National Park Service
U.S. Department of the Interior

Natural Resource Program Center
Fort Collins, Colorado

Weather and Climate Inventory
National Park Service
Southeast Coast Network

Natural Resource Technical Report NPS/SECN/NRTR—2007/010

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WRCC Report 2007-06

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April 2007

U.S. Department of the Interior
National Park Service
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Please cite this publication as follows:

Davey, C. A., K. T. Redmond, and D. B. Simeral. 2007. Weather and Climate Inventory, National Park Service, Southeast Coast Network. Natural Resource Technical Report NPS/SECN/NRTR—2007/010. National Park Service, Fort Collins, Colorado.

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Acronyms

AASC	American Association of State Climatologists
ACIS	Applied Climate Information System
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
BLM	Bureau of Land Management
CAHA	Cape Hatteras National Seashore
CALO	Cape Lookout National Seashore
CANA	Canaveral National Seashore
CASA	Castillo de San Marcos National Monument
CASTNet	Clean Air Status and Trends Network
CHAT	Chattahoochee River National Recreation Area
CHPI	Charles Pinckney National Historic Site
CONG	Congaree National Park
COOP	Cooperative Observer Program
CRN	NOAA Climate Reference Network
CUIS	Cumberland Island National Seashore
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
FAWN	Florida Automated Weather Network
FOCA	Fort Caroline National Memorial
FOFR	Fort Frederica National Monument
FOMA	Fort Mantanzas National Monument
FOPU	Fort Pulaski National Monument
FORA	Fort Raleigh National Historic Site
FOSU	Fort Sumter National Monument
FIPS	Federal Information Processing Standards
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GPMP	Gaseous Pollutant Monitoring Program
GPS	Global Positioning System
GPS-MET	NOAA ground-based GPS meteorology
HOBE	Horseshoe Bend National Military Park
I&M	NPS Inventory and Monitoring Program
KEMO	Kennesaw Mountain National Battlefield Park
LEO	Low Earth Orbit
LST	local standard time
MDN	Mercury Deposition Network
MOCR	Moores Creek National Battlefield
NADP	National Atmospheric Deposition Program
NASA	National Aeronautics and Space Administration

NCDC	National Climatic Data Center
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
OCMU	Ocmulgee National Monument
PRISM	Parameter Regression on Independent Slopes Model
RAWS	Remote Automated Weather Station network
RCC	regional climate center
SAO	Surface Airways Observation network
SECN	Southeast Coast Inventory and Monitoring Network
SNOTEL	Snowfall Telemetry network
SOD	Summary Of the Day
Surfrad	Surface Radiation Budget network
TIMU	Timucuan Ecological and Historic Preserve
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
WBAN	Weather Bureau Army Navy
WMO	World Meteorological Organization
WRBR	Wright Brothers National Memorial
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 Southeast Coast Inventory and Monitoring Network (SECN). 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. Southeastern climates are humid and warm-temperate to subtropical, with significant maritime influences from the Atlantic Ocean and Gulf of Mexico. The southern end of the Appalachian Mountains also influences climate patterns in the SECN park units located in eastern Alabama and northern Georgia. Extreme weather events in the SECN drive both coastal and riverine geomorphic changes. Impacts from storm washover episodes associated with strong nor'easter events in the winter and tropical systems in the summer and fall, and the recovery periods from such events, are an important issue for coastal SECN ecosystems. Thunderstorms are an integral part of the SECN climate, especially during the spring and summer months. The El Niño Southern Oscillation (ENSO) plays a large role in the interannual variations of the climate of the SECN, with El Niño years typically bringing lower temperatures in winter and spring, increased winter precipitation, and fewer tropical systems. Potential sea-level rises due to predicted global-scale climate changes are also a concern for many SECN park units. Periods of prolonged drought introduce stressors to vegetation communities with potentially severe effects. Human impacts on the landscape of the SECN region have introduced local- and regional-scale climate changes in the SECN, many of which are adversely impacting the region's plant and animal communities. Because of its influence on the ecology of SECN park units and the surrounding areas, climate was identified as a high-priority vital sign for SECN 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 SECN park units.
- Inventory of weather and climate station locations in and near SECN 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.

Mean annual precipitation in the SECN is fairly uniform but increases gradually towards the Atlantic coast and also towards western portions of SECN. Some of the wettest park units in the SECN receive over 1400 millimeters (mm) of precipitation every year. The driest park units in the SECN generally receive between 1000 and 1200 mm of precipitation each year. Western portions of the SECN tend to receive more of their annual precipitation in winter, while park units along the Atlantic coast tend to get more precipitation during the summer months. Temperatures in the SECN vary largely as a function of latitude and proximity to the coast. Mean annual temperatures are coolest for the park units in northern Georgia (about 14°C) while some SECN park units in Florida see mean annual temperatures above 20°C. Winter

temperatures are fairly mild, showing a strong latitudinal gradient. During the summer months, factors such as elevation and proximity to the coast become more important. Summer temperatures are moderated along the coastal SECN park units, while park units immediately inland of the coast are generally a few degrees warmer. Although the proximity of oceans generally moderates extreme temperature conditions, with average summertime maximum temperatures around 30°C, daytime temperatures can occasionally reach 40°C. Precipitation and temperature trends are generally neutral throughout the SECN. Large variations in temperature patterns for the SECN over the past century highlight the emphasis on measurement consistency that is needed in order to properly detect long-term climatic changes.

Through a search of national databases and inquiries to NPS staff, we have identified 15 weather and climate stations within SECN park units. The most stations are found in Cape Hatteras National Seashore (CAHA) and Congaree National Park (CONG). Both park units have four weather/climate stations.

The SECN office was helpful in identifying weather/climate stations within SECN park units. Many SECN park units, historical sites or other memorials in particular, have no weather/climate stations at or within park boundaries. As a result, these park units must rely heavily on stations outside of the park units for their weather and climate data. Fortunately, each of these park units have numerous near-real-time and long-term weather/climate stations nearby. For those park units that do have weather/climate stations inside their boundaries, very few of these stations have verifiable long-term data records. Those records which are available are valuable for climate monitoring efforts in the SECN, highlighting the importance of retaining such long-term sites.

The national seashore park units in the SECN, CAHA and Cape Lookout National Seashore (CALO) in particular, contain large stretches of barrier islands that currently have no weather/climate station coverage. The stations that are available are located at the edges of these barrier islands or are usually a significant distance away from the barrier islands, either at inland sites or on ocean buoys. New station installations on previously-unsampled stretches of barrier islands would be helpful for monitoring coast-interior climate gradients and other climate dynamics that work to shape the coastal ecosystems of the SECN.

Acknowledgements

This work was supported and completed under Task Agreement H8R07010001, with the Great Basin Cooperative Ecosystem Studies Unit. We would like to acknowledge very helpful assistance from various National Park Service personnel associated with the Southeast Coast Inventory and Monitoring Network. Particular thanks are extended to Christina Wright and Joe DeVivo. We also thank John Gross, Margaret Beer, Grant Kelly, Greg McCurdy, and Heather Angeloff for all their help. Seth Gutman with the National Oceanic and Atmospheric Administration Earth Systems Research Laboratory provided valuable input on the GPS-MET station network. Portions of the work were supported by the NOAA Western Regional Climate Center.

1.0. Introduction

Weather and climate are key drivers in ecosystem structure and function. Global- and regional-scale climate variations will have a tremendous impact on natural systems (Chapin et al. 1996; Schlesinger 1997; Jacobson et al. 2000; Bonan 2002). Long-term patterns in temperature and precipitation provide first-order constraints on potential ecosystem structure and function. Secondary constraints are realized from the intensity and duration of individual weather events and, additionally, from seasonality and inter-annual climate variability. These constraints influence the fundamental properties of ecologic systems, such as soil–water relationships, plant–soil processes, and nutrient cycling, as well as disturbance rates and intensity. These properties, in turn, influence the life-history strategies supported by a climatic regime (Neilson 1987; DeVivo 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 Southeast Coast Inventory and Monitoring Network (SECN) 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 SECN (Table 1.1; Figure 1.1). In this report, we provide the following informational elements:

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

The primary objectives for climate- and weather-monitoring in the SECN are as follows (DeVivo et al. 2005):

A. Determine status and trends in temperature and precipitation.
B. Determine the severity and frequency of droughts.
C. Determine the frequency of hurricanes, tropical storms, and other high-energy storm events.
D. Determine the frequency and distribution of lightning strikes.
E. Determine status and trends in mean sea level.

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.

Table 1.1. Park units in the Southeast Coast Network.

Acronym	Name
CAHA	Cape Hatteras National Seashore
CALO	Cape Lookout National Seashore
CANA	Canaveral National Seashore
CASA	Castillo de San Marcos National Monument
CHAT	Chattahoochee River National Recreation Area
CHPI	Charles Pinckney National Historic Site
CONG	Congaree National Park
CUIS	Cumberland Island National Seashore
FOCA	Fort Caroline National Memorial
FOFR	Fort Frederica National Monument
FOMA	Fort Mantanzas National Monument
FOPU	Fort Pulaski National Monument
FORA	Fort Raleigh National Historic Site
FOSU	Fort Sumter National Monument
HOBE	Horseshoe Bend National Military Park
KEMO	Kennesaw Mountain National Battlefield Park
MOCR	Moores Creek National Battlefield
OCMU	Ocmulgee National Monument
TIMU	Timucuan Ecological and Historic Preserve
WRBR	Wright Brothers National Memorial

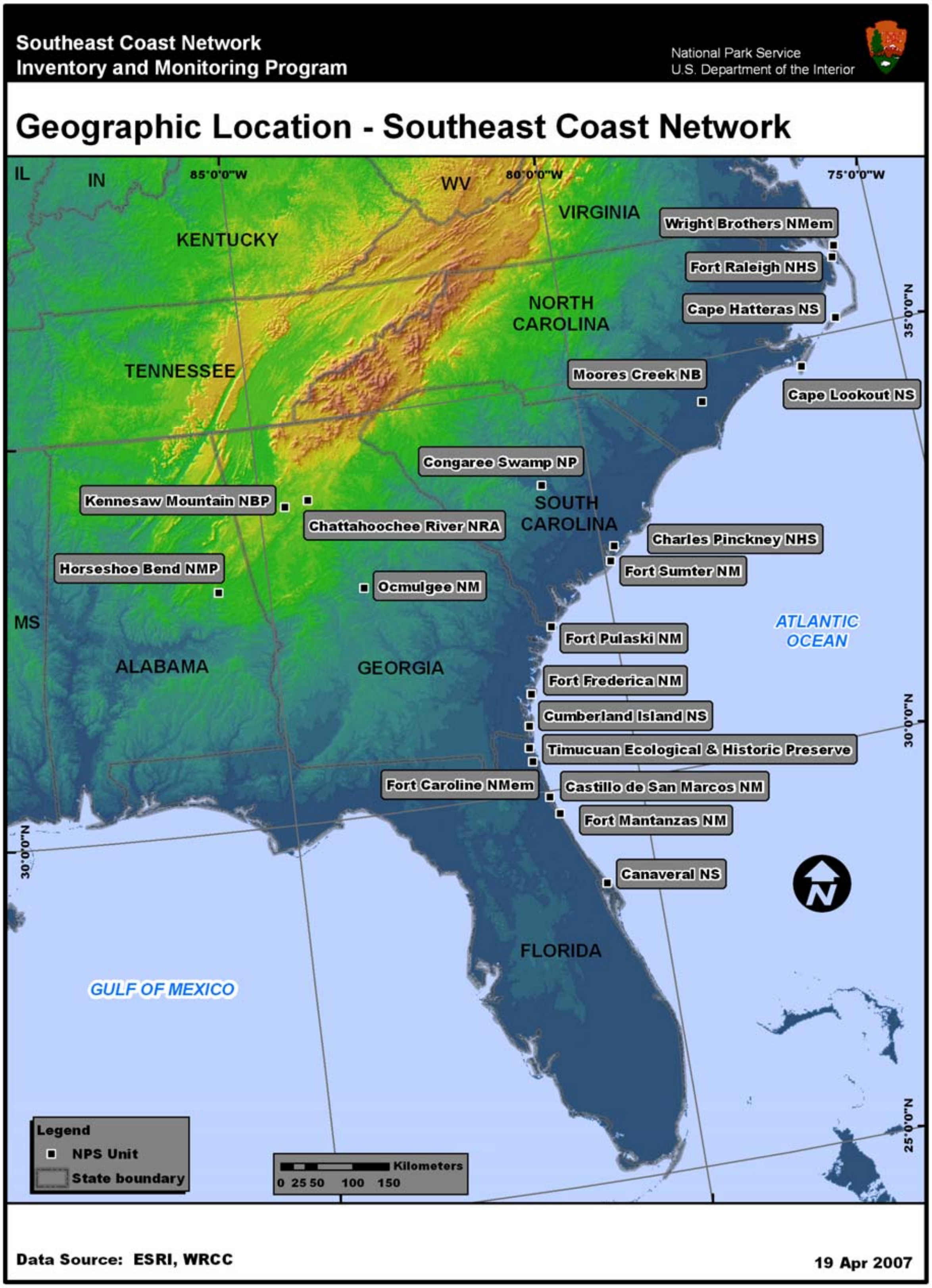


Figure 1.1. Map of the Southeast Coast Network.

