina (c) is along BLRI.

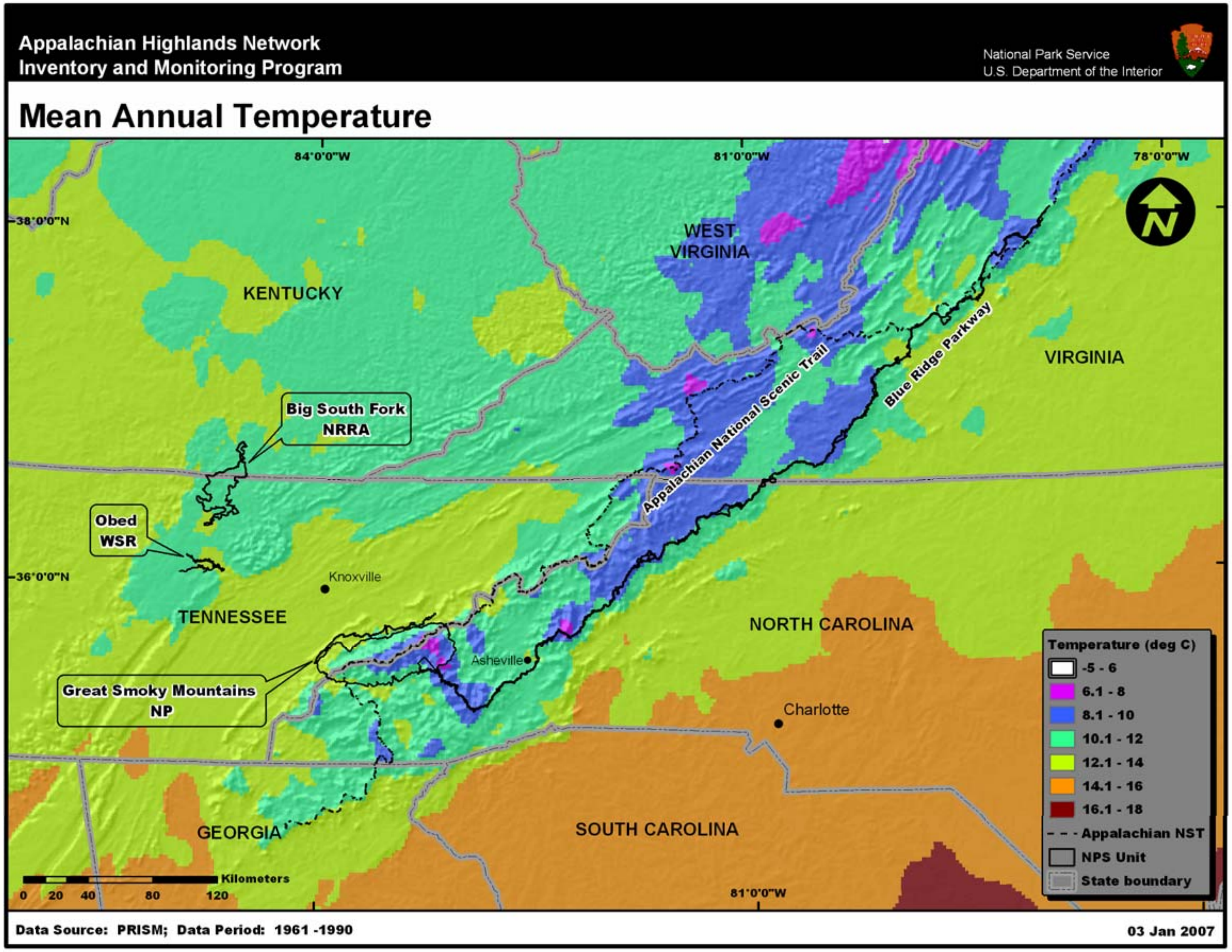


Figure 2.3. Mean annual temperature, 1961-1990, for the APHN.

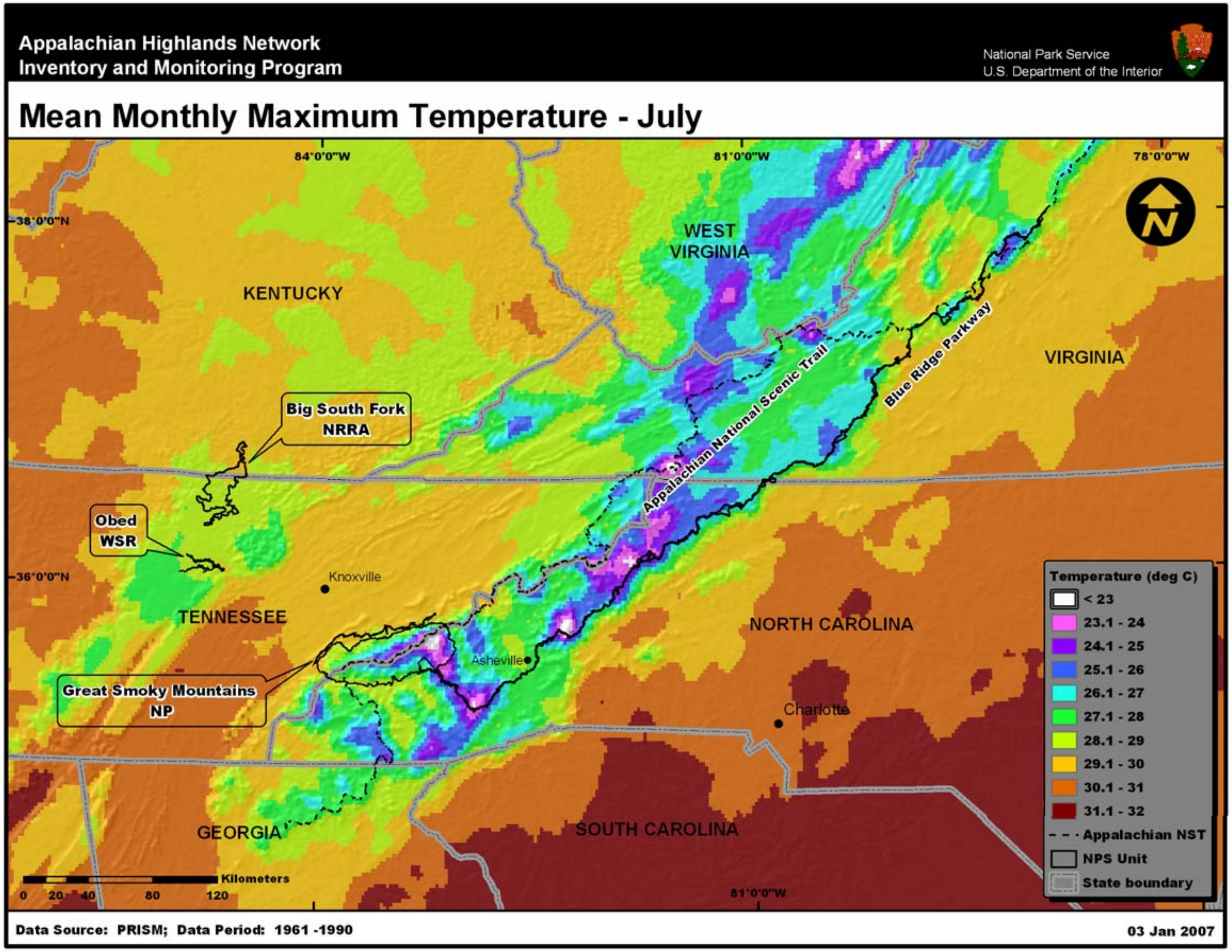


Figure 2.4. Mean July maximum temperature, 1961-1990, for the APHN.

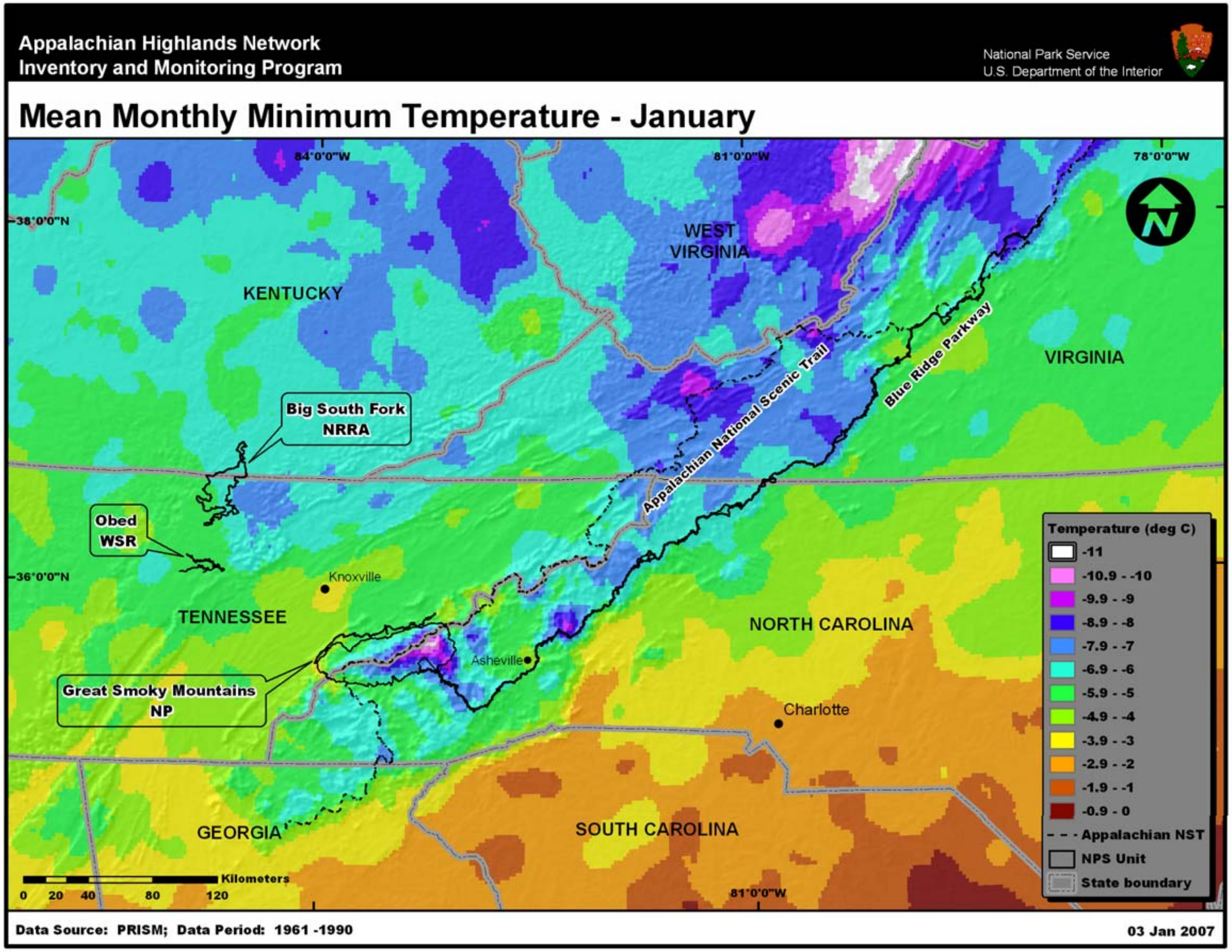


Figure 2.5. Mean January minimum temperature, 1961-1990, for the APHN.