1.1.2. NPS I&M Networks

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

1.2. Weather versus Climate Definitions

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

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

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

1.3. Purpose of Measurements

Climate inventory and monitoring climate activities should be based on a set of guiding fundamental principles. Any evaluation of weather/climate monitoring programs begins with asking the following question:

- What is the purpose of weather and climate measurements?

Evaluation of past, present, or planned weather/climate monitoring activities must be based on the answer to this question.

Weather and climate data and information constitute a prominent and widely requested component of the NPS I&M networks (I&M 2006). Within the context of the NPS, the following services constitute the main purposes for recording weather and climate observations:

- Provide measurements for real-time operational needs and early warnings of potential hazards (landslides, mudflows, washouts, fallen trees, plowing activities, fire conditions, aircraft and watercraft conditions, road conditions, rescue conditions, fog, restoration and remediation activities, etc.).
- Provide visitor education and aid interpretation of expected and actual conditions for visitors while they are in the park and for deciding if and when to visit the park.
- Establish engineering and design criteria for structures, roads, culverts, etc., for human comfort, safety, and economic needs.

- Consistently monitor climate over the long-term to detect changes in environmental drivers affecting ecosystems, including both gradual and sudden events.
- Provide retrospective data to understand *a posteriori* changes in flora and fauna.
- Document for posterity the physical conditions in and near the park units, including mean, extreme, and variable measurements (in time and space) for all applications.

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

1.4. Design of Climate-Monitoring Programs

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

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

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

1.4.1. Need for Consistency

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

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

1.4.2. Metadata

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

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

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

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

1.4.3. Maintenance

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

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

1.4.4. Automated versus Manual Stations

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

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

1.4.5. Communications

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

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

1.4.6. Quality Assurance and Quality Control

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

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

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

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

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

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

1.4.7. Standards

Although there is near-universal recognition of the value in systematic weather and climate measurements, these measurements will have little value unless they conform to accepted standards. There is not a single source for standards for collecting weather and climate data nor a single standard that meets all needs. Measurement standards have been developed by the American Association of State Climatologists (AASC 1985), U.S. Environmental Protection Agency (EPA 1987), World Meteorological Organization (WMO 1983; 2005), Finklin and Fischer (1990), National Wildfire Coordinating Group (2004), and the RAWS program (Bureau of Land Management [BLM] 1997). Variations to these measurement standards also have been offered by instrument makers (e.g., Tanner 1990).

1.4.8. Who Makes the Measurements?

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

2.0. Climate Background

The ecosystems in the SECN, both aquatic and terrestrial, are strongly influenced by climate characteristics (DeVivo et al. 2005). Weather and climate drive freshwater inputs to aquatic and wetland systems. Climate is a key driver of fire frequency and magnitude in terrestrial systems. Extreme weather events in the SECN drive both coastal and riverine geomorphic changes.

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

2.1. Climate and the SECN Environment

Southeastern climates are humid and warm-temperate to subtropical (Ruffner 1985; White et al. 1998). Major variation in climate occurs with change in latitude and elevation. Longitude has a more subtle influence on climate than latitude, as a result of maritime influence to the south and east and continental influences to the north and west. Latitudinal gradients in temperature are steeper in winter than in summer, producing a strong geographic pattern in freeze-free periods and cold temperatures (White et al. 1998).

Precipitation throughout the network typically comes in the form of rain from winter and spring storm fronts, and tropical storms and hurricanes in the summer and/or early fall (White et al. 1998). The winter and spring storms that impact the SECN include coastal nor'easter storms that develop just off the southeastern U.S. coast before moving up the eastern seaboard. Thunderstorms are an integral part of the SECN climate, especially during the spring and summer months. In fact, northern Florida, including such park units as CANA, CASA, and FOMA, is one of the most active areas for lightning in the entire U.S. (Changnon 1988a; 1988b; Hodanish et al. 1997; Zajac and Rutledge 2001; Orville et al. 2001; DeVivo et al. 2005.

The El Niño Southern Oscillation (ENSO) plays a large role in the interannual variations of the climate of the SECN. El Niño years typically bring lower temperatures in winter and spring and increased winter precipitation throughout the SECN. During La Niña years, however, drought conditions can occur and have significant negative consequences on SECN ecosystems (DeVivo et al. 2005). Further, ENSO has a strong influence on the number of Atlantic Basin tropical storms and hurricanes, which regularly impact portions of the SECN during the summer and fall months (Smith 1999; Lyons 2004). Hurricanes play a significant role in shaping the structure and characteristics of SECN ecosystems, particularly coastal systems. During La Niña events, the average number of hurricanes in the Atlantic Basin increases compared to El Niño years (Gray 1984a; Gray 1984b; Landsea 1993; Goldenberg and Shapiro 1996; Bove et al. 1998).

Several of the management issues identified for the park units of the SECN (DeVivo et al. 2005) have impacts on local climate, and vice versa. Impacts from storm washover episodes associated with strong nor'easter events in the winter and tropical systems in the summer and fall, and the recovery periods from such events, are an important issue for barrier islands in many of the SECN park units along the Atlantic coast (Hosier and Cleary 1978). In addition, potential sea-level rises due to predicted global-scale climate changes are also a concern along these coastal park units (Zimmerman et al. 1991; NAST 2001). Periods of prolonged drought introduce stressors to vegetation communities with potentially severe effects. For instance, wildfire and forest-pest (i.e., turpentine beetle) outbreaks at park units such as CONG have both been linked to periods of prolonged drought (DeVivo et al. 2005). Human impacts on the landscape of the SECN region have introduced disturbances and land-use heterogeneities that have introduced local- and regional-scale climate changes in the SECN, many of which are adversely impacting the region's plant and animal communities. Exotic plant species introduced to the SECN have already had negative impacts on the region's ecosystems. The spread of these non-native plant species could be accelerated in response to future climate changes, particularly in those areas where native plant species are unable to adapt to the climate changes (DeVivo et al. 2005).

2.2. Spatial Variability

Much of the SECN lies on the Coastal Plain and Piedmont regions of the southeastern U.S. Therefore, both the Atlantic Ocean and the Gulf of Mexico are strong drivers of the climate characteristics of the SECN. The southern end of the Appalachian Mountains also influences climate patterns in the SECN park units located in eastern Alabama and northern Georgia. Mean annual precipitation in the SECN (Figure 2.1) is fairly uniform but increases gradually towards the Atlantic coast and also towards western portions of SECN. Some of the wettest park units in the SECN, including CALO and HOBE, see mean annual precipitation totals in excess of 1400 mm. The driest park units in the SECN, including CONG and OCMU, are located in the Piedmont region of Georgia and South Carolina. These locations generally receive between 1000 and 1200 mm of precipitation every year. During the course of a given year, western portions of the SECN tend to receive more of their annual precipitation during the winter months (Figure 2.2). However, for SECN park units along the Atlantic coast, precipitation tends to reach a maximum during the late summer months, with substantially drier conditions from fall through spring. Much of the summertime precipitation along the coast can be attributed to daily land-sea breeze interactions (Marshall et al. 2004) along with occasional tropical storm and hurricane activity (NAST 2001).

Temperatures in the SECN vary largely as a function of latitude and proximity to the coast. Mean annual temperatures are coolest for the park units in northern Georgia, averaging around 14°C (Figure 2.3). The warmest park unit in the SECN is CANA, with a mean annual temperature above 20°C. The latitudinal gradient in temperatures is quite evident in winter temperatures (White et al. 1998). For example, January minimum temperatures (Figure 2.4) are warmest for CANA, at just under 8°C. The coldest SECN park units are in northern Georgia, where mean January minimum temperatures are just below -4°C.

During the summer months, latitude becomes less of a driving factor for SECN temperatures and factors such as elevation and proximity to the coast become more important. Mean July maximum temperatures, for example, are moderated along the immediate coast in the SECN (Figure 2.5). Locations immediately inland of the coast are generally a few degrees warmer than coastal locations. Some of the coolest coastal park units are found along coastal North Carolina,

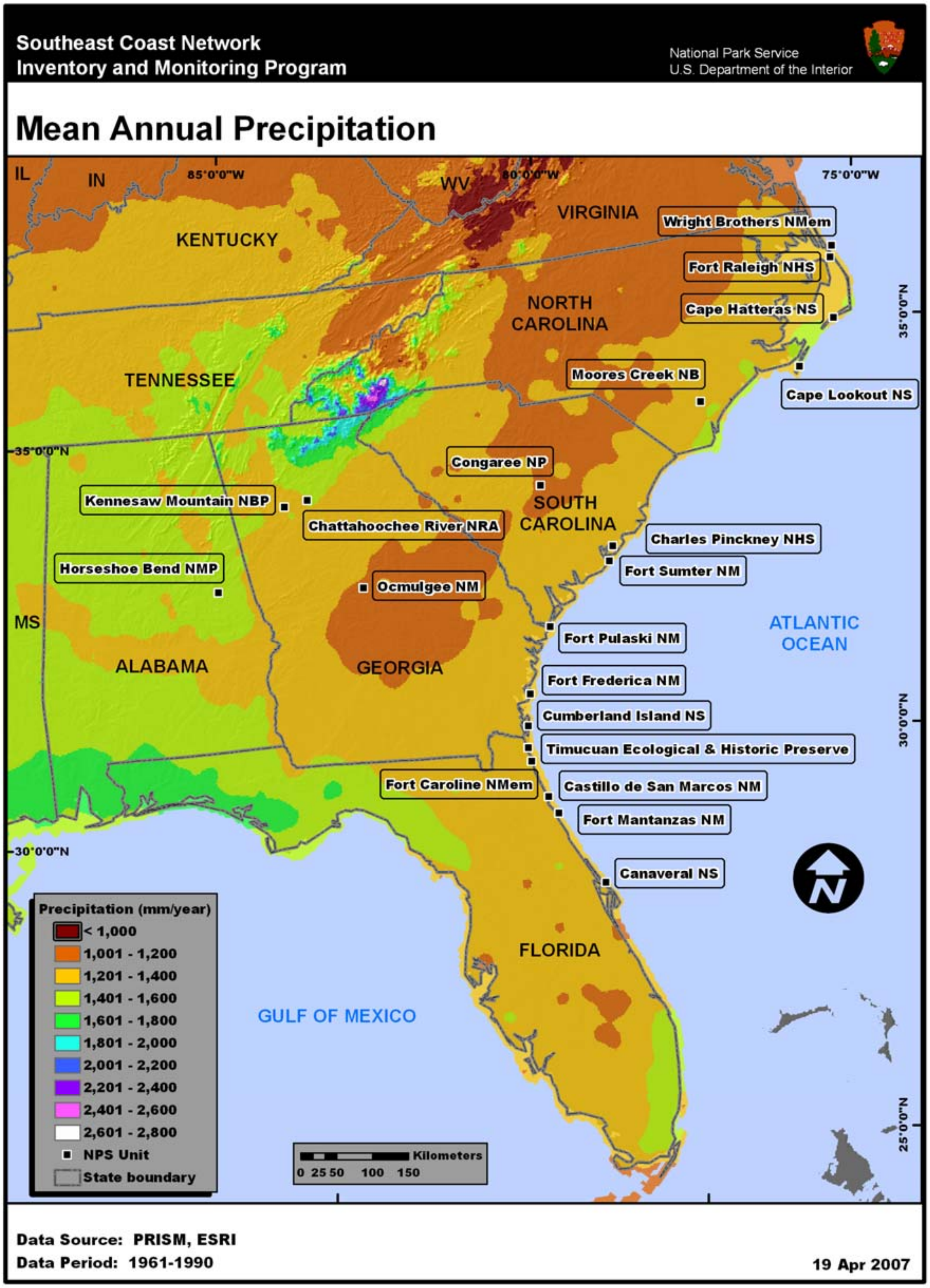


Figure 2.1. Mean annual precipitation, 1961-1990, for the SECN.

a)

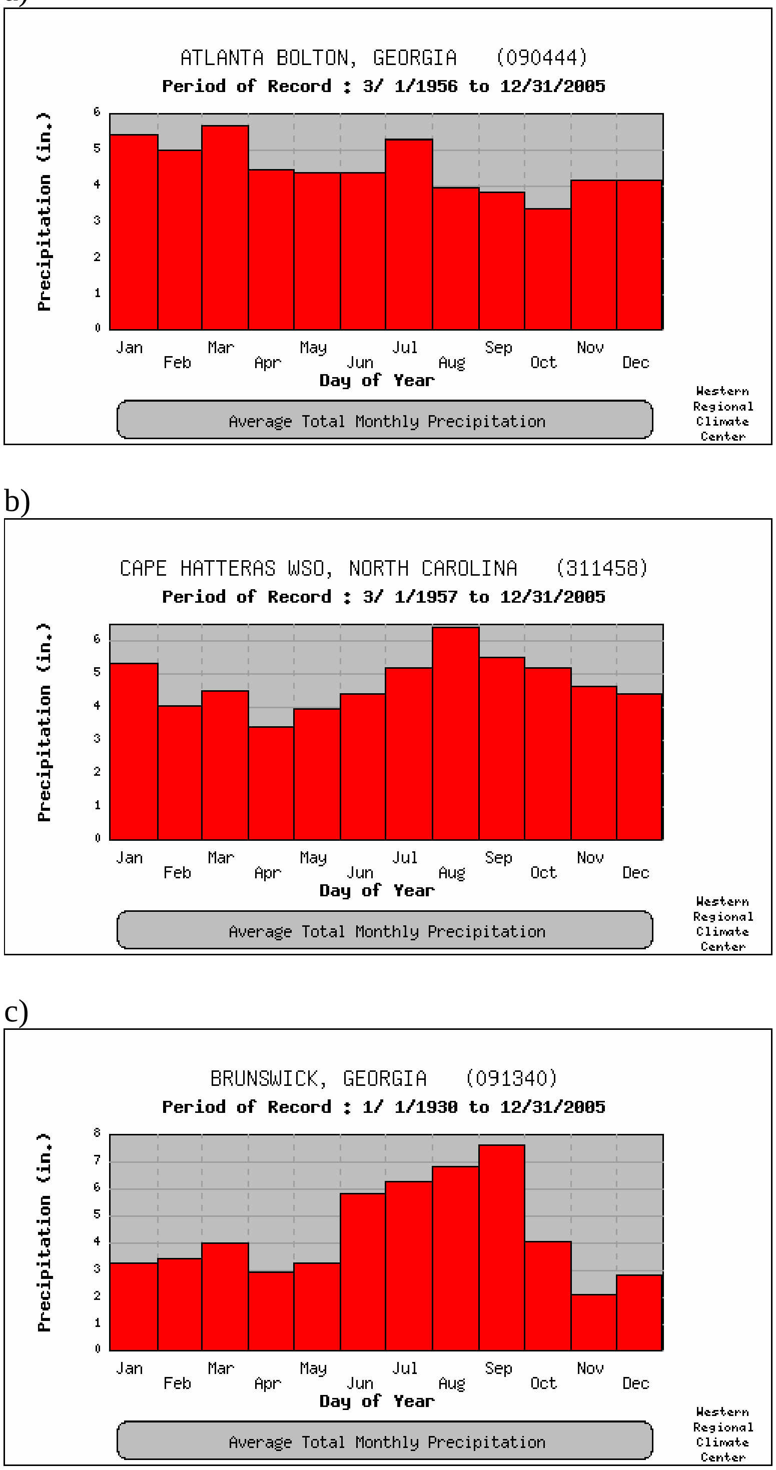


Figure 2.2. Mean monthly precipitation at selected locations in the SECN. Atlanta Bolton (a) is near CHAT and KEMO, Cape Hatteras WSO (b; also known as Cape Hatteras Billy Mitchell Airport) is in CAHA, and Brunswick (c) is near CUIS and FOFR.

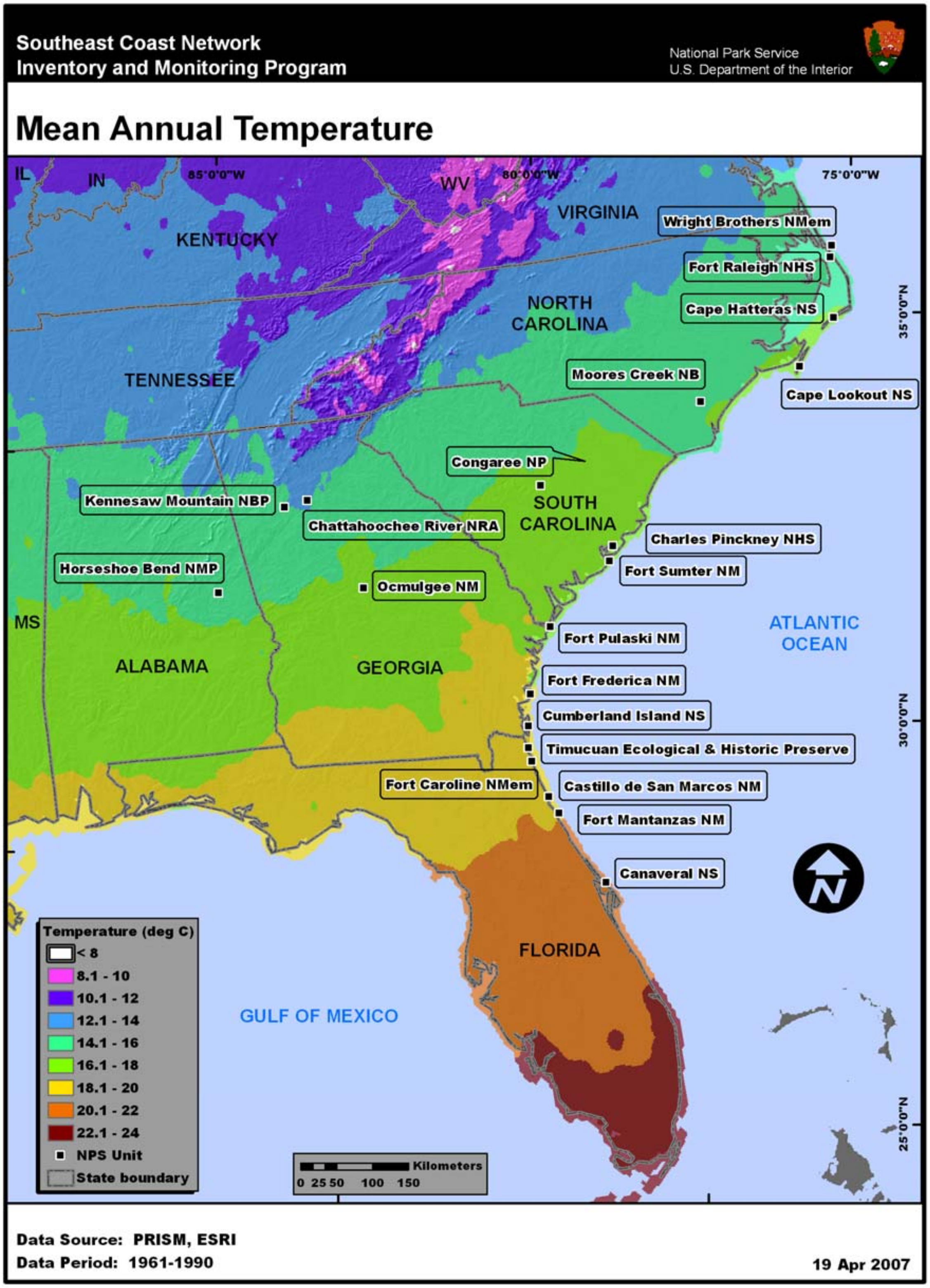


Figure 2.3. Mean annual temperature, 1961-1990, for the SECN.

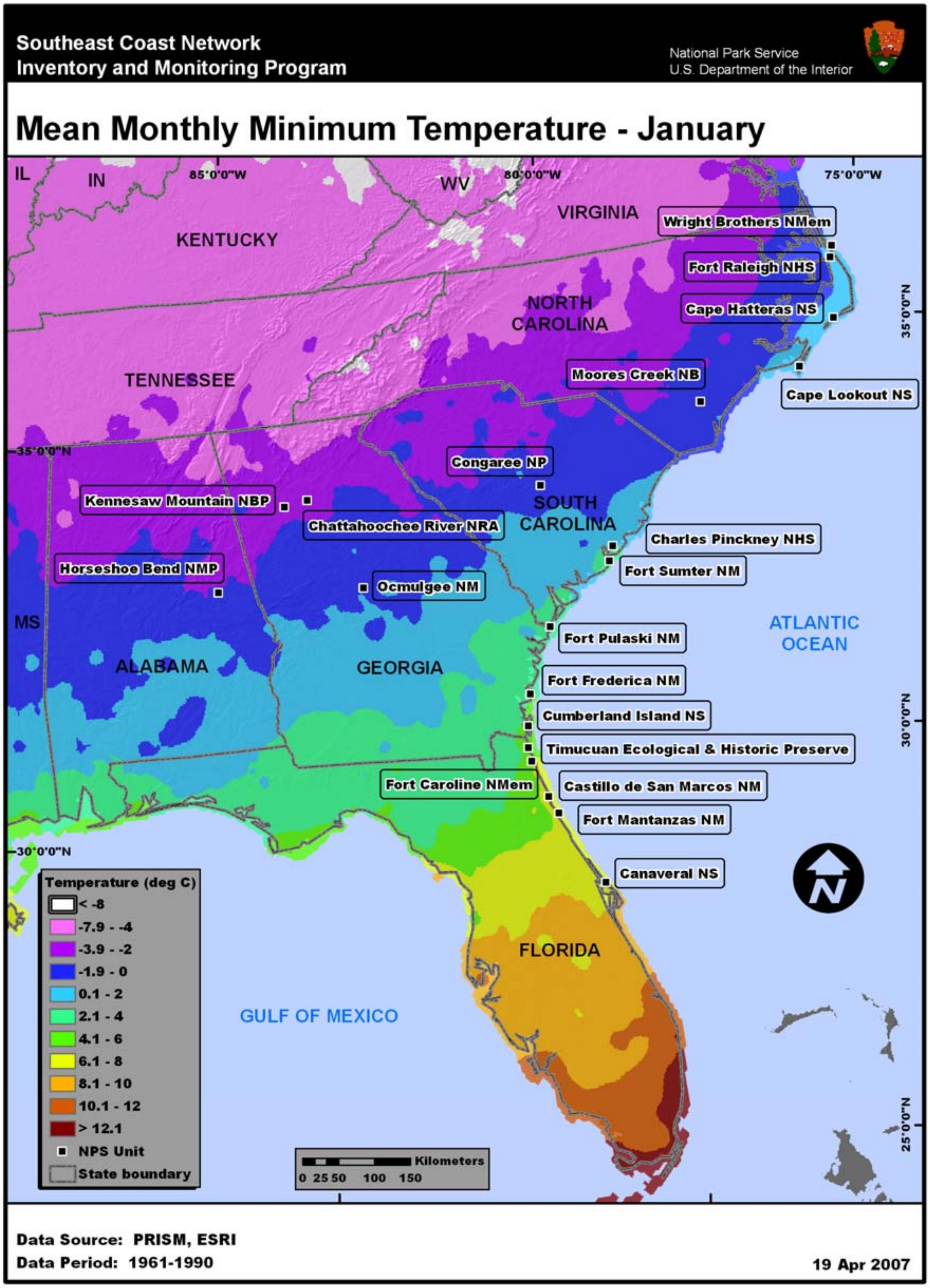


Figure 2.4. Mean January minimum temperature, 1961-1990, for the SECN.