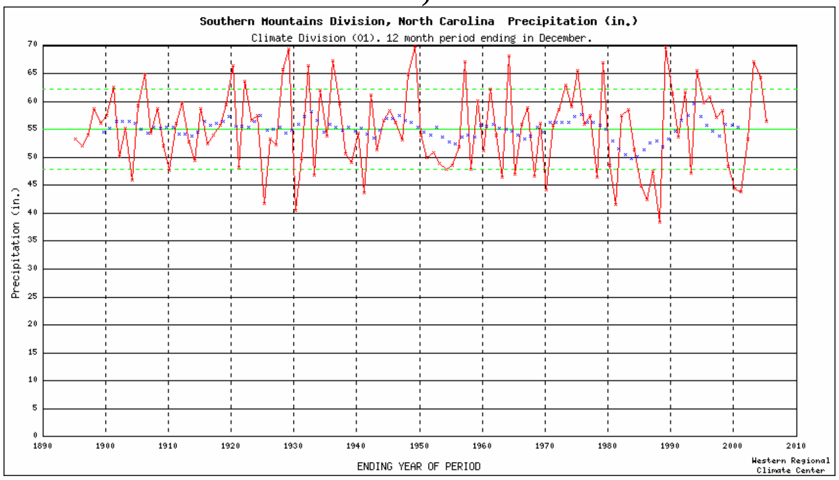
winter temperatures occur in eastern North America when the NAO-AO index is positive. The El Niño-Southern Oscillation (ENSO) also influences interannual climate variability in the APHN. Warm ENSO phases (El Niño events) tend to bring cooler and wetter winter conditions across the southeastern U.S. (NAST 2001), including the APHN.

The number and severity of storm events in the APHN varies greatly from year to year. Several nor’easters of varying intensities impact the APHN each year (Groisman et al. 2000). Other storm events are not as frequent. Ice storms also occur occasionally in the APHN (Changnon 2003). Tropical cyclones and their remnants are significant extreme storm events that occasionally impact the APHN in the summer and fall. Although some wind damage can accompany these storms, the heavy precipitation and flooding from these storms is by far a more important disturbance factor for the APHN ecosystems. About three tropical storms and/or hurricanes have made landfall in the U.S. each year over the past century (Lyons 2004). Most of these storms that make landfall in the U.S. originate either in the Gulf of Mexico or the Western Caribbean (Lyons 2004). Strong hurricanes have generally made landfall in the U.S. at a rate of just under one per year over the past century (Smith 1999; Lyons 2004). The number of these storms that impact the APHN has been very sporadic during this time period but the events, when they do occur, tend to do so in clusters. These clusters of storms occur on time scales of a couple decades (Smith 1999).

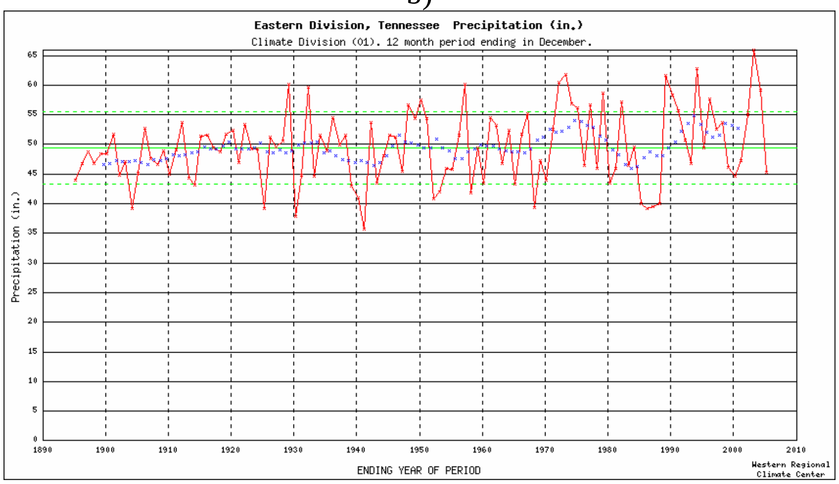
2.4. Parameter Regression on Independent Slopes Model

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 western 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 western 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.

a)



b)



c)

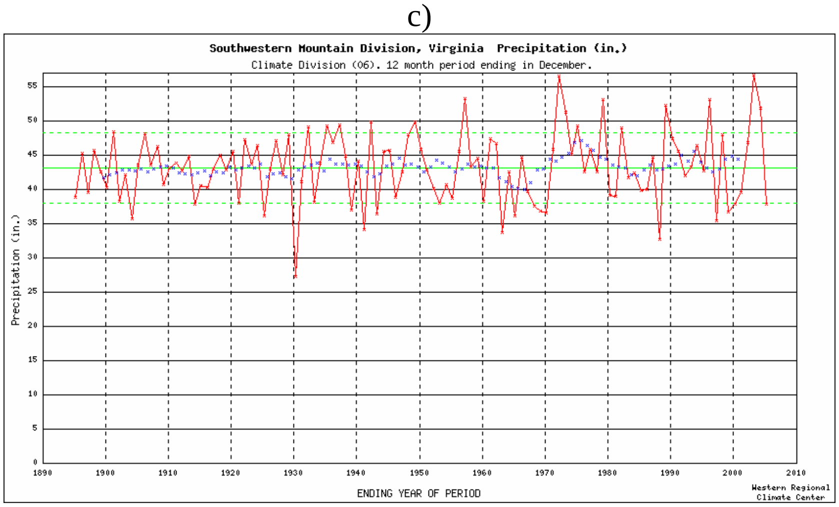
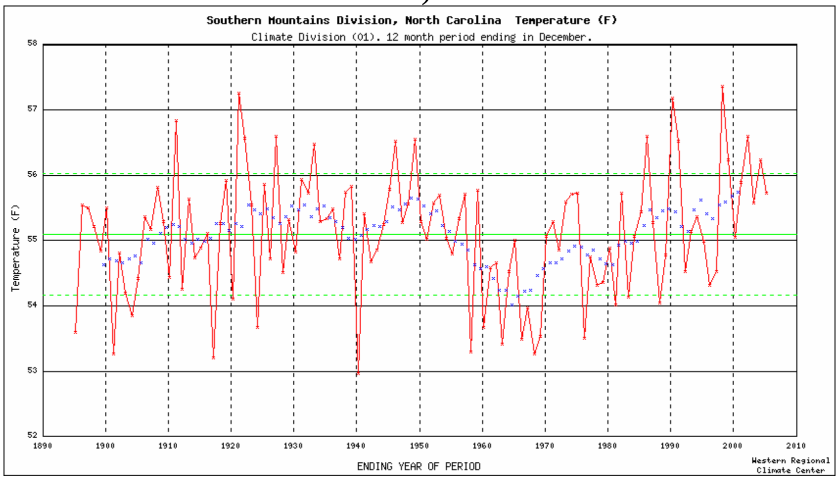
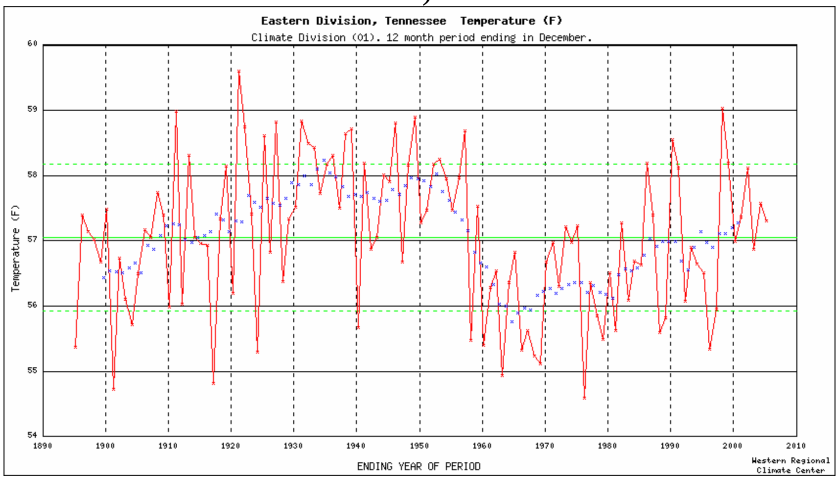


Figure 2.6. Precipitation time series, 1895-2005, for selected regions in the APHN. These include twelve-month precipitation (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include southwestern North Carolina (a),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

a)



b)



c)