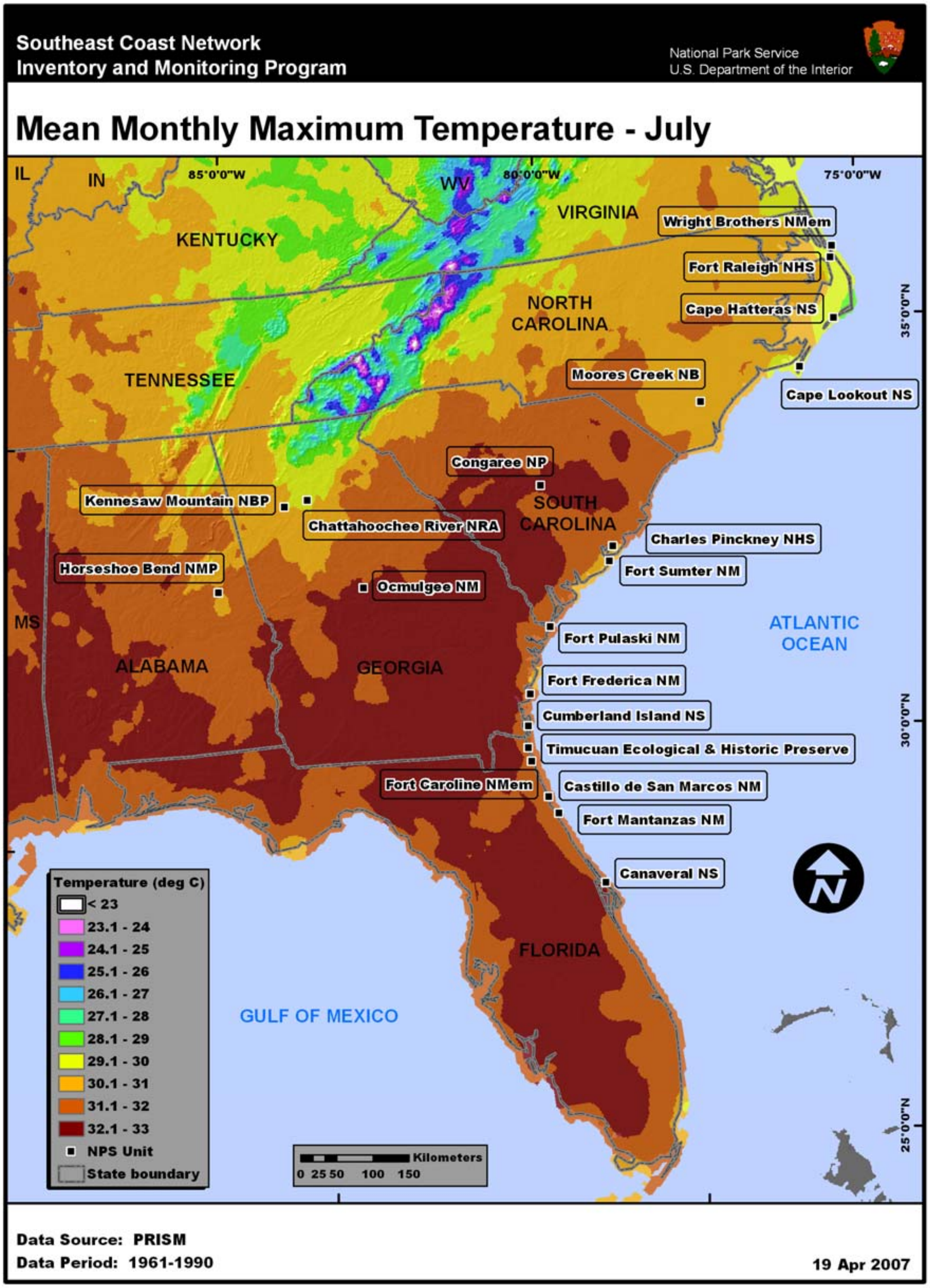


Figure 2.5. Mean July maximum temperature, 1961-1990, for the SECN.

where mean July maximum temperatures are just below 30°C. The SECN park units in northern Georgia are at somewhat higher elevations than the other SECN park units and are therefore relatively cool, with mean July maximum temperatures also just below 30°C. The warmest locations in the SECN, including CONG and OCMU, have mean July maximum temperatures over 32°C. Although the proximity of oceans generally moderates extreme temperature conditions, summertime maximum temperatures can reach 40°C in the SECN.

2.3. Temporal Variability

Some studies indicate that precipitation has increased slightly over the last century for much of the eastern U.S. (Karl et al. 1996b; Karl and Knight 1998; NAST 2001). This pattern is not apparent across much of the SECN (Figure 2.6).

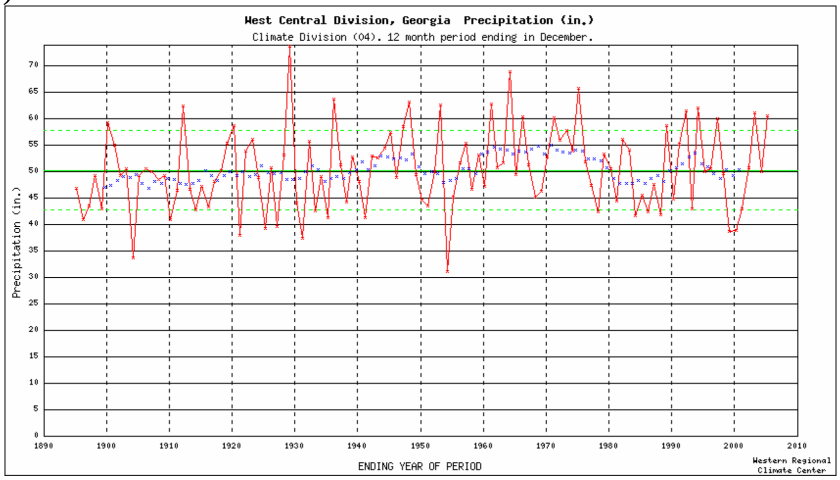
Temperature patterns for the SECN (Figure 2.7) show large fluctuations over the past century, with no obvious trend. The warmest temperatures on record in the SECN generally occurred during the 1920s and 1930s, even as late as the 1940s in portions of North Carolina. After a cooling in the 1960s, temperatures in the SECN 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.

Interannual climate variability in the southeastern U.S., including the SECN, is influenced by ENSO (NAST 2001). Warm ENSO phases (El Niño events) tend to bring cooler and wetter winter conditions across this region. Increased occurrences of severe thunderstorms are also evident in the SECN during warm ENSO phases, particularly in the winter and spring months. Hurricanes and other tropical storm activity tend to decrease in the SECN during warm ENSO phases.

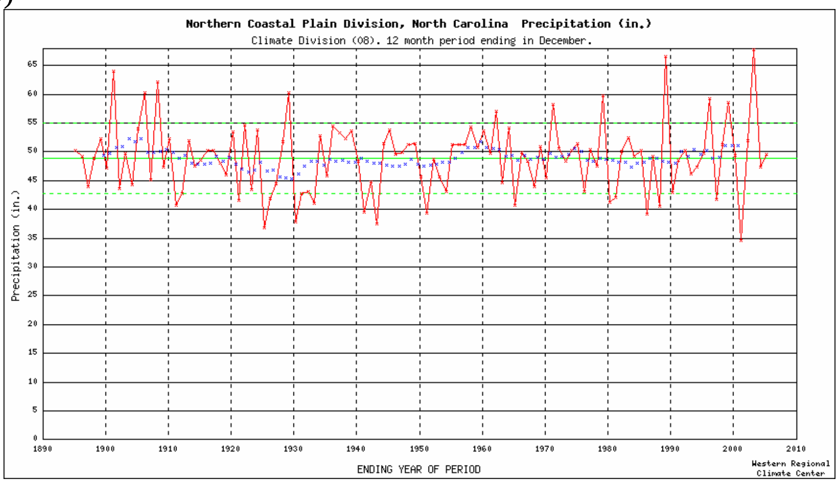
2.4. Parameter Regression on Independent Slopes Model

The climate maps presented here were generated using the Parameter Regression on Independent Slopes Model (PRISM). This model was developed to address the extreme spatial and elevation gradients exhibited by the climate of the U.S. (Daly et al. 1994; 2002; Gibson et al. 2002; Doggett et al. 2004). The maps produced through PRISM have undergone rigorous evaluation in the entire 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)

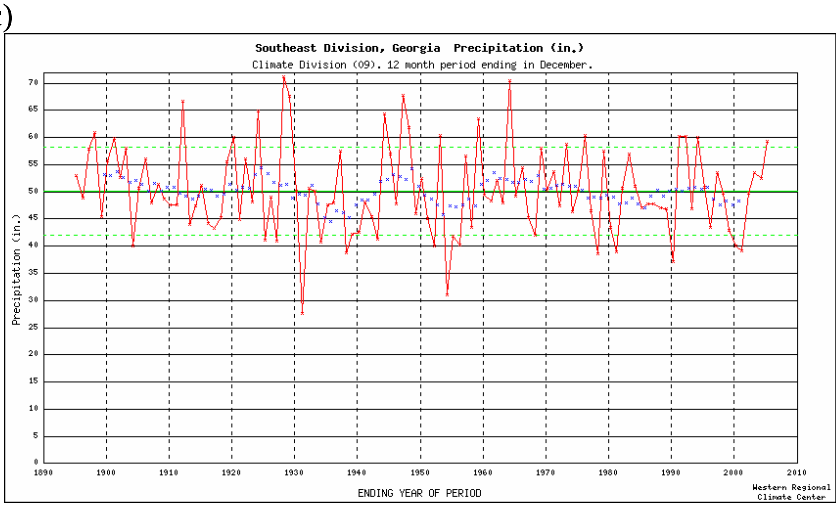
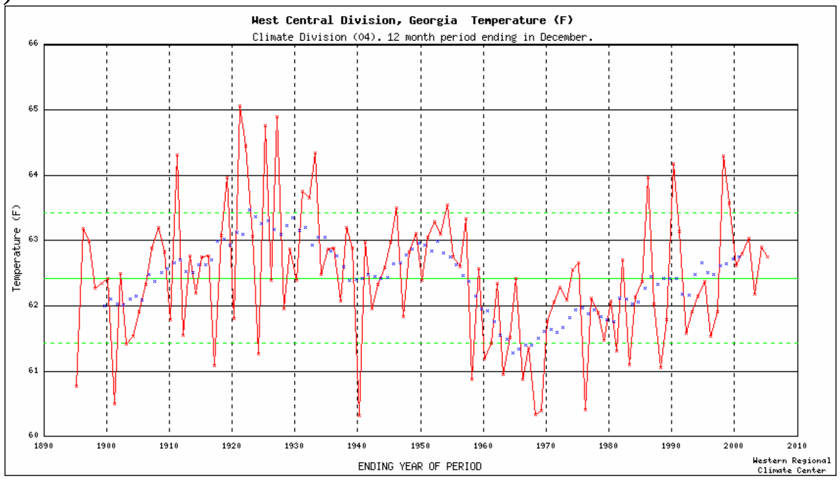
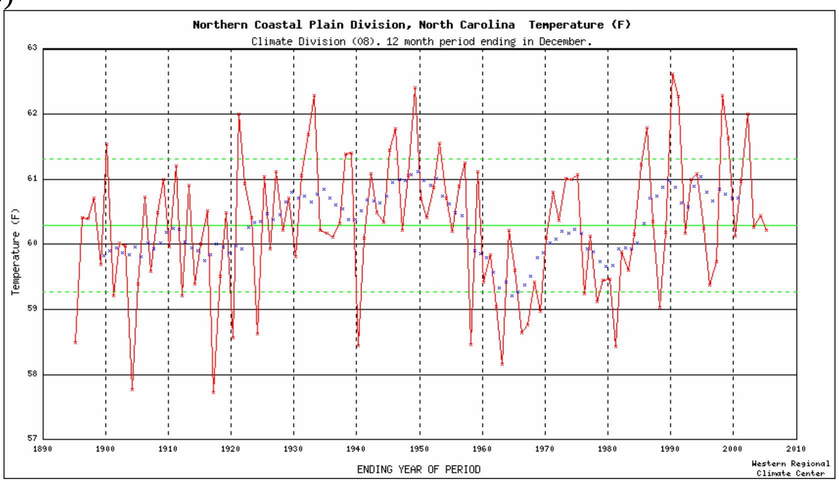