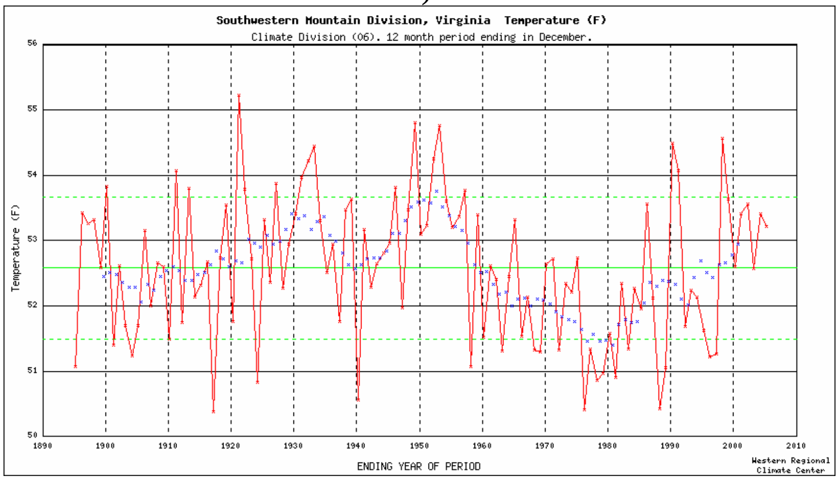


Figure 2.7. Temperature time series, 1895-2005, for selected regions in the APHN. These include twelve-month average temperature (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include southwestern North Carolina (a),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

3.0. Methods

Having discussed the climatic characteristics of the APHN, we now present the procedures that were used to obtain information for weather/climate stations within the APHN. 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 (SAO) network 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 APHN weather/climate stations identified from the ACIS database are available in file “APHN_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 APHN 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 (COOP, RAWS, 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 APHN weather/climate station metadata from ACIS, metadata were obtained from NPS staff at the APHN office in Asheville, North Carolina. The metadata provided from the APHN office are available in file “APHN_NPS.tar.gz.” Most of the stations noted by APHN 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 APHN 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 APHN, we selected only those that were located within a specified buffer distance of the APHN park units. This buffer distance was 10 km for BLRI. For all other APHN parks, this buffer distance was set at 30 km. We selected these buffer distances in an attempt to include at least a few automated stations from major networks such as SAO, 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 APHN. 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 APHN region in relation to the boundaries of the NPS park units within the APHN. 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 APHN region are associated with at least one of 11 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 APHN.

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
NADP	National Atmospheric Deposition Program
POMS	Portable Ozone Monitoring System
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. 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. This network includes the Mercury Deposition Network (MDN). Precipitation is the primary climate parameter measured at NADP sites.

4.1.7. Portable Ozone Monitoring System (POMS)

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

4.1.8. Remote Automated Weather Station Network (RAWS)

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.

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

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.

4.1.10. 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 meteorological elements measured at these sites include air temperature, precipitation, humidity, wind, pressure, solar radiation, snow depth, and snow water content.

4.1.11. Weather For You Network (WX4U)

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

4.1.12. 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.

4.1.13. 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 APHN (discussed in Section 4.1) have at most a few dozen stations that are inside each park unit (Table 4.2). Great Smoky Mountain National Park (GRSM) has the greatest number of stations inside park boundaries (31).

Lists of stations have been compiled for the APHN. 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.

Table 4.2. Number of stations within or nearby APHN 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	BISO	BLRI	GRSM	OBRI
CASTNet	**0**(0)	**0**(0)	**1**(1)	**0**(0)
COOP	**25**(0)	**109**(4)	**99**(19)	**25**(0)
CRN	**0**(0)	**2**(0)	**0**(0)	**1**(0)
CWOP	**0**(0)	**12**(0)	**10**(0)	**3**(0)
GPMP	**0**(0)	**1**(0)	**7**(7)	**0**(0)
NADP	**0**(0)	**2**(0)	**1**(1)	**0**(0)
NPS	**0**(0)	**0**(0)	**1**(1)	**0**(0)
POMS	**1**(1)	**0**(0)	**0**(0)	**0**(0)
RAWS	**3**(1)	**9**(0)	**4**(2)	**1**(0)
SAO	**1**(0)	**4**(0)	**4**(0)	**1**(0)
SCAN	**0**(0)	**1**(0)	**0**(0)	**0**(0)
WX4U	**0**(0)	**1**(0)	**0**(0)	**0**(0)
Other	**2**(0)	**0**(0)	**3**(0)	**0**(0)
Total	**32**(2)	**141**(4)	**130**(31)	**31**(0)

4.2.1. Great Smoky Mountains National Park

We have identified 31 weather and climate stations within the boundaries of GRSM (Table 4.3). Of these stations, 15 are still active. Five manual COOP stations are active within GRSM. “Cataloochee,” located in southeastern GRSM (Figure 4.1), has a data record that begins in 1949. Unfortunately, this data record has numerous data gaps. Temperatures are only available from this site since April, 1964. The longest record among the active COOP stations in GRSM is found at “Gatlinburg 2 SW,” in northern GRSM. This station has been operating since 1921 and its data record is quite complete. The last significant data gap occurred in January, 1988. On the other side of GRSM, near the Oconaluftee Visitor Center, the COOP station “Oconaluftee” provides a data record that is over 45 years in length (1958-present) and is fairly complete with the exception of numerous gaps in the mid-1970s. The last large data gap at “Oconaluftee” appears to have occurred in June, 1986. A COOP station has been operating at Mount LeConte since 1987 (Mt. LeConte). Finally, “Townsend 5 S” is a COOP station which has been operating near Cades Cove since 1999.

Table 4.3. Weather/climate stations for Great Smoky Mountains National Park (GRSM). Stations inside GRSM and within 30 km of GRSM are included. Missing entries are indicated by “M”.

Great Smoky Mountains National Park – GRSM							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Look Rock	35.633	-83.942	793	CASTNet	10/1/1998	Present	Yes
Abrams Creek	35.617	-83.933	427	COOP	1/1/1949	3/31/1962	Yes
Cataloochee	35.638	-83.096	808	COOP	1/1/1949	Present	Yes
Clingmans Dome	35.550	-83.500	1906	COOP	9/1/1948	3/31/1962	Yes
Cosby	35.783	-83.217	525	COOP	1/1/1949	3/31/1962	Yes
Deep Creek	35.467	-83.433	567	COOP	12/1/1954	7/31/1962	Yes
Elkmont	35.650	-83.567	668	COOP	12/1/1924	11/30/1943	Yes
Forney Creek	35.500	-83.567	665	COOP	7/1/1949	2/28/1955	Yes

Great Smoky Mountains National Park – GRSM							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Gatlinburg 2 SW	35.688	-83.537	443	COOP	12/1/1921	Present	Yes
Gatlinburg Greystone	35.717	-83.517	390	COOP	1/1/1977	7/1/1989	Yes
Mount LeConte	35.650	-83.433	1937	COOP	1/1/1949	1/31/1960	Yes
Mt. LeConte	35.655	-83.441	1979	COOP	7/1/1987	Present	Yes
Noland Creek	35.500	-83.500	769	COOP	1/1/1949	3/31/1962	Yes
Oconaluftee	35.526	-83.309	622	COOP	11/1/1958	Present	Yes
Proctor	35.467	-83.717	531	COOP	1/1/1949	3/31/1962	Yes
Ravensford	35.517	-83.300	641	COOP	1/1/1949	12/31/1958	Yes
Spruce Mountain	35.617	-83.200	1403	COOP	9/1/1948	8/31/1976	Yes
Townsend	35.683	-83.750	320	COOP	6/1/1951	3/31/1962	Yes
Townsend 5 S	35.603	-83.778	551	COOP	1/1/1999	Present	Yes
Twentymile	35.467	-83.883	400	COOP	1/1/1949	3/31/1962	Yes
Cades Cove	35.604	-83.783	564	GPMP	7/1/1993	Present	Yes
Clingmans Dome	35.562	-83.498	2021	GPMP	10/2/1992	Present	Yes
Cove Mountain	35.697	-83.609	1243	GPMP	7/1/1988	Present	Yes
Elkmont	35.664	-83.590	640	GPMP	7/1/1980	9/30/1983	Yes
Look Rock	35.633	-83.942	793	GPMP	7/1/1988	Present	Yes
Purchase Knob	35.590	-83.078	1500	GPMP	6/1/1995	Present	Yes
Twin Creeks	35.686	-83.501	610	GPMP	6/1/1993	8/31/1993	Yes
Great Smoky Mtns. NP-Elkmont	35.665	-83.590	640	NADP	1/30/2002	Present	Yes
Noland Divide	35.567	-83.467	1727	NPS	7/1/1991	Present	Yes
Cherokee	35.620	-83.207	1036	RAWS	2/1/2002	Present	Yes
Indian Grave	35.624	-83.808	823	RAWS	2/1/1997	Present	Yes
Alcoa	35.800	-83.967	275	COOP	1/1/1949	2/28/1951	No
Andrews	35.201	-83.839	533	COOP	8/1/1909	10/1/2005	No
Balsam	35.417	-83.083	1067	COOP	1/1/1949	7/5/1995	No
Beaverdam Creek	35.233	-84.083	641	COOP	1/1/1949	4/30/1951	No
Blount County Exp. Stn.	35.850	-83.950	287	COOP	1/1/1961	10/1/1964	No
Bryson City	35.433	-83.450	537	COOP	9/1/1948	8/31/1949	No
Bryson City 2	35.443	-83.440	618	COOP	5/15/1997	Present	No
Bryson City 2	35.433	-83.450	549	COOP	9/1/1887	11/16/1973	No
Calderwood Powerhouse	35.500	-83.983	290	COOP	1/1/1949	3/31/1962	No
Canto	35.704	-82.770	621	COOP	7/1/1971	Present	No
Canton 1 SW	35.517	-82.850	811	COOP	9/1/1930	6/1/1993	No
Cataloochee Ranch	35.550	-83.100	1464	COOP	1/1/1949	3/31/1962	No
Chambers Mountain	35.567	-82.900	1312	COOP	9/1/1948	3/31/1962	No
Cherokee	35.483	-83.317	616	COOP	1/1/1949	7/31/1950	No
Cullowhee	35.326	-83.191	668	COOP	12/1/1909	Present	No
Dandridge	36.017	-83.417	317	COOP	12/1/1904	3/31/1962	No
Dix Creek	35.433	-82.867	1000	COOP	1/1/1949	5/31/1950	No
Dix Creek	35.450	-82.867	933	COOP	12/1/1950	3/31/1962	No

Great Smoky Mountains National Park – GRSM							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Dix Creek TVA	35.433	-82.883	1092	COOP	6/1/1950	12/31/1950	No
Doggett Gap	35.717	-82.833	1159	COOP	1/1/1949	12/31/1952	No
Doggett Gap 2	35.717	-82.833	1064	COOP	12/1/1952	3/31/1962	No
Douglas Dam	35.967	-83.533	284	COOP	1/1/1949	3/31/1962	No
Eaglenest Mountain	35.483	-83.033	1000	COOP	1/1/1949	3/31/1962	No
Ela	35.450	-83.367	558	COOP	1/1/1949	3/31/1962	No
Fontana Dam	35.450	-83.800	400	COOP	9/1/1948	3/31/1962	No
Franklin	35.180	-83.393	648	COOP	3/1/1872	Present	No
Franklin Power House	35.217	-83.367	610	COOP	1/1/1927	5/31/1950	No
Hartford	35.817	-83.150	384	COOP	1/1/1949	3/31/1962	No
Haw Knob	35.350	-84.033	1415	COOP	9/1/1948	Present	No
Haw Knob Stratton MD	35.350	-84.033	1415	COOP	10/1/1954	7/1/1976	No
Hot Springs	35.895	-82.831	426	COOP	1/1/1927	Present	No
Hot Springs 2	35.900	-82.833	451	COOP	1/1/1902	3/31/1984	No
Hyatt Creek	35.200	-83.950	747	COOP	1/1/1949	3/31/1962	No
Jack Cove	35.400	-83.283	586	COOP	1/1/1949	3/31/1962	No
Jones Cove	35.833	-83.333	354	COOP	4/1/1957	3/31/1962	No
Kittie	35.450	-84.167	305	COOP	1/1/1949	3/31/1962	No
Knoxville	35.967	-83.917	296	COOP	9/1/1948	Present	No
Knoxville Exp. Stn.	35.882	-83.957	253	COOP	1/1/1949	Present	No
Knoxville Garage	35.983	-83.917	281	COOP	1/1/1949	10/31/1953	No
Knoxville McGhee Tyson Arpt.	35.818	-83.986	293	COOP	1/1/1893	Present	No
Knoxville Univ. Of Tenn.	35.950	-83.917	273	COOP	4/1/1943	9/30/1982	No
Lakemont 2	35.850	-83.950	250	COOP	10/7/1953	7/31/1957	No
Little Santeetlah Cr.	35.383	-83.950	1418	COOP	5/1/1961	3/31/1962	No
Maggie	35.517	-83.083	878	COOP	1/1/1967	8/31/1967	No
Maple Spring Gap 2	35.733	-82.933	1156	COOP	7/1/1960	3/31/1962	No
Maple Springs Gap	35.750	-82.950	1235	COOP	6/1/1952	7/31/1960	No
Max Patch Mountain	35.817	-82.950	1226	COOP	9/1/1948	4/30/1981	No
Mc Ghee	35.617	-84.217	259	COOP	12/1/1904	Present	No
Mc Ghee 2 SE	35.617	-84.217	259	COOP	1/1/1927	2/28/1949	No
Mint	35.633	-84.017	293	COOP	1/1/1949	3/31/1962	No
Mount Sterling	35.717	-83.083	891	COOP	1/1/1949	3/31/1962	No
Nantahala	35.267	-83.683	613	COOP	2/1/1934	7/31/1976	No
Nantahala Dam	35.200	-83.650	900	COOP	1/1/1949	3/31/1962	No
Needmore	35.333	-83.533	558	COOP	1/1/1949	3/31/1962	No
Newport 1 NW	35.983	-83.201	316	COOP	8/1/1891	Present	No
Newport TVA	35.983	-83.167	320	COOP	1/1/1949	3/31/1962	No
North Citico Creek	35.400	-84.067	586	COOP	1/1/1961	3/31/1962	No
Pigeon Forge	35.783	-83.550	314	COOP	1/1/1949	3/31/1962	No
Pittman Center	35.750	-83.400	400	COOP	1/1/1958	3/31/1962	No

Great Smoky Mountains National Park – GRSM							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Providence	35.850	-83.783	336	COOP	1/1/1949	3/31/1962	No
Raven Mountain	35.333	-83.367	1373	COOP	9/1/1948	3/31/1962	No
Robbinsville 1 S	35.304	-83.811	678	COOP	11/20/2004	Present	No
Robbinsville Ag. 5 NE	35.374	-83.701	608	COOP	10/15/1993	Present	No
Rockyface Mountain	35.583	-82.800	946	COOP	1/1/1949	3/31/1962	No
Santeetlah Dam	35.383	-83.883	595	COOP	1/1/1949	3/31/1962	No
Santeetlah Gap	35.350	-83.900	848	COOP	1/1/1949	3/31/1962	No
Sevierville	35.883	-83.583	275	COOP	1/1/1906	3/31/1962	No
Sevierville	35.930	-83.598	274	COOP	4/1/1955	Present	No
Stecoah	35.367	-83.683	619	COOP	1/1/1949	3/31/1962	No
Tapoco	35.456	-83.940	338	COOP	9/1/1929	Present	No
Tellico R.S.	35.350	-84.233	336	COOP	1/1/1949	1/31/1960	No
Teyahalee Bald	35.250	-83.800	1434	COOP	9/1/1948	3/31/1962	No
Univ. Of Tenn. Farm	35.950	-83.950	244	COOP	1/1/1949	12/31/1956	No
Univ. Of Tenn. Lysimet	35.950	-83.950	259	COOP	1/1/1949	3/31/1962	No
Walland	35.767	-83.850	275	COOP	1/1/1949	6/30/1951	No
Waterville 2	35.774	-83.098	439	COOP	8/1/1948	Present	No
Wayah Bald	35.183	-83.567	1632	COOP	9/1/1948	3/31/1962	No
Waynesville 1 E	35.487	-82.968	810	COOP	5/1/1894	Present	No
Wildwood	35.783	-83.883	271	COOP	6/1/1951	3/31/1962	No
Wolf Creek	35.917	-82.933	366	COOP	1/1/1949	3/31/1962	No
AE4VP Greenback	35.682	-84.114	275	CWOP	M	Present	No
CW0008 Franklin	35.200	-83.419	677	CWOP	M	Present	No
CW1822 Knoxville	35.929	-83.915	274	CWOP	M	Present	No
CW5014 Maryville	35.700	-84.086	302	CWOP	M	Present	No
CW5045 Sevierville	35.920	-83.490	317	CWOP	M	Present	No
CW5106 Waynesville	35.475	-82.920	890	CWOP	M	Present	No
CW5602 Waynesville	35.446	-83.034	1001	CWOP	M	Present	No
K4RWH Maryville	35.730	-83.976	314	CWOP	M	Present	No
KC4ASF Maryville	35.752	-83.890	312	CWOP	M	Present	No
KG4HLW-1 Prosperity	35.708	-82.901	1220	CWOP	M	Present	No
Cheoah	35.333	-83.817	640	RAWS	2/1/2003	Present	No
Sutton Top	35.731	-83.052	914	RAWS	2/1/2003	2/28/2005	No
Andrews Murphy Arpt.	35.195	-83.865	517	SAO	M	Present	No
Hot Springs 2	35.900	-82.833	451	SAO	1/1/1902	3/31/1984	No
Knoxville McGhee Tyson Arpt.	35.818	-83.986	293	SAO	1/1/1893	Present	No
Macon Co. Arpt.	35.223	-83.419	616	SAO	1/1/2004	Present	No
Hot Springs	35.900	-82.817	75	WBAN	M	M	No
Knoxville	35.967	-83.917	292	WBAN	10/1/1889	12/31/1942	No
Knoxville McGhee Tyson	35.817	-84.000	302	WBAN	1/1/1954	11/30/1957	No

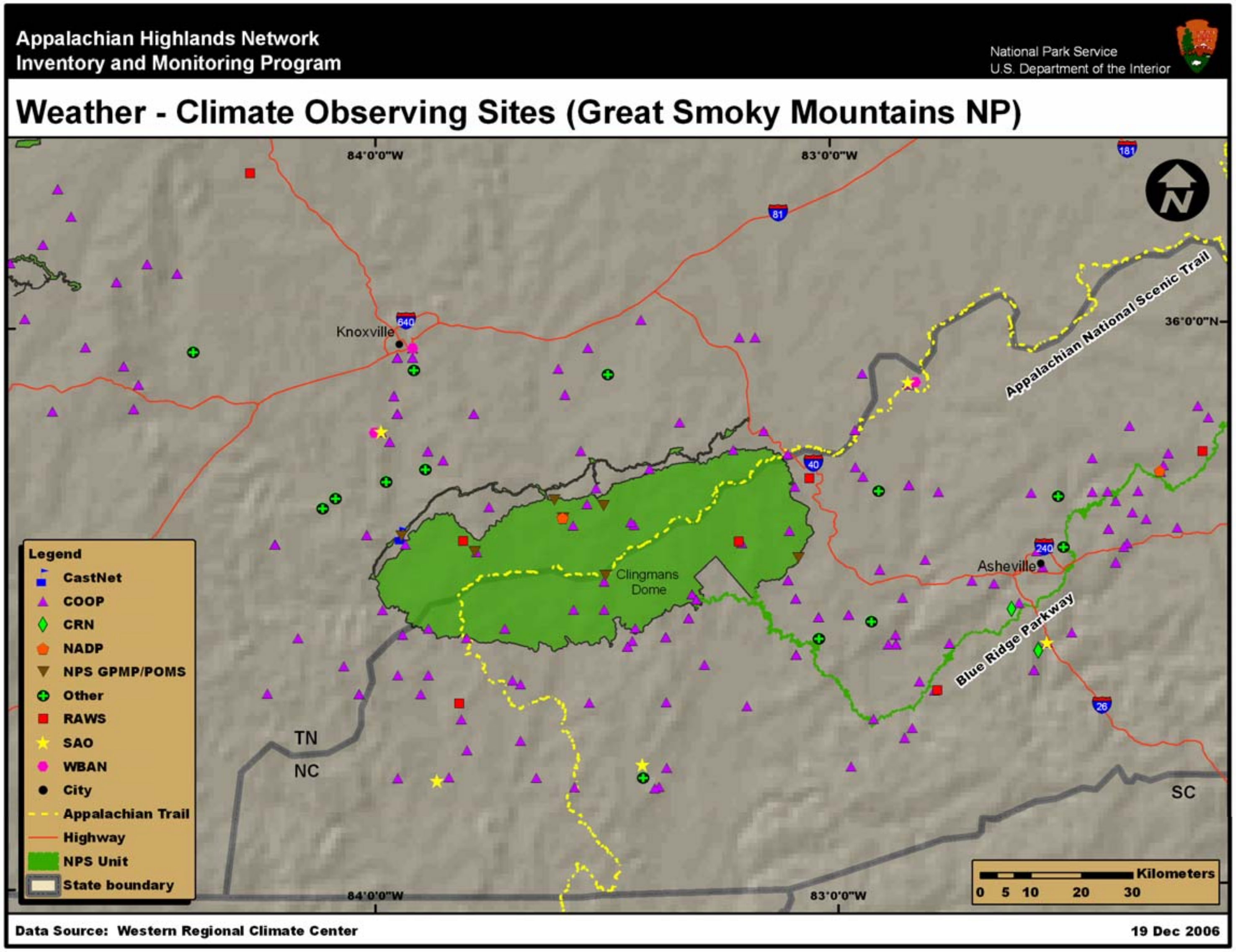


Figure 4.1. Station locations for Great Smoky Mountains National Park.