Figure 2.6. Precipitation time series, 1895-2005, for selected regions in the SECN. These include twelve-month precipitation (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include western Georgia (a), the northern North Carolina Coast (b), and the coast of Georgia (c).

a)



b)



c)

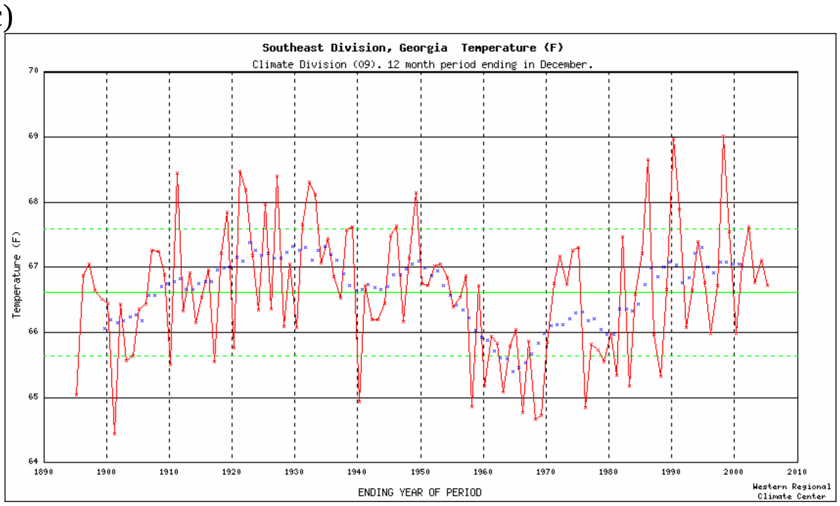


Figure 2.7. Temperature time series, 1895-2005, for selected regions in the SECN. These include twelve-month average temperature (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include western Georgia (a), the northern North Carolina Coast (b), and the coast of Georgia (c).

3.0. Methods

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

3.1. Metadata Retrieval

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

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

The primary source of metadata at WRCC is the Applied Climate Information System (ACIS), a joint effort among RCCs and other NOAA entities. Metadata for SECN weather/climate stations identified from the ACIS database are available in file "SECN_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. We have also relied on information supplied at various times in the past by the BLM, NPS, NCDC, and NWS.

Table 3.1. Primary metadata fields for SECN weather/climate stations. Explanations are provided as appropriate.

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

Two types of information have been used to complete the SECN 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, poor metadata, or poor access to metadata..
- Real-time networks having poor access to real-time data.

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

3.2. Criteria for Locating Stations

To identify stations for each park unit in the SECN, we selected all weather and climate stations, past and present, which were located inside SECN park units or within 30 km of a SECN park-unit boundary. We selected a 30-km buffer in order to ensure the inclusion of a sufficient number of both manual and automated stations in and near the park units in the SECN, 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 SECN. 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 SECN region in relation to the boundaries of the NPS park units within the SECN. 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 SECN 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 SECN.

Acronym	Name
CASTNet	Clean Air Status and Trends Network
COOP	NWS Cooperative Observer Program
CRN	NOAA Climate Reference Network
CWOP	Citizen Weather Observer Program
FAWN	Florida Automated Weather Network
GPMP	Gaseous Pollutant Monitoring Program
GPS-MET	NOAA ground-based GPS meteorology
NADP	National Atmospheric Deposition Program
RAWS	Remote Automated Weather Station network
SAO	NWS/FAA Surface Airways Observation 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. Florida Automated Weather Network (FAWN)

The FAWN network was initiated in Florida in the late 1990s in response to funding cutbacks at NWS in the area of localized weather information for agriculture, including frost and freeze warnings. Today FAWN provides useful weather data for Florida farmers and growers, primarily for daily management decisions. FAWN is also being used as a source of weather information for the general public.

4.1.6. 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.

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

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

4.1.8. 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 USGS and USDA. This network includes the Mercury Deposition Network (MDN). Precipitation is the primary climate parameter measured at NADP sites.

4.1.9. 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.

4.1.10. 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.

4.1.11. Weather For You Network (WX4U)

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

4.1.12. 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 SECN 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)
- 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 SECN (discussed in Section 4.1) have at most a few stations that are inside each park unit (Table 4.2). Cape Hatteras National Seashore (CAHA) and Congaree National Park (CONG) have the greatest number of stations inside park boundaries (four).

Table 4.2. Number of stations within or nearby SECN 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	CAHA	CALO	CANA	CASA	CHAT	CHPI	CONG	CUIS	FOCA	FOFR
CASTNet	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
COOP	**13**(3)	**8**(0)	**8**(0)	**7**(0)	**28**(0)	**9**(0)	**14**(0)	**6**(0)	**7**(0)	**6**(0)
CRN	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)
CWOP	**4**(0)	**5**(0)	**11**(0)	**4**(0)	**41**(0)	**2**(0)	**4**(0)	**8**(0)	**18**(0)	**3**(0)
FAWN	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
GPMP	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(2)	**0**(0)	**0**(0)	**0**(0)
GPS-MET	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(0)	**0**(0)
NADP	**0**(0)	**1**(0)	**1**(0)	**0**(0)	**1**(0)	**2**(0)	**1**(1)	**1**(0)	**0**(0)	**2**(1)
RAWS	**2**(0)	**2**(0)	**1**(0)	**0**(0)	**2**(0)	**0**(0)	**2**(1)	**1**(1)	**0**(0)	**2**(0)
SAO	**5**(1)	**5**(1)	**5**(0)	**1**(0)	**9**(0)	**4**(0)	**7**(0)	**3**(0)	**5**(0)	**3**(0)
WX4U	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**6**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
Other	**5**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**2**(0)	**2**(0)	**1**(0)	**1**(0)	**1**(0)
Total	**29**(4)	**23**(1)	**28**(0)	**14**(0)	**88**(0)	**19**(0)	**32**(4)	**22**(2)	**32**(0)	**17**(1)

Network	FOMA	FOPU	FORA	FOSU	HOBE	KEMO	MOCR	OCMU	TIMU	WRBR
CASTNet	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
COOP	**7**(0)	**11**(0)	**6**(0)	**10**(0)	**11**(0)	**26**(0)	**9**(1)	**8**(0)	**8**(0)	**5**(1)
CRN	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)
CWOP	**2**(0)	**4**(0)	**3**(0)	**2**(0)	**2**(0)	**27**(0)	**1**(0)	**5**(0)	**20**(0)	**3**(0)
FAWN	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
GPMP	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
GPS-MET	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**1**(0)	**1**(0)	**0**(0)
NADP	**0**(0)	**1**(0)	**0**(0)	**2**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
RAWS	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**2**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)
SAO	**1**(0)	**5**(0)	**2**(0)	**4**(0)	**1**(0)	**8**(0)	**1**(0)	**3**(0)	**5**(0)	**2**(1)
WX4U	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**4**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
Other	**0**(0)	**2**(0)	**3**(0)	**2**(0)	**0**(0)	**2**(0)	**3**(0)	**1**(0)	**1**(0)	**4**(0)
Total	**11**(0)	**25**(0)	**14**(0)	**20**(0)	**14**(0)	**70**(0)	**15**(1)	**19**(0)	**36**(0)	**14**(2)

Lists of stations have been compiled for the SECN. As previously stated, 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.

4.2.1. North Carolina

Four stations were identified within CAHA (Table 4.3), all of which are active currently. The COOP station "Cape Hatteras Billy Mitchell Arpt." has a very complete data record that begins in 1957. A SAO station is co-located with this COOP station. The other two COOP stations we identified within CAHA ("Nags Head 4 S" and "Oregon Inlet") have data records that are of unknown quality.

Five of the 10 COOP stations we identified within 30 km of CAHA are currently active (Table 4.3). These stations all have data records beginning in the 1950s or later. "Cedar Island" (1955-present) provides the longest data record among these active COOP stations. This data record is very complete. One long-term COOP station (Hatteras) discontinued observations as of 2004. Although this station had a large data gap in the late 1980s and early 1990s, it provided a valuable long-term climate record for the region, so the station's closure is unfortunate.

The primary sources for near-real-time weather data within 30 km of CAHA come from SAO stations. The two RAWS stations we identified (Table 4.3) are no longer active. The SAO stations "Oregon Inlet Stn." and "Okracoke Station" are located just outside of CAHA (Figure 4.1). The SAO station "Kill Devil Hills First Flight" is 14 km north of CAHA. Finally, the SAO station "Diamond Shoals Light Stn." is 22 km southeast of CAHA, in the open waters of the Atlantic Ocean.

One station was identified within CALO (Table 4.3). This is an active SAO station (Cape Lookout L.S.) that has been active since 1935. This station is located at the southwest end of CALO (Figure 4.1).

Outside of CALO, we identified eight COOP stations within 30 km of the park unit boundary. Five of these stations are currently active (Table 4.3). The closest active COOP station to CALO is "Okracoke," which is 7 km northeast of CALO (Figure 4.1). The COOP station with the longest record within 30 km of CALO, "Morehead City 2 WNW," has been making observations since 1948 and its data record is very complete. This station is 8 km northwest of CALO. Another reliable long-term data record comes from the COOP station "Cedar Island" (1955-present), discussed previously. This station is 9 km northwest of CALO.

Several reliable stations within 30 km of CALO provide near-real-time data for the park unit. The CASTNet station "Beaufort" is 21 km northwest of CALO (Figure 4.1) and has been operating since 1993 (Table 4.3). Two RAWS sites have been identified within 30 km of CALO. Only "Croatan" is still active. Four SAO stations were identified for CALO. "Beaufort Smith

Table 4.3. Weather/climate stations for the SECN park units in North Carolina. Stations inside park units and within 30 km of the park unit boundary are included. Missing entries are indicated by "M".

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Cape Hatteras National Seashore – CAHA							
Cape Hatteras Billy Mitchell Arpt.	35.233	-75.622	3	COOP	3/1/1957	Present	Yes
Nags Head 4 S	35.900	-75.600	2	COOP	10/17/1957	Present	Yes
Oregon Inlet	35.800	-75.550	0	COOP	M	Present	Yes
Cape Hatteras Billy Mitchell Arpt.	35.233	-75.622	3	SAO	3/1/1957	Present	Yes
Bodie Island	35.833	-75.550	2	COOP	1/1/1955	10/31/1976	No
Cedar Island	34.983	-76.300	2	COOP	10/1/1955	Present	No
Frisco	35.260	-75.583	2	COOP	10/1/2005	Present	No
Hatteras	35.217	-75.717	5	COOP	1/1/1893	6/1/2004	No
Kill Devil Hills N M	36.017	-75.667	3	COOP	7/17/1943	1/1/1977	No
Lola	34.950	-76.283	3	COOP	5/1/1950	10/31/1955	No
Manteo	35.917	-75.683	3	COOP	7/1/1929	4/1/1967	No
Manteo Arpt.	35.917	-75.700	4	COOP	4/1/1966	Present	No
Ocracoke	35.108	-75.987	1	COOP	5/1/1957	Present	No
Ocracoke Station	35.117	-75.983	2	COOP	4/1/1963	Present	No
CW1848 Southern Shores	36.105	-75.721	11	CWOP	M	Present	No
CW4967 Ocracoke	35.113	-75.973	4	CWOP	M	Present	No
K4OBX Rothanthe	35.582	-75.467	1	CWOP	M	Present	No
KF4UXI Southern Shores	36.096	-75.733	9	CWOP	M	Present	No
Alligator River NWR	35.513	-75.523	2	RAWS	2/1/2003	5/31/2005	No
Cedar Island	35.002	-76.297	2	RAWS	2/1/2003	5/31/2005	No
Diamond Shoals Light Stn.	35.150	-75.300	1	SAO	4/1/1966	Present	No
Kill Devil Hills First Flight	36.018	-75.671	4	SAO	1/15/2004	Present	No
Ocracoke Station	35.117	-75.983	2	SAO	4/1/1963	Present	No
Oregon Inlet Stn.	35.767	-75.517	13	SAO	7/1/1939	Present	No
Cape Hatteras	35.250	-75.517	3	WBAN	8/1/1931	3/31/1933	No
Diamond Shoals Lightship	35.083	-75.333	6	WBAN	1/26/1915	11/7/1966	No
Kill Devil Hills	36.017	-75.650	5	WBAN	7/1/1943	12/31/1946	No
Manteo	35.900	-75.667	3	WBAN	11/1/1904	12/31/1929	No
Manteo NAAS	35.917	-75.700	4	WBAN	3/1/1945	12/31/1945	No
Cape Lookout National Seashore – CALO							
Cape Lookout L.S.	34.600	-76.533	4	SAO	9/1/1935	Present	Yes
Beaufort	34.885	-76.620	2	CASTNet	12/1/1993	Present	No
Atlantic	34.883	-76.333	2	COOP	6/1/1957	4/30/1965	No
Atlantic Beach	34.700	-76.750	1	COOP	11/1/1962	Present	No
Atlantic Beach Water Plant	34.700	-76.738	1	COOP	12/12/2003	Present	No
Cedar Island	34.983	-76.300	2	COOP	10/1/1955	Present	No
Lola	34.950	-76.283	3	COOP	5/1/1950	10/31/1955	No
Morehead City 2 WNW	34.734	-76.736	3	COOP	4/8/1948	Present	No
Ocracoke	35.108	-75.987	1	COOP	5/1/1957	Present	No
Ocracoke Station	35.117	-75.983	2	COOP	4/1/1963	Present	No
CW2132 Havelock	34.932	-76.692	3	CWOP	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
CW2541 Morehead City	34.725	-76.761	8	CWOP	M	Present	No
CW2542 Newport	34.727	-76.943	7	CWOP	M	Present	No
CW3784 Atlantic Beach	34.711	-76.746	1	CWOP	M	Present	No
CW4967 Ocracoke	35.113	-75.973	4	CWOP	M	Present	No
Beaufort	34.885	-76.621	2	NADP	1/26/1999	Present	No
Cedar Island	35.002	-76.297	2	RAWS	2/1/2003	5/31/2005	No
Croatan	34.783	-76.867	6	RAWS	2/1/2003	Present	No
Beaufort Smith Field	34.734	-76.661	3	SAO	5/1/1949	Present	No
Cherry Point MCAS	34.900	-76.883	11	SAO	7/1/1942	Present	No
Ocracoke Station	35.117	-75.983	2	SAO	4/1/1963	Present	No
Otway	34.776	-76.558	2	WX4U	M	Present	No
Fort Raleigh National Historic Site – FOR A							
Bodie Island	35.833	-75.550	2	COOP	1/1/1955	10/31/1976	No
Kill Devil Hills N M	36.017	-75.667	3	COOP	7/17/1943	1/1/1977	No
Manteo	35.917	-75.683	3	COOP	7/1/1929	4/1/1967	No
Manteo Arpt.	35.917	-75.700	4	COOP	4/1/1966	Present	No
Nags Head 4 S	35.900	-75.600	2	COOP	10/17/1957	Present	No
Oregon Inlet	35.800	-75.550	0	COOP	M	Present	No
CW1848 Southern Shores	36.105	-75.721	11	CWOP	M	Present	No
CW3038 Duck	36.200	-75.760	7	CWOP	M	Present	No
KF4UXI Southern Shores	36.096	-75.733	9	CWOP	M	Present	No
Kill Devil Hills First Flight	36.018	-75.671	4	SAO	1/15/2004	Present	No
Oregon Inlet Stn.	35.767	-75.517	13	SAO	7/1/1939	Present	No
Kill Devil Hills	36.017	-75.650	5	WBAN	7/1/1943	12/31/1946	No
Manteo	35.900	-75.667	3	WBAN	11/1/1904	12/31/1929	No
Manteo NAAS	35.917	-75.700	4	WBAN	3/1/1945	12/31/1945	No
Moores Creek National Battlefield – MOCR							
Moores Creek National Battlefield	34.459	-78.108	8	COOP	1/2/2000	Present	Yes
Burgaw Ag. 1 S	34.549	-77.972	15	COOP	10/15/1993	Present	No
Cape Fear L & D	34.403	-78.293	15	COOP	6/1/1969	2/11/2005	No
East Arcadia 2 NE	34.399	-78.316	16	COOP	1/4/2005	Present	No
Ivanhoe 8 S	34.538	-78.276	15	COOP	2/18/2000	12/1/2003	No
Willard 4 SW	34.653	-78.049	17	COOP	9/1/1907	Present	No
Wilmington	34.233	-77.950	14	COOP	8/1/1888	10/2/1951	No
Wilmington 7 N	34.321	-77.921	12	COOP	7/1/1949	Present	No
Wilmington Intl. Arpt.	34.268	-77.900	10	COOP	1/1/1933	Present	No
CW3321 Leland	34.246	-78.032	11	CWOP	M	Present	No
Castle-Hayne	34.340	-77.880	20	GPS-MET	M	Present	No
Wilmington Intl. Arpt.	34.268	-77.900	10	SAO	1/1/1933	Present	No
Bluethenthal AAF	34.267	-77.900	10	WBAN	6/1/1942	8/31/1951	No
Wallace	34.717	-78.033	M	WBAN	1/1/1978	12/31/1978	No
Wilmington	34.217	-77.950	M	WBAN	1/1/1978	12/31/1978	No
Wright Brothers National Memorial – WRBR							
Kill Devil Hills N M	36.017	-75.667	3	COOP	7/17/1943	1/1/1977	Yes

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Kill Devil Hills First Flight	36.018	-75.671	4	SAO	1/15/2004	Present	Yes
Bodie Island	35.833	-75.550	2	COOP	1/1/1955	10/31/1976	No
Manteo	35.917	-75.683	3	COOP	7/1/1929	4/1/1967	No
Manteo Arpt.	35.917	-75.700	4	COOP	4/1/1966	Present	No
Nags Head 4 S	35.900	-75.600	2	COOP	10/17/1957	Present	No
Oregon Inlet	35.800	-75.550	0	COOP	M	Present	No
CW1848 Southern Shores	36.105	-75.721	11	CWOP	M	Present	No
CW3038 Duck	36.200	-75.760	7	CWOP	M	Present	No
KF4UXI Southern Shores	36.096	-75.733	9	CWOP	M	Present	No
Oregon Inlet Stn.	35.767	-75.517	13	SAO	7/1/1939	Present	No
Caffeys Inlet	36.217	-75.767	3	WBAN	5/1/1939	12/31/1944	No
Kill Devil Hills	36.017	-75.650	5	WBAN	7/1/1943	12/31/1946	No
Manteo	35.900	-75.667	3	WBAN	11/1/1904	12/31/1929	No
Manteo NAAS	35.917	-75.700	4	WBAN	3/1/1945	12/31/1945	No

Field" is only about 5 km north of the west end of CALO, while "Okracoke Station" is about 7 km northeast of CALO. The remaining two SAO stations we identified are located at Cherry Point Marine Corps Air Strip, 30 km northwest of CALO. In addition to these, five CWOP stations and one WX4U station also provide near-real-time weather data in the vicinity of CALO.

We have identified no stations within FORA (Table 4.3). Of the six COOP stations that have been identified within 30 km of FORA, three are active currently. The closest active COOP station to FORA is "Manteo Arpt.," 2 km southeast of FORA. This station has been operating since 1967. The longest record of the COOP stations identified for FORA comes from "Nags Head 4 S," with observations starting in 1957. This station is 10 km east of FORA. The COOP station "Oregon Inlet" is located 20 km southeast of FORA.

The primary sources of near-real-time weather data within 30 km of FORA are the SAO station "Kill Devil Hills First Flight," 9 km northeast of the park unit, and the SAO station "Oregon Inlet Stn.," located 25 km southeast of the park unit (Figure 4.1). The SAO station at Oregon Inlet also has a long data record (1939-present) that is useful for climate analyses. Three CWOP stations within 30 km of FORA also provide near-real-time data (Table 4.3).

We identified one station within MOCR (Table 4.3). This is an active COOP station (Moores Creek National Battlefield) that has been taking measurements since 2000. Outside of MOCR, we have identified eight COOP stations, five of which are active, within 30 km of the park unit. The longest data record from these COOP stations comes from "Willard 4 SW," which is 22 km northeast of MOCR. This record starts in 1907 and is very complete. Another very complete data record comes from the COOP station "Wilmington Intl. Arpt.," which is 28 km southeast of MOCR and has been active since 1933. This site also hosts a SAO station that is the primary source of near-real-time weather data we have identified for MOCR.

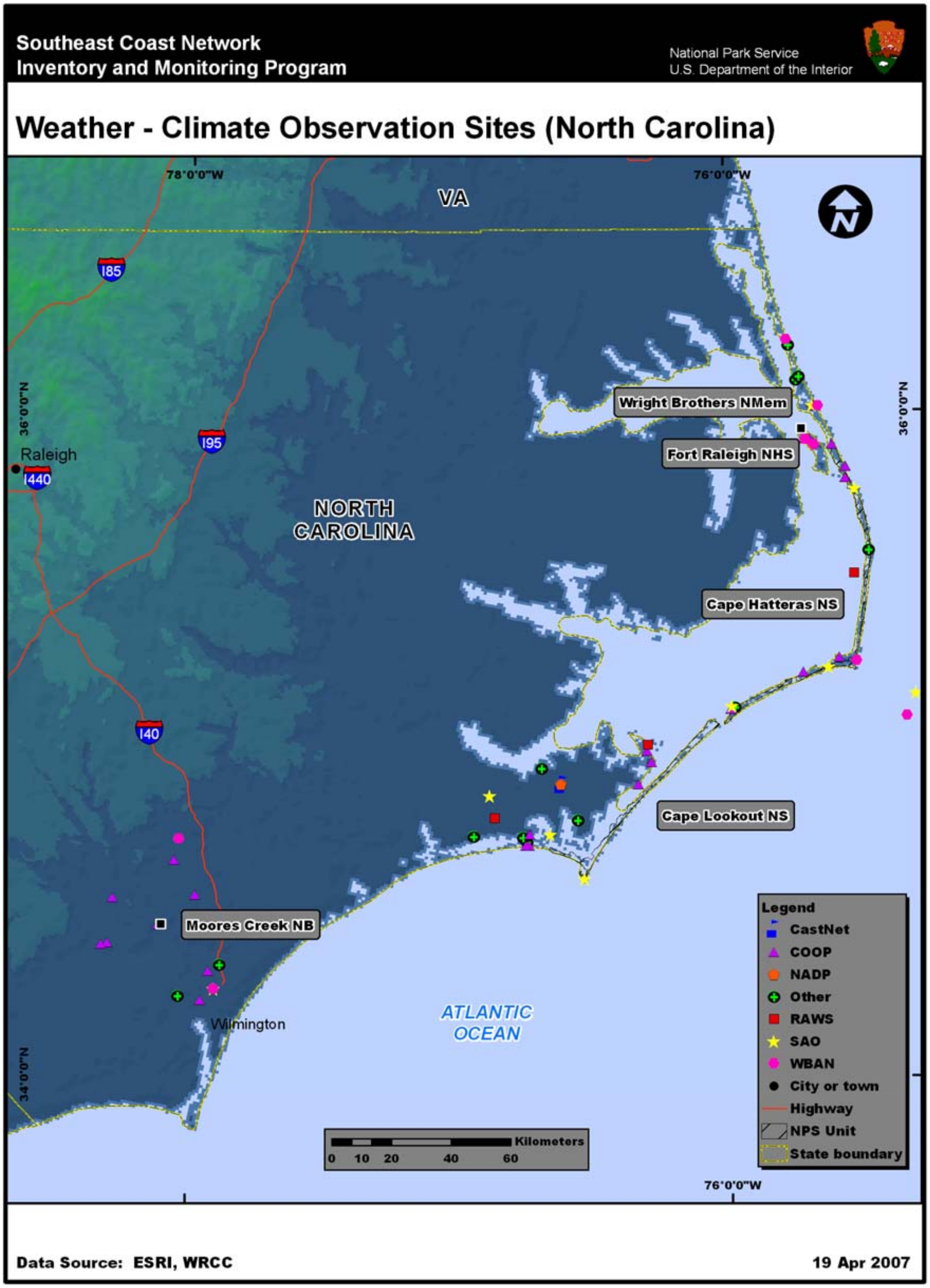


Figure 4.1. Station locations for SECN park units in North Carolina.