Near-real-time meteorological data are available from nine stations operating currently inside GRSM. A NPS station has operated at Noland Divide since July 1991 (Table 4.3). Two active RAWS stations provide near-real-time within GRSM. The RAWS station “Cherokee” is located in eastern GRSM (Figure 4.1), while “Indian Grave” is located in extreme western GRSM, between Cades Cove and Look Rock. The remaining active near-real-time stations within GRSM are associated primarily with air quality monitoring networks. A CASTNet station near Look Rock in extreme northwestern GRSM has provided reliable data since 1998. Five GPMP stations are active within GRSM, including stations at well-known locations such as Cades Cove and Clingmans Dome. A manual NADP station operates at Elkmont, in northern GRSM.

Most of the stations we have identified outside of GRSM are associated with the COOP network (Table 4.3). Four of the active COOP stations we have identified have data records that go back to the 1800s. The longest data record is at the COOP station “Franklin,” which is about 30 km south of GRSM (Figure 4.1) and has been active since 1872. The data record at “Franklin” is very complete. Reliable data records are also obtained at the other COOP stations within 30 km of GRSM that have data records going back to the 1800s. “Knoxville McGhee Tyson Arpt.” (1893-present) is about 20 km northwest of GRSM. “Newport 1 NW” (1891-present) is about 20 km northeast of GRSM. “Waynesville 1 E” (1894-present) is about 10 km southeast of GRSM. Several other COOP stations that have been identified near GRSM also have reliable longer-term data records. “Cullowhee” (1909-present) is about 20 km southeast of the south entrance of GRSM. “Tapoco” (1929-present) is 5 km southwest of GRSM, near the North Carolina/Tennessee border. “Waterville 2” (1948-present) is located along Interstate 40 just outside the east boundary of GRSM.

At present, the most reliable sources of near-real-time weather observations within 30 km of GRSM are at one RAWS station and three SAO stations. The RAWS station “Cheoah” is located 15 km southwest of GRSM (Figure 4.1), near the east end of Santeetlah Lake. The Knoxville McGhee Tyson Airport has an SAO station, co-located with the COOP station discussed earlier. The SAO station “Andrews Murphy Arpt.” is located in Andrews, North Carolina, about 30 km south of GRSM. The SAO station “Macon Co. Arpt.” is located about 20 km south of GRSM and 10 km northwest of Franklin, North Carolina. Several CWOP stations also provide near-real-time data within 30 km of GRSM.

4.2.2. Blue Ridge Parkway

We have identified four weather and climate stations along BLRI (Table 4.4). These are all COOP stations. Only one of these stations is active (Blowing Rock 1 NW). The station “Blowing Rock 1 NW” is located in northwestern North Carolina and has a data record that goes back to 1893. This data record was reliable between July 1956 and December 1999. Outside this time period, however, the data record at “Blowing Rock 1 NW” is riddled with data gaps.

More reliable data records are available from stations outside of BLRI. At present, 31 COOP stations are active within 10 km of BLRI (Table 4.4). Three of these stations have data records going back to the 1890s. The longest of these data records is found at “Buchanan,” which is located about 7 km northwest of BLRI and 35 km northeast of Roanoke, Virginia (Figure 4.2). This station has been active since 1892. A significant gap is present in the data record of “Buchanan” beginning in April 1984 and continuing through May 1989. Otherwise, the data

Table 4.4. Weather/climate stations for the Blue Ridge Parkway (BLRI). Stations inside BLRI and within 10 km of BLRI are included. Missing entries are indicated by "M".

Blue Ridge Parkway – BLRI

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Beetree Gap	35.700	-82.400	1583	COOP	8/1/1948	12/31/1950	Yes
Blowing Rock 1 NW	36.147	-81.703	1173	COOP	1/1/1893	Present	Yes
Bluff	36.400	-81.217	991	COOP	1/1/1949	7/31/1976	Yes
Haywood Gap	35.300	-82.917	1647	COOP	9/1/1948	4/30/1981	Yes
Afton Boxwood Garden	38.033	-78.833	381	COOP	1/1/1931	9/30/1957	No
Altapass	35.900	-82.017	842	COOP	11/1/1910	3/31/1962	No
Asheville	35.595	-82.557	682	COOP	1/1/1902	Present	No
Asheville NCDC Trng.	35.600	-82.533	684	COOP	10/1/1964	12/31/1970	No
Asheville Regl. Arpt.	35.432	-82.538	645	COOP	11/1/1940	Present	No
Ashford	35.892	-81.935	546	COOP	5/27/1942	Present	No
Ashford 2 N	35.900	-81.950	604	COOP	9/1/1973	10/31/1980	No
Balcony Falls	37.617	-79.450	223	COOP	12/1/1930	9/1/1967	No
Balsam	35.417	-83.083	1067	COOP	1/1/1949	7/5/1995	No
Banner Elk	36.153	-81.863	1142	COOP	9/1/1907	Present	No
Barnardsville 2 SE	35.760	-82.433	707	COOP	1/1/1949	Present	No
Bedford 4 NW	37.380	-79.561	372	COOP	2/1/1973	Present	No
Beech	35.700	-82.433	1021	COOP	3/1/1948	12/31/1952	No
Beech Mountain	36.188	-81.874	1540	COOP	11/12/1997	Present	No
Beetree Dam	35.633	-82.400	775	COOP	8/1/1948	6/30/1972	No
Beetree Dam 2	35.633	-82.400	775	COOP	1/1/1949	3/31/1962	No
Bent Creek	37.537	-78.829	116	COOP	2/1/1972	Present	No
Big East Fork Pigeon	35.367	-82.817	1030	COOP	1/1/1949	7/1/1989	No
Biltmore 2 SE	35.568	-82.545	603	COOP	10/1/1963	Present	No
Black Mountain 2 W	35.607	-82.359	698	COOP	10/1/1949	Present	No
Boone	36.217	-81.667	988	COOP	1/1/1929	6/3/1980	No
Boone 1 SE	36.211	-81.644	1024	COOP	6/1/1980	Present	No
Buchanan	37.527	-79.678	264	COOP	11/26/1892	Present	No
Buchanan River	37.531	-79.679	245	COOP	9/1/1964	Present	No
Buena Vista	37.727	-79.363	253	COOP	6/15/1937	Present	No
Buena Vista River	37.762	-79.393	258	COOP	7/1/1987	Present	No
Candler 1 W	35.545	-82.699	718	COOP	5/1/1972	Present	No
Cataloochee Ranch	35.550	-83.100	1464	COOP	1/1/1949	3/31/1962	No
Celo	35.850	-82.200	839	COOP	11/12/1934	3/31/1962	No
Celo 2 S	35.830	-82.177	817	COOP	8/1/1948	Present	No
Cherokee	35.483	-83.317	616	COOP	1/1/1949	7/31/1950	No
Copper Hill	37.086	-80.142	820	COOP	4/1/1940	Present	No
Coxcombe Mountain	35.817	-82.350	1296	COOP	9/1/1948	3/31/1962	No
Craggy Knob	35.683	-82.383	1516	COOP	12/1/1950	3/31/1962	No
Crossnore	36.017	-81.933	1046	COOP	1/1/1938	9/30/1959	No
Dix Creek	35.450	-82.867	933	COOP	12/1/1950	3/31/1962	No