Two weather/climate stations have been identified within WRBR. Only one of these is currently active, however (Table 4.3). The active station is the SAO station “Kill Devil Hills First Flight,” mentioned previously. The COOP station identified within WRBR (Kill Devil Hills N M) was active from 1943 to 1977.

We have identified five COOP stations outside of WRBR that are within 30 km of the park unit. Three of these are active (Table 4.3). The closest active COOP station, “Manteo Arpt.,” is 10 km south of the park unit and has been mentioned previously. The COOP station “Nags Head 4 S”, mentioned previously, is 14 km southeast of WRBR and has the longest data record of these stations, with observations starting in 1957. This station has been discussed previously. The SAO station “Oregon Inlet Stn.,” 30 km southeast of WRBR (Figure 4.1), is the primary source of near-real-time weather observations outside of WRBR. This station has also been discussed previously.

4.2.2. Florida and Georgia Coasts

We identified no weather/climate stations within CANA (Table 4.4). The closest source of reliable weather/climate information for CANA is the COOP station “Titusville 7 E,” located 3 km southwest of CANA. Six of the eight COOP stations we identified within 30 km of CANA are active currently. Of these, “Titusville” has the longest data record, with observations beginning in 1888. This data record is largely complete, although notable data gaps occurred from April 1978 to August 1979 and in May 1997. The COOP station “Daytona Beach Intl. Arpt.,” located 30 km northwest of CANA, has a very complete data record that begins in 1938. The nearby COOP station “Daytona Beach” has a longer record (1923-present) but it is not as reliable.

A NADP station is located at Kennedy Space Center, 12 km south of CANA. In addition, several stations provide near-real-time data within 30 km of CANA. The RAWS station “Merritt Island” is 19 km southwest of CANA (Figure 4.2). Five SAO stations provide near-real-time data in this area (Table 4.4). The longest available record is at “Daytona Beach” (1938-present). The remaining SAO stations are located near Cape Kennedy or Titusville, southwest of CANA. Other sources for near-real-time data around CANA include 11 CWOP stations and one WX4U station.

No stations were identified within CASA (Table 4.4). Outside of CASA, the closest active COOP station is “St. Augustine Lighthouse,” which is located 2 km from CASA. This station has a data record that begins in 1952, but the record is largely incomplete until April 1973. The longest data record we identified within 30 km of CASA is at the COOP station “Federal Point,” located 27 km southwest of CASA. This station’s data record has several scattered gaps in the late 1960s and early 1970s, with a significant data gap also from March 1999 to February 2000. The COOP station “Marineland” (1948-present), located 27 km south of CASA, has a data record of uncertain quality.

The FAWN station “Hastings” and the SAO station “St. Augustine Arpt.” are the primary sources for near-real-time weather data within 30 km of CASA. “Hastings is located 26 km southwest of CASA, while “St. Augustine Arpt.” is located 7 km northwest of CASA (Figure 4.2). In addition to these, at least four CWOP stations and one WX4U stations also provide near-real-time weather data within 30 km of CASA (Table 4.4).

Table 4.4. Weather/climate stations for the SECN park units along the Florida and Georgia coasts. Stations inside park units and within 30 km of the park unit boundary are included. Missing entries are indicated by “M”.

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Cape Canaveral National Seashore – CANA							
Daytona Beach	29.189	-81.014	9	COOP	2/1/1923	Present	No
Daytona Beach Intl. Arpt.	29.183	-81.048	9	COOP	1/1/1938	Present	No
New Smyrna Beach	29.050	-80.950	3	COOP	11/1/1892	5/31/1973	No
Ponce De Leon Inlet	29.067	-80.917	3	COOP	8/11/1957	2/1/1974	No
Ponce Inlet	29.066	-80.915	2	COOP	10/4/2001	Present	No
Scottsmoor 2 NNW	28.788	-80.882	9	COOP	6/2/2000	Present	No
Titusville	28.624	-80.816	2	COOP	1/1/1888	Present	No
Titusville 7 E	28.616	-80.693	1	COOP	5/6/2005	Present	No
CW0587 Merritt Island	28.426	-80.715	2	CWOP	M	Present	No
CW2689 Titusville	28.512	-80.860	5	CWOP	M	Present	No
CW2783 Port Orange	29.121	-80.974	2	CWOP	M	Present	No
CW3545 Titusville	28.560	-80.812	15	CWOP	M	Present	No
CW5909 Port St. John	28.462	-80.813	8	CWOP	M	Present	No
K4NBR Mims	28.711	-80.910	5	CWOP	M	Present	No
K4PIG Merritt Island	28.377	-80.713	3	CWOP	M	Present	No
KC6TYC Port St. John	28.484	-80.803	10	CWOP	M	Present	No
KG4ZVW Merritt Island	28.426	-80.712	2	CWOP	M	Present	No
N4PLT Edgewater	28.954	-80.899	4	CWOP	M	Present	No
W9TT-10 Daytona Beach	29.110	-80.994	11	CWOP	M	Present	No
Cape Canaveral	28.460	-80.550	4	GPS-MET	M	Present	No
Kennedy Space Center	28.543	-80.644	2	NADP	8/2/1983	Present	No
Merritt Island	28.474	-80.731	9	RAWS	6/1/2002	Present	No
Cape Kennedy AFS	28.483	-80.567	5	SAO	5/1/1950	Present	No
Daytona Beach Intl. Arpt.	29.183	-81.048	9	SAO	1/1/1938	Present	No
Ponce De Leon Inlet	29.067	-80.917	3	SAO	8/11/1957	2/1/1974	No
Titusville NASA Shuttle Landing	28.617	-80.683	4	SAO	3/1/1978	Present	No
Titusville Space Center Exec. Arpt.	28.517	-80.800	11	SAO	1/1/1970	Present	No
Port St. John Cocoa	28.484	-80.803	11	WX4U	M	Present	No
Castillo de San Marcos National Monument – CASA							
Federal Point	29.755	-81.539	2	COOP	1/1/1892	Present	No
Hastings	29.800	-81.583	3	COOP	6/1/1924	7/31/1944	No
Hastings 4 NE	29.752	-81.467	3	COOP	11/1/1977	Present	No
Marineland	29.670	-81.215	2	COOP	8/1/1948	Present	No
St. Augustine	29.883	-81.333	6	COOP	7/1/1892	4/1/1973	No
St. Augustine Beach	29.833	-81.267	3	COOP	1/1/1949	8/31/1953	No
St. Augustine Lighthouse	29.888	-81.292	4	COOP	8/19/1952	Present	No
CW0777 St Augustine	30.055	-81.517	9	CWOP	M	Present	No
CW4561 St Augustine	30.046	-81.554	10	CWOP	M	Present	No
KD4QOF St. Augustine	29.859	-81.335	12	CWOP	M	Present	No
W4LGH St. Augustine	30.057	-81.500	6	CWOP	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Hastings	29.693	-81.445	8	FAWN	M	Present	No
St. Augustine Arpt.	29.959	-81.340	3	SAO	8/10/1990	Present	No
Sampson St. Augustine	30.064	-81.502	8	WX4U	M	Present	No
Cumberland Island National Seashore – CUIS							
Brunswick 23 S	30.813	-81.466	18	CRN	12/16/2004	Present	Yes
Stafford-CUIS	30.917	-81.429	8	RAWS	2/1/2003	Present	Yes
Brunswick	31.168	-81.502	4	COOP	1/1/1895	Present	No
Brunswick Malcolm McKinnon Arpt.	31.152	-81.391	5	COOP	4/1/1931	Present	No
Fernandina Beach	30.659	-81.464	4	COOP	1/1/1892	Present	No
Jacksonville Intl. Arpt.	30.495	-81.694	8	COOP	12/1/1928	Present	No
St. Simons Island	31.133	-81.367	5	COOP	6/1/1970	Present	No
Woodbine	30.959	-81.707	5	COOP	12/1/1997	Present	No
CW0041 Brunswick	31.237	-81.495	5	CWOP	M	Present	No
CW2050 Fernandina Beach	30.649	-81.445	5	CWOP	M	Present	No
CW2861 Jacksonville	30.462	-81.627	3	CWOP	M	Present	No
CW3184 Jekyll Island	31.090	-81.410	12	CWOP	M	Present	No
CW4676 Saint Marys	30.748	-81.605	7	CWOP	M	Present	No
KD4NUD Jekyll Is.	31.089	-81.418	5	CWOP	M	Present	No
WK1F-2 Yulee	30.665	-81.539	9	CWOP	M	Present	No
WX4JAX Jacksonville	30.484	-81.700	10	CWOP	M	Present	No
Jacksonville	30.480	-81.700	9	GPS-MET	M	Present	No
Fort Frederica NM	31.225	-81.392	2	NADP	9/3/1985	9/27/1988	No
Brunswick Glynn Co. Arpt.	31.250	-81.467	9	SAO	2/1/1943	Present	No
Brunswick Malcolm McKinnon Arpt.	31.152	-81.391	5	SAO	4/1/1931	Present	No
Jacksonville Intl. Arpt.	30.495	-81.694	8	SAO	12/1/1928	Present	No
St. Simons Island NAS	31.167	-81.400	3	WBAN	2/1/1943	4/30/1947	No
Fort Caroline National Memorial – FOCA							
Fernandina Beach	30.659	-81.464	4	COOP	1/1/1892	Present	No
Jacksonville	30.333	-81.650	25	COOP	10/1/1871	12/31/1956	No
Jacksonville Beach	30.290	-81.392	3	COOP	7/24/1944	Present	No
Jacksonville Beach E	30.283	-81.417	0	COOP	M	Present	No
Jacksonville Craig Muni. Arpt.	30.336	-81.515	12	COOP	10/1/1970	Present	No
Jacksonville Intl. Arpt.	30.495	-81.694	8	COOP	12/1/1928	Present	No
Mayport Pilot Stn.	30.400	-81.417	5	COOP	7/1/1955	Present	No
AA4QI Jacksonville	30.298	-81.645	4	CWOP	M	Present	No
CW0569 Jacksonville	30.361	-81.560	12	CWOP	M	Present	No
CW0639 Jacksonville	30.256	-81.704	4	CWOP	M	Present	No
CW2050 Fernandina Beach	30.649	-81.445	5	CWOP	M	Present	No
CW2098 Jacksonville	30.383	-81.517	28	CWOP	M	Present	No
CW2292 Jacksonville	30.260	-81.646	6	CWOP	M	Present	No
CW2595 Palm Valley	30.188	-81.387	8	CWOP	M	Present	No
CW2703 Jacksonville	30.305	-81.735	4	CWOP	M	Present	No
CW2742 Jacksonville	30.194	-81.537	10	CWOP	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
CW2861 Jacksonville	30.462	-81.627	3	CWOP	M	Present	No
CW4513 Jacksonville	30.281	-81.482	8	CWOP	M	Present	No
CW4840 Jacksonville	30.388	-81.650	3	CWOP	M	Present	No
CW4952 Jacksonville	30.213	-81.602	9	CWOP	M	Present	No
KD4MWO Holly Ford	30.412	-81.653	4	CWOP	M	Present	No
KS4KP-5 Jacksonville	30.133	-81.632	2	CWOP	M	Present	No
N6EIV W. Jacksonville	30.244	-81.746	8	CWOP	M	Present	No
W4EDP Jacksonville	30.129	-81.613	2	CWOP	M	Present	No
WX4JAX Jacksonville	30.484	-81.700	10	CWOP	M	Present	No
Jacksonville	30.480	-81.700	9	GPS-MET	M	Present	No
Jacksonville Craig Muni. Arpt.	30.336	-81.515	12	SAO	10/1/1970	Present	No
Jacksonville Herlong Arpt.	30.278	-81.437	27	SAO	M	Present	No
Jacksonville Intl. Arpt.	30.495	-81.694	8	SAO	12/1/1928	Present	No
Jacksonville NAS	30.233	-81.667	9	SAO	9/1/1941	Present	No
Mayport Pilot Stn.	30.400	-81.417	5	SAO	7/1/1955	Present	No
St. Johns Lightship	30.400	-81.300	5	WBAN	12/5/1929	12/31/1954	No
Fort Frederica National Monument – FOFR							
Fort Frederica NM	31.225	-81.392	2	NADP	9/3/1985	9/27/1988	Yes
Brunswick	31.168	-81.502	4	COOP	1/1/1895	Present	No
Brunswick Malcolm McKinnon Arpt.	31.152	-81.391	5	COOP	4/1/1931	Present	No
Darien	31.373	-81.437	4	COOP	2/1/1892	Present	No
Everett City	31.433	-81.600	6	COOP	5/1/1925	1/31/1944	No
Sapelo Island	31.397	-81.281	3	COOP	5/1/1957	Present	No
St. Simons Island	31.133	-81.367	5	COOP	6/1/1970	Present	No
CW0041 Brunswick	31.237	-81.495	5	CWOP	M	Present	No
CW3184 Jekyll Island	31.090	-81.410	12	CWOP	M	Present	No
KD4NUD Jekyll Is.	31.089	-81.418	5	CWOP	M	Present	No
Sapelo Island	31.396	-81.281	3	NADP	11/26/2002	Present	No
Stafford-CUIS	30.917	-81.429	8	RAWS	2/1/2003	Present	No
Sterling	31.257	-81.611	2	RAWS	2/1/2003	Present	No
Brunswick Glynco Jetport Arpt.	31.259	-81.466	8	SAO	10/1/1998	Present	No
Brunswick Glynn Co. Arpt.	31.250	-81.467	9	SAO	2/1/1943	Present	No
Brunswick Malcolm McKinnon Arpt.	31.152	-81.391	5	SAO	4/1/1931	Present	No
St. Simons Island NAS	31.167	-81.400	3	WBAN	2/1/1943	4/30/1947	No
Fort Mantanzas National Monument – FOMA							
Federal Point	29.755	-81.539	2	COOP	1/1/1892	Present	No
Hastings 4 NE	29.752	-81.467	3	COOP	11/1/1977	Present	No
Marineland	29.670	-81.215	2	COOP	8/1/1948	Present	No
Palm Coast 6 NE	29.635	-81.206	2	COOP	10/1/1999	Present	No
St. Augustine	29.883	-81.333	6	COOP	7/1/1892	4/1/1973	No
St. Augustine Beach	29.833	-81.267	3	COOP	1/1/1949	8/31/1953	No
St. Augustine Lighthouse	29.888	-81.292	4	COOP	8/19/1952	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
CW3666 Palm Coast	29.500	-81.233	9	CWOP	M	Present	No
KD4QOF St. Augustine	29.859	-81.335	12	CWOP	M	Present	No
Hastings	29.693	-81.445	8	FAWN	M	Present	No
St. Augustine Arpt.	29.959	-81.340	3	SAO	8/10/1990	Present	No
Timucuan Ecological and Historical Preserve – TIMU							
Fernandina Beach	30.659	-81.464	4	COOP	1/1/1892	Present	No
Hilliard	30.700	-81.933	21	COOP	9/1/1908	8/31/1956	No
Jacksonville	30.333	-81.650	25	COOP	10/1/1871	12/31/1956	No
Jacksonville Beach	30.290	-81.392	3	COOP	7/24/1944	Present	No
Jacksonville Beach E.	30.283	-81.417	0	COOP	M	Present	No
Jacksonville Craig Muni. Arpt.	30.336	-81.515	12	COOP	10/1/1970	Present	No
Jacksonville Intl. Arpt.	30.495	-81.694	8	COOP	12/1/1928	Present	No
Mayport Pilot Stn.	30.400	-81.417	5	COOP	7/1/1955	Present	No
Brunswick 23 S	30.813	-81.466	18	CRN	12/16/2004	Present	No
AA4QI Jacksonville	30.298	-81.645	4	CWOP	M	Present	No
CW0569 Jacksonville	30.361	-81.560	12	CWOP	M	Present	No
CW0639 Jacksonville	30.256	-81.704	4	CWOP	M	Present	No
CW2050 Fernandina Beach	30.649	-81.445	5	CWOP	M	Present	No
CW2098 Jacksonville	30.383	-81.517	28	CWOP	M	Present	No
CW2292 Jacksonville	30.260	-81.646	6	CWOP	M	Present	No
CW2595 Palm Valley	30.188	-81.387	8	CWOP	M	Present	No
CW2703 Jacksonville	30.305	-81.735	4	CWOP	M	Present	No
CW2742 Jacksonville	30.194	-81.537	10	CWOP	M	Present	No
CW2861 Jacksonville	30.462	-81.627	3	CWOP	M	Present	No
CW4513 Jacksonville	30.281	-81.482	8	CWOP	M	Present	No
CW4676 Saint Marys	30.748	-81.605	7	CWOP	M	Present	No
CW4840 Jacksonville	30.388	-81.650	3	CWOP	M	Present	No
CW4952 Jacksonville	30.213	-81.602	9	CWOP	M	Present	No
CW4986 Jacksonville	30.329	-81.849	28	CWOP	M	Present	No
KD4MWO Holly Ford	30.412	-81.653	4	CWOP	M	Present	No
N6EIV W. Jacksonville	30.244	-81.746	8	CWOP	M	Present	No
W4EDP Jacksonville	30.129	-81.613	2	CWOP	M	Present	No
WK1F-2 Yulee	30.665	-81.539	9	CWOP	M	Present	No
WX4JAX Jacksonville	30.484	-81.700	10	CWOP	M	Present	No
Jacksonville	30.480	-81.700	9	GPS-MET	M	Present	No
Jacksonville Craig Muni. Arpt.	30.336	-81.515	12	SAO	10/1/1970	Present	No
Jacksonville Herlong Arpt.	30.278	-81.437	27	SAO	M	Present	No
Jacksonville Intl. Arpt.	30.495	-81.694	8	SAO	12/1/1928	Present	No
Jacksonville NAS	30.233	-81.667	9	SAO	9/1/1941	Present	No
Mayport Pilot Stn.	30.400	-81.417	5	SAO	7/1/1955	Present	No
St. Johns Lightship	30.400	-81.300	5	WBAN	12/5/1929	12/31/1954	No