Blue Ridge Parkway – BLRI							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Eaglenest Mountain	35.483	-83.033	1000	COOP	1/1/1949	3/31/1962	No
Ela	35.450	-83.367	558	COOP	1/1/1949	3/31/1962	No
Enka	35.539	-82.651	625	COOP	11/1/1930	Present	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
Floyd 2	36.917	-80.300	793	COOP	11/1/1949	4/30/1960	No
Floyd 2 NE	36.928	-80.291	800	COOP	2/1/1933	Present	No
Galax 3 S	36.633	-80.933	769	COOP	7/1/1951	12/31/1954	No
Galax Radio WBRF	36.663	-80.914	727	COOP	8/1/1948	Present	No
Galax Water Plant	36.654	-80.918	719	COOP	M	M	No
Gillespie Gap	35.867	-82.050	860	COOP	12/1/1952	7/31/1976	No
Glasgow 1 SE	37.620	-79.437	226	COOP	9/1/1967	Present	No
Glendale Springs	36.350	-81.383	887	COOP	1/1/1943	7/1/1993	No
Gloucester Gap	35.267	-82.850	952	COOP	9/1/1948	3/31/1962	No
Grandfather Mountain	36.109	-81.833	1615	COOP	8/1/1955	Present	No
Holcomb Rock	37.544	-79.403	189	COOP	5/1/1960	Present	No
Holcombs Rock River	37.501	-79.263	168	COOP	10/1/1970	Present	No
Idlewild	36.312	-81.459	884	COOP	3/29/1940	3/1/2005	No
Jefferson 2 E	36.416	-81.429	844	COOP	2/1/1896	Present	No
Laurel Springs 1 Mi.	36.417	-81.267	900	COOP	3/29/1940	6/30/1950	No
Little Switzerland	35.850	-82.100	1083	COOP	9/1/1948	3/31/1962	No
Maggie	35.517	-83.083	878	COOP	1/1/1967	8/31/1967	No
Meadows Of Dan 5 SW	36.667	-80.448	678	COOP	11/1/1950	Present	No
Montebello 3 NE	37.881	-79.132	817	COOP	7/5/1937	12/5/2001	No
Montebello Fish Hatchery	37.849	-79.131	807	COOP	9/1/1948	Present	No
Montreat	35.650	-82.317	793	COOP	1/1/1917	9/30/1949	No
Mortimer	35.983	-81.783	458	COOP	8/1/1948	2/26/1973	No
Mount Mitchell 2 SSW	35.733	-82.283	1992	COOP	10/1/1953	4/30/1979	No
Mount Mitchell TVA	35.767	-82.267	2024	COOP	6/1/1925	3/31/1962	No
Mount Pisgah	35.433	-82.750	1574	COOP	9/1/1948	3/31/1962	No
Mt. Mitchell	35.745	-82.277	1902	COOP	11/17/1988	Present	No
Natural Bridge Stn.	37.583	-79.500	253	COOP	1/1/1941	10/31/1962	No
North Fork	35.700	-82.333	845	COOP	9/1/1948	4/30/1981	No
North Fork 2	35.663	-82.347	756	COOP	10/1/1942	Present	No
Oconaluftee	35.526	-83.309	622	COOP	11/1/1958	Present	No
Old Fort Ag. 3 W	35.667	-82.124	434	COOP	10/15/1992	Present	No
Owens Gap	35.217	-82.967	1074	COOP	1/1/1949	3/31/1962	No
Peaks Of Otter	37.467	-79.600	796	COOP	1/5/1944	10/31/1976	No
Pedlar Dam	37.671	-79.279	308	COOP	11/1/1926	Present	No
Pink Beds	35.350	-82.783	1003	COOP	4/1/1905	3/31/1962	No
Pinnacles Mdws. Of Dan	36.683	-80.417	860	COOP	3/1/1934	6/30/1949	No
Pisgah Forest 8 W	35.283	-82.833	842	COOP	9/1/1948	8/31/1950	No

Blue Ridge Parkway – BLRI							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Plumtree	36.033	-82.000	885	COOP	1/1/1949	3/31/1962	No
Point Lookout	35.633	-82.250	732	COOP	1/1/1949	4/30/1952	No
Poor Mountain	37.200	-80.150	1208	COOP	6/1/1949	6/30/1951	No
Ravensford	35.517	-83.300	641	COOP	1/1/1949	12/31/1958	No
Roanoke	37.267	-79.933	278	COOP	9/1/1901	2/1/1964	No
Roanoke Regl. Arpt.	37.317	-79.974	358	COOP	7/1/1934	Present	No
Roanoke River Gage	37.258	-79.939	276	COOP	8/1/1948	Present	No
Roaring Gap 1 NW	36.408	-80.996	860	COOP	10/1/1942	Present	No
Rocky Knob	36.850	-80.367	939	COOP	7/1/1940	10/1/1976	No
Roseland 1 NNW	37.800	-78.983	268	COOP	2/1/1986	3/1/1991	No
Smoky Gap	36.117	-81.933	1122	COOP	1/1/1949	3/31/1962	No
Sparta 2 SE	36.482	-81.093	916	COOP	1/28/1942	Present	No
Spruce Mountain	35.617	-83.200	1403	COOP	9/1/1948	8/31/1976	No
Spruce Pine	35.900	-82.067	796	COOP	1/1/1949	Present	No
Spruce Pine 1 SW	35.900	-82.083	878	COOP	M	3/31/1962	No
Spruce Pine 2 NE	35.933	-82.002	869	COOP	8/22/1997	Present	No
Spruce Pine 2 S	35.883	-82.083	921	COOP	5/1/1958	4/30/1961	No
Swannanoa 2 E	35.600	-82.367	683	COOP	3/7/1931	8/26/1987	No
Swannanoa 2 SSE	35.573	-82.385	1317	COOP	1/1/1984	Present	No
Transou	36.392	-81.304	876	COOP	4/1/1946	Present	No
Waynesboro	38.058	-78.908	395	COOP	1/14/1987	Present	No
Waynesboro Sewage	38.080	-78.875	390	COOP	10/1/1993	Present	No
Waynesville 1 E	35.487	-82.968	810	COOP	5/1/1894	Present	No
Weaverville	35.700	-82.567	671	COOP	1/1/1949	10/1/1992	No
Wilbar 4 NW	36.283	-81.333	708	COOP	9/1/1942	4/22/1976	No
Woolwine	36.783	-80.283	397	COOP	9/1/1950	6/30/1951	No
Woolwine 4 S	36.782	-80.269	463	COOP	6/1/1951	Present	No
Asheville 13 W	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
CW0692 Little Switzerland	35.846	-82.097	1056	CWOP	M	Present	No
CW2403 Blowing Rock	36.120	-81.736	1085	CWOP	M	Present	No
CW3212 Buffalo Mountain	36.838	-80.453	932	CWOP	M	Present	No
CW5112 Buchanan	37.480	-79.704	434	CWOP	M	Present	No
CW5266 Asheville	35.603	-82.499	679	CWOP	M	Present	No
CW5364 Weaverville	35.694	-82.509	655	CWOP	M	Present	No
CW5602 Waynesville	35.446	-83.034	1001	CWOP	M	Present	No
N4BHM Roanoke	37.339	-79.882	390	CWOP	M	Present	No
W4GHS Hillsville	36.690	-80.608	824	CWOP	M	Present	No
W4HF-9 Skyland Lakes	36.632	-80.732	854	CWOP	M	Present	No
WA4SSP-2 Linville	36.099	-81.890	1363	CWOP	M	Present	No
WG4R Meadows of Dan	36.770	-80.402	945	CWOP	M	Present	No
Sawmill Run	38.106	-78.831	445	GPMP	5/1/1983	10/31/1994	No

Blue Ridge Parkway – BLRI							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Mt. Mitchell	35.735	-82.286	1987	NADP	11/26/1985	Present	No
Natural Bridge Station	37.628	-79.512	274	NADP	7/2/2002	Present	No
Busick	35.769	-82.192	881	RAWS	2/1/2003	Present	No
Cherokee	35.620	-83.207	1036	RAWS	2/1/2002	Present	No
Davidson River	35.351	-82.779	975	RAWS	1/1/2004	Present	No
Laurel Springs	36.400	-81.283	914	RAWS	10/1/2002	Present	No
North Cove	35.817	-81.937	808	RAWS	3/1/2002	Present	No
North Cove Pinnacle	35.817	-81.937	780	RAWS	1/1/2005	Present	No
Rendezvous Mtn.	36.228	-81.298	727	RAWS	7/1/2002	Present	No
Stackrock Creek (FR2) North	36.070	-81.799	884	RAWS	12/1/2004	Present	No
Umholt	37.739	-79.336	341	RAWS	5/1/1998	5/31/2005	No
Asheville Regl. Arpt.	35.432	-82.538	645	SAO	11/1/1940	Present	No
Boone Watauga Co. Hosp.	36.200	-81.650	M	SAO	M	M	No
Jefferson Ashe Co. Arpt.	36.432	-81.419	969	SAO	M	M	No
Roanoke Regl. Arpt.	37.317	-79.974	358	SAO	7/1/1934	Present	No
Shenandoah	37.920	-79.200	537	SCAN	M	Present	No
WSLS Studios Roanoke	37.270	-79.940	300	WX4U	M	Present	No

record is quite complete. The COOP station “Jefferson 2 E,” located near Jefferson, North Carolina, started operating in 1896. This was a precipitation-only station until temperature data began in December, 1965. The data from this site are very complete. A third site with data records going back to the 1890s is the COOP station “Waynesville 1 E,” discussed previously. Two other COOP stations have reliable long-term data records going back to the 1900s. These stations are “Banner Elk” (1907-present), located in northwestern North Carolina, and “Asheville” (1902-present). Unfortunately, “Banner Elk” has become less reliable over the past 10 years. At least 19 additional active COOP stations have data records that start in the 1940s or earlier. Seven of these stations are within 80 km of Asheville, North Carolina, while the remaining stations are distributed more evenly along the northern portions of the BLRI. The COOP station “Grandfather Mountain” is a useful higher-elevation station near the BLRI, about 5 km south of the parkway. The data record at this site began in 1955 and it is of high quality.

Stations from the CRN, RAWS, SAO, and SCAN networks provide reliable automated weather data within 10 km of BLRI. Two CRN stations are located near the BLRI about 10-15 km south and west of Asheville, North Carolina (Table 4.4; Figure 4.2). The most reliable SAO observations come from the airports at Asheville and Roanoke, both of which have data records starting in the 1930s or early 1940s. Other SAO stations are situated at airports in the towns of Boone and Jefferson, both in North Carolina, although the lengths of their data records are unknown. A SCAN station is located near Montebello, Virginia, about 30 km southwest of the south entrance to Shenandoah National Park. We have identified eight active RAWS stations within 10 km of BLRI. Most of these stations began operating within the past five years. All of these stations are located along the North Carolina segment of the BLRI. In turn, many of these stations are located along the more mountainous southern portions of the BLRI. As a result,

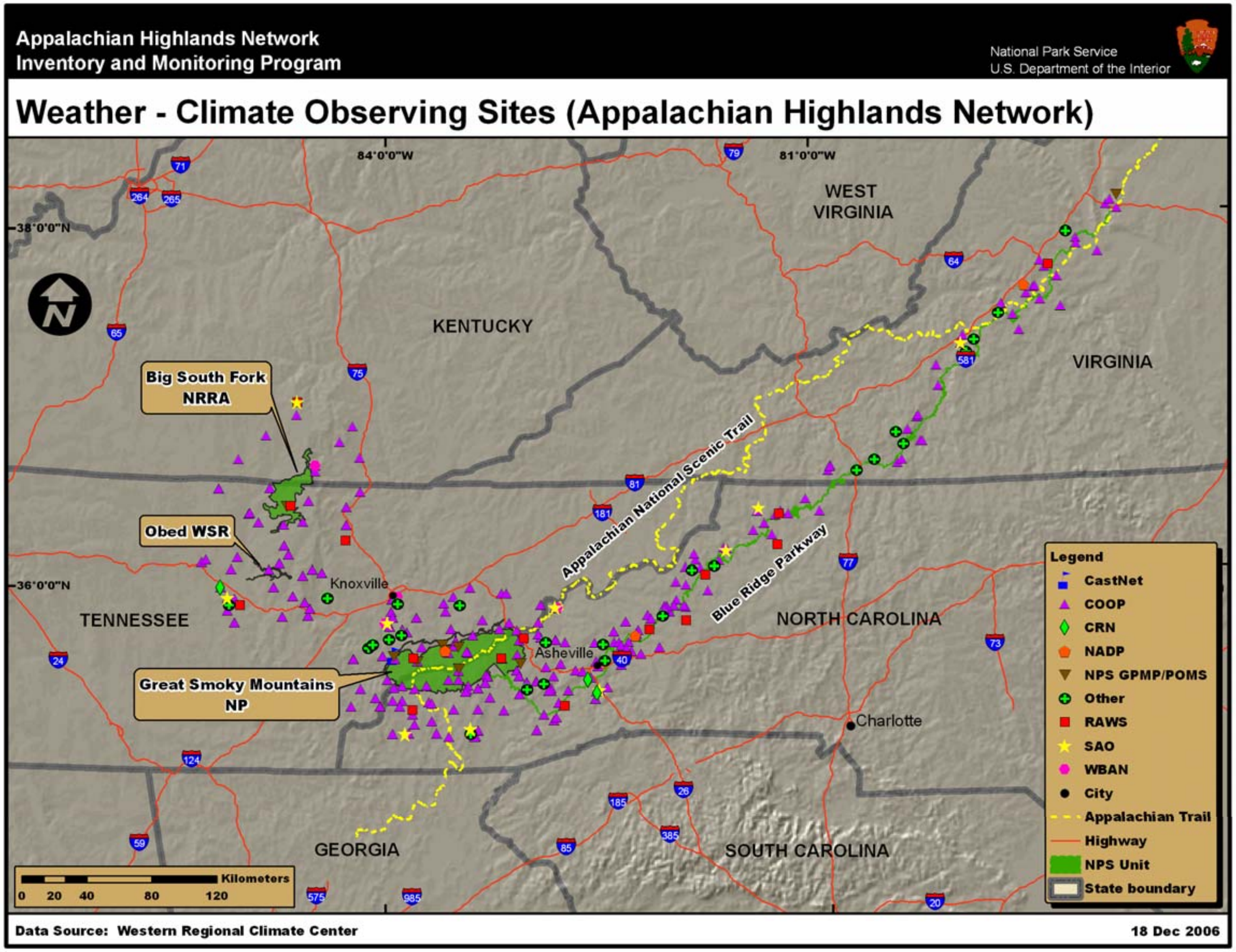


Figure 4.2. Station locations for the APHN.

many of the RAWS stations we have identified are located at significantly different elevations than the nearby stretches of the BLRI. The stations are often at lower valley locations while the BLRI is located along an adjacent ridgeline or higher area. Two of the more representative RAWS stations within 10 km of the BLRI may be "North Cove" and "North Cove Pinnacle." These two stations are about 30 km east of the summit of Mount Mitchell and about 10 km south of BLRI on a parallel ridgeline, separated from the parkway by the North Fork Catawba River drainage. The RAWS stations are at about 900 m elevation, while the BLRI is closer to 1000 m elevation. Further to the northeast, topographic variations become less severe. The RAWS stations in this area, such as "Laurel Springs," are therefore more likely to represent weather conditions along the BLRI than their corresponding stations further to the south and west. Weather stations from the CWOP and WX4U networks also provide near-real-time data in the area.

4.2.3. Eastern Tennessee Park Units

Two stations have been identified within BISO (Table 4.5). The RAWS station "Big South" has been providing near-real-time weather data for BISO since 2000 and is located near Highway 297 about a kilometer north of park headquarters (Figure 4.2). The POMS station "Taft Story Fields" is located across the Big South gorge about 3 km west of park headquarters.

Table 4.5. Weather/climate stations for the APHN park units in eastern Tennessee. 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?
Big South Fork National River and Recreational Area – BISO							
Taft Story Fields	36.473	-84.681	451	POMS	6/1/2003	Present	Yes
Big South	36.475	-84.654	440	RAWS	10/1/2000	Present	Yes
Allardt	36.381	-84.874	501	COOP	1/1/1928	Present	No
Alpha	36.733	-85.017	247	COOP	12/1/1893	5/24/1921	No
Burnside	36.983	-84.617	217	COOP	8/1/1896	7/31/1953	No
Byrdstown 1 W	36.567	-85.150	314	COOP	1/1/1893	10/31/1951	No
Byrdstown TVA	36.567	-85.150	299	COOP	10/1/1949	1/31/1950	No
Clarkrange	36.183	-85.017	549	COOP	1/1/1949	3/31/1962	No
Corbin 8 W	36.922	-84.227	377	COOP	4/8/2002	Present	No
Cumberland Falls S.P.	36.833	-84.317	326	COOP	10/1/1951	4/1/1982	No
Elk Valley 2 SW	36.467	-84.267	366	COOP	5/1/1896	8/31/1957	No
Frankfort	36.117	-84.800	445	COOP	1/1/1949	3/31/1962	No
Jamestown	36.433	-84.933	519	COOP	10/1/1949	11/30/1951	No
Jamestown	36.426	-84.941	515	COOP	10/1/1951	Present	No
Lancing 6 NW	36.150	-84.728	463	COOP	2/25/1989	Present	No
Monticello 3 NE	36.867	-84.828	298	COOP	4/15/1936	Present	No
New River	36.383	-84.567	357	COOP	2/19/1908	3/31/1952	No
Newcomb	36.552	-84.172	300	COOP	12/1/1951	Present	No
Oneida	37.267	-83.650	232	COOP	6/1/1936	Present	No
Pickett State Park	36.571	-84.798	495	COOP	9/1/1999	Present	No
Pilot Mountain	36.200	-84.667	390	COOP	1/1/1949	3/31/1962	No
Rugby	36.367	-84.700	436	COOP	5/1/1890	6/30/1949	No
Stearns 1 W	36.700	-84.483	393	COOP	8/11/1970	9/11/1979	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Stearns 2 S	36.667	-84.483	372	COOP	5/1/1936	Present	No
Sunbright 1 W	36.249	-84.697	456	COOP	9/1/1948	Present	No
Turley	36.367	-84.267	427	COOP	1/1/1949	3/31/1962	No
Williamsburg 1 NW	36.746	-84.175	329	COOP	12/9/2003	Present	No
Coker Creek	36.280	-84.275	518	RAWS	10/1/1997	Present	No
Somerset	37.056	-84.615	283	RAWS	3/1/2002	Present	No
Somerset Pulaski Co. Jt. Wil.	37.054	-84.615	283	SAO	12/1/1989	Present	No
Stearns	36.700	-84.483	433	WBAN	1/1/1937	12/31/1944	No
Williamsburg	36.767	-84.167	316	WBAN	4/1/1941	7/31/1944	No
Obed Wild and Scenic River – OBRI							
Allardt	36.381	-84.874	501	COOP	1/1/1928	Present	No
Big Lick	35.817	-85.033	540	COOP	10/1/1949	3/31/1962	No
Clarkrange	36.183	-85.017	549	COOP	1/1/1949	3/31/1962	No
Clarkrange #2	36.117	-85.059	566	COOP	7/1/2002	2/1/2003	No
Crossville	35.950	-85.033	564	COOP	6/1/1934	6/30/1954	No
Crossville Exp. Stn.	36.015	-85.131	552	COOP	3/1/1912	Present	No
Crossville Mem. Arpt.	35.954	-85.083	569	COOP	4/1/1954	Present	No
Frankfort	36.117	-84.800	445	COOP	1/1/1949	3/31/1962	No
Harriman	35.933	-84.550	235	COOP	3/1/1893	3/31/1962	No
Hebbertsburg	36.017	-84.767	540	COOP	1/1/1949	3/31/1962	No
Jamestown	36.426	-84.941	515	COOP	10/1/1951	Present	No
Kingston	35.858	-84.528	223	COOP	12/6/1884	Present	No
Kingston Steam Plant	35.900	-84.517	232	COOP	5/1/1951	3/31/1962	No
Lancing 6 NW	36.150	-84.728	463	COOP	2/25/1989	Present	No
Lantana	35.883	-85.083	583	COOP	9/1/1948	3/31/1962	No
Monterey	36.154	-85.264	567	COOP	4/1/1904	Present	No
Monterey 5 NE	36.167	-85.233	512	COOP	6/1/1963	10/31/1965	No
Morgan	35.967	-84.633	400	COOP	4/1/1950	2/28/1953	No
Morgan State Forest	36.117	-84.500	409	COOP	1/1/1949	11/30/1953	No
Petros	36.100	-84.433	427	COOP	1/1/1949	3/31/1962	No
Pilot Mountain	36.200	-84.667	390	COOP	1/1/1949	3/31/1962	No
Rockwood 2	35.853	-84.705	262	COOP	12/1/1884	Present	No
Rugby	36.367	-84.700	436	COOP	5/1/1890	6/30/1949	No
Sunbright 1 W	36.249	-84.697	456	COOP	9/1/1948	Present	No
Wartburg 2 SE	36.083	-84.567	403	COOP	12/1/1953	3/31/1962	No
Crossville 7 NW	36.014	-85.135	573	CRN	12/3/2004	Present	No
CW4578 Oliver Springs	35.960	-84.398	238	CWOP	M	Present	No
WO4U-10 Crossville	35.919	-85.073	581	CWOP	M	Present	No
WO4U-10 Crossville	35.918	-85.074	576	CWOP	M	Present	No
Crossville Area Office	35.918	-84.997	539	RAWS	10/1/2003	Present	No
Crossville Mem. Arpt.	35.954	-85.083	569	SAO	4/1/1954	Present	No

Outside of BISO, there are 11 active COOP stations within 30 km of the park unit. The longest data record is at the COOP station “Allardt,” which is about 10 km southwest of BISO (Figure

4.2) and has been active since 1928. The data record at this station is quite complete. Three other COOP stations within 30 km of BISO have data records going back to the 1930s. “Monticello 3 NE,” about 30 km northwest of BISO, is a very reliable site that has been operating since 1936, although temperatures have only been measured since 1956. The COOP station “Oneida” has also been operating since 1936, with temperatures being measured since 1958. This station is located 10 km east of BISO, near the town of Oneida, Tennessee. Several data gaps occurred at “Oneida” in the late 1980s through the early 1990s; otherwise, the data record is quite complete. “Stearns 2 S,” about 5 km northeast of BISO, has been operating since 1936, but has an unreliable data record, including a large data gap through the 1970s. The COOP station “Sunbright 1 W,” active since 1948, is located 10 km south of BISO. “Jamestown” and “Newcomb” are both COOP stations that measure only precipitation but have very complete data records starting in 1951. “Jamestown” is 10 km west of BISO while “Newcomb” is 30 km east of BISO.

No stations have been identified within OBRI. Outside of OBRI, there are nine active COOP stations within 30 km of the park unit (Table 4.5). Two of these COOP stations, “Kingston” and “Rockwood 2,” have data records going back to 1884. These stations are both about 25 km southeast of OBRI and their data records are quite complete. The COOP station “Kingston” measures precipitation only, while the COOP station “Rockwood 2” measures precipitation and temperature. The COOP station “Monterey” (1904-present) is about 25 km west of OBRI and has a data record that is largely complete for precipitation (except for a data gap from June 1963 to November 1965) but is very unreliable for temperature. The COOP station “Crossville Exp. Stn.” has been active since 1912 and has a very complete data record for both temperature and precipitation. “Allardt” and “Sunbright 1 W,” both discussed previously, also provide long-term climate records for OBRI.

Near-real-time weather data for OBRI are currently provided by one CRN station, one RAWS station, one SAO station, and three CWOP stations within 30 km of the park unit. All except one of these stations are located near the town of Crossville, Tennessee, about 15 km southwest of OBRI (Table 4.5; Figure 4.2). The longest record from these stations is found at the SAO station “Crossville Mem. Arpt.,” which has been active since 1954. The one near-real-time station not located near Crossville is the CWOP station “CW4578 Oliver Springs,” located about 25 km east of OBRI.

5.0. Conclusions and Recommendations

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

5.1. Appalachian Highlands Inventory and Monitoring Network

The APHN network has done much work in preliminary collections of weather/climate station metadata, particularly with regards to air quality monitoring sites in GRSM that measure meteorological elements. The metadata provided by the APHN office was very helpful particularly in the initial stages of the APHN weather/climate station inventory described in this report.

Coverage of long-term climate stations for the APHN park units, both within park boundaries and in adjacent regions, is sufficient for monitoring region-wide characteristics of climate changes in the APHN region. The park units in eastern Tennessee currently lack long-term climate records within their boundaries. However, they do both have reliable long-term records available nearby. Unfortunately, the current coverage of climate stations is not sufficient currently for extending this understanding of climate changes in the APHN to include characteristics of these changes at finer spatial scales. Also, many of the long-term climate records we identified are at lower elevations; therefore, it is more difficult to identify long-term climate change characteristics at higher elevations in the APHN. In light of this situation, it is important that NPS work together with local agencies to ensure that any active longer-term climate stations, especially those occurring at higher elevations, continue operating in order to continue their valuable contributions for weather and climate monitoring in the APHN.

Steps could also be considered for expanding the coverage of near-real-time sites in APHN parks. First, the APHN may want to consider expanding the meteorological measurements taken by air quality monitoring sites within their park units. This is particularly true in GRSM, where existing air quality monitoring sites associated with the NADP networks (e.g., the NADP site at Elkmont) currently measure a limited set of meteorological elements (mainly precipitation). The air quality stations in GRSM are often located at positions from which a full set of near-real-time weather measurements would be quite valuable (e.g. Clingmans Dome). These sites could be augmented with additional automated sensors measuring temperature, relative humidity, and wind. Another option is to install near-real-time sites devoted to weather observations, such as RAWS stations, at these air-quality monitoring sites.

Second, as additional near-real-time weather station installations are considered, transects along significant elevation gradients, especially in GRSM, would provide useful meteorological data, particularly for attempts to monitor migrations of plant and animal communities in response to climate changes. To start with, a transect along U.S. Highway 441 through the center of GRSM would likely be valuable, with stations present about every 300 meters (1000 feet) in elevation. As resources allow, additional stations could be considered along existing transects, allowing for finer sampling of elevation climate gradients, or additional transects could be set up at other readily-accessible locations such as Cades Cove.

Vital signs monitoring efforts in the highly-variable topography of the APHN park units underscore the need for near-real-time weather observations at denser spatial scales. New installations are needed in OBRI, as no near-real-time stations are currently available. In BISO, the existing POMS and RAWS sites in the southern part of the park unit would be complimented by new installations in northern BISO, allowing the APHN to monitor overall climate gradients along the Big South watershed. Since the GRSM is so variable topographically, initial efforts to improve the near-real-time station coverage in the park unit may want to focus on maintaining automated stations at a few key high points along the Appalachian Crest, along with installing at least one station in each of the larger watersheds in the park unit, such as the Cataloochee, Little Pigeon, and Prong watersheds. Any existing ranger stations in these watersheds would serve as useful locations for such sites. As resources allow, this coverage may then be expanded to include smaller-scale drainage basins.

Several reliable long-term climate stations and near-real-time weather stations have been identified along the length of BLRI. These stations provide an excellent opportunity for documenting latitudinal gradients of current weather conditions and long-term climate changes across the APHN.

5.2. Spatial Variations in Mean Climate

Topography and coastal-interior gradients are major controlling factors on the park units within APHN, leading to systematic spatial variations in mean surface climate. With local variations over short horizontal and vertical distances, topography introduces considerable fine-scale structure to mean climate (temperature and precipitation). Issues encountered in mapping mean climate are discussed in Appendix 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 (a) stations should not be located in deep valley bottoms (cold air drainage pockets) or near excessively steep slopes and (b) stations should be distributed spatially in the major biomes of each park. If such stations already are present in the vicinity, then additional stations would be best used for two important and somewhat competing purposes: (a) add redundancy as backup for loss of data from current stations (or loss of the physical stations) or (b) provide added information on spatial heterogeneity in climate arising from topographic diversity, particularly inversions.

5.3. Climate Change Detection

There is much interest in the adaptation of APHN ecosystems in response to possible future climate change. This particularly includes the migration of plant and animal communities northward and to higher elevations and how introduced human land uses on the APHN landscape hinder or help such migrations. The placement and/or utilization of weather/climate stations along latitudinal and elevational gradients could be quite useful for such monitoring activities. Other applications for climate monitoring related to climate change detection in the APHN include hydrologic studies.

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 APHN in both topography and 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 APHN 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 APHN park units but also to climate-monitoring efforts for APHN. 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

- Much preliminary weather/climate station metadata has been collected by the APHN. This information has been helpful in the completion of this inventory report.
- Long-term climate station coverage in the APHN is generally satisfactory for documenting overall characteristics of climate changes for APHN park units. However, characteristics of climate changes at higher elevations and at finer spatial scales are more difficult to determine.
- Existing NADP air-quality monitoring sites in GRSM provide limited meteorological elements (precipitation only) and could either be augmented with additional meteorological instrumentation (temperature, wind, relative humidity) or co-located with dedicated near-real-time weather stations such as RAWS sites.
- Climate transects could be considered at areas with significant elevational gradients, including U.S. Highway 441 through GRSM. Climate data from such transects would be useful in monitoring possible migrations of plant and animal communities in response to climate changes.
- Water monitoring efforts in the APHN would benefit by additional coverage of near-real-time weather stations, starting in larger watersheds and working towards smaller drainages.
- Reliable long-term climate stations and near-real-time weather stations identified along BLRI provide an excellent opportunity for documenting latitudinal gradients of current weather conditions and long-term climate changes across the APHN.

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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

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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 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 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).

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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 U.S.

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

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.

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. 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. The network includes MDN sites. Precipitation is the primary climate parameter measured at NADP sites.

G.7. Portable Ozone Monitoring System (POMS) Network

- 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.
  - Station spacing and coverage: station installation is episodic, driven by opportunistic situations.

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.8. 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.9. 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.

- o Wind gust.
  - o Gust direction.
  - o Barometric pressure.
  - o Precipitation (not at many FAA sites).
  - o Sky cover.
  - o Ceiling (cloud height).
  - o Visibility.
- Sampling frequency: element-dependent.
- Reporting frequency: element-dependent.
- Estimated station cost: $100000–$200000, with maintenance costs approximately $10000/year.
- Network strengths:
  - o Records generally extend over several decades.
  - o Consistent maintenance and station operations.
  - o Data record is reasonably complete and usually high quality.
  - o Hourly or sub-hourly data.
- Network weaknesses:
  - o Nearly all sites are located at airports.
  - o Data quality can be related to size of airport—smaller airports tend to have poorer datasets.
  - o 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.10. 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:
  - o Air temperature.
  - o Precipitation.
  - o Relative humidity.
  - o Wind speed.
  - o Wind direction.
  - o Barometric pressure.
  - o Solar radiation.
  - o Snow water content.
  - o Snow depth.
  - o 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.11. 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.

The U.S. Department of the Interior (DOI) is the nation's principal conservation agency, charged with the mission "*to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities."* More specifically, DOI protects America's treasures for future generations, provides access to our Nation's natural and cultural heritage, offers recreational opportunities, honors its trust responsibilities to American Indians and Alaskan Natives and its responsibilities to island communities, conducts scientific research, provides wise stewardship of energy and mineral resources, fosters sound use of land and water resources, and conserves and protects fish and wildlife. The work that we do affects the lives of millions of people; from the family taking a vacation in one of our national parks to the children studying in one of our Indian schools.

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