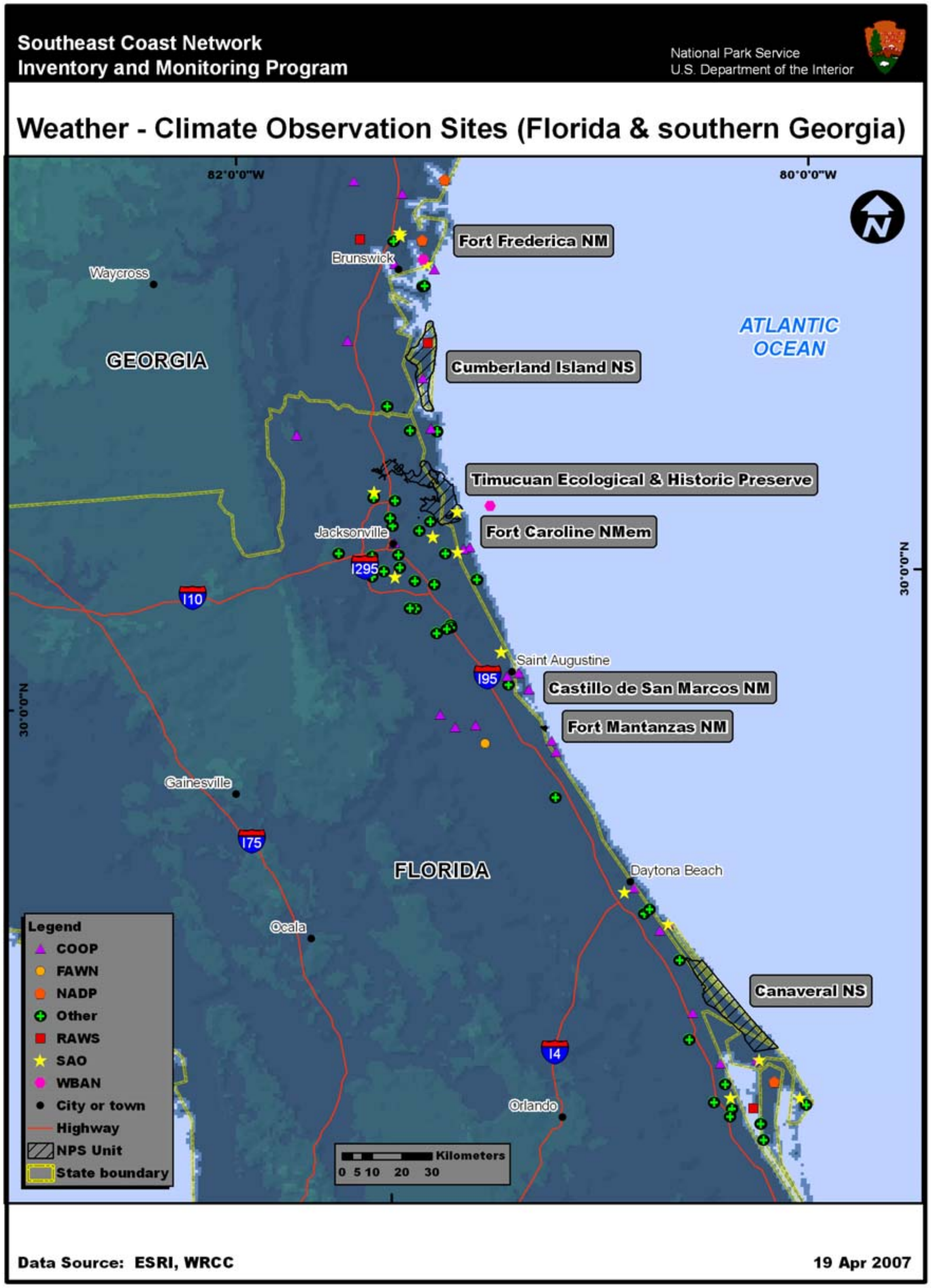


Figure 4.2. Station locations for SECN park units along the Florida and Georgia coasts.

Cumberland Island National Seashore (CUIS) has two stations within its boundaries that provide near-real-time weather data (Table 4.4). The CRN station “Brunswick 23 S” has been operational since 2004, while the RAWS station “Stafford-CUIS” has been operational since 2003.

Six COOP stations, all active, were identified within 30 km of CUIS (Table 4.4). The closest COOP station is “Fernandina Beach,” located 6 km south of the park unit. This COOP station also has the longest data record (1892-present) of the COOP stations identified for CUIS. This station has several data gaps in the early 1970s as well as a gap from March to May of 1991. The COOP station “Brunswick” is 22 km north of CUIS and has a reliable data record that only includes a few small gaps. The COOP station “Brunswick Malcolm McKinnon Arpt.” is 19 km north of CUIS and has a very complete data record that starts in 1931. The COOP station “Jacksonville Intl. Arpt.” is 29 km southwest of CUIS and has a very complete data record that begins in 1928.

The two airport sites just discussed are also home to SAO stations. In addition to these, there is a SAO station at Brunswick Glynn County Airport, about 30 km north of CUIS (Figure 4.2). This station has been operating since 1943. A NADP station (Fort Frederica NM) was active during the late 1980s, 27 km north of CUIS.

No weather/climate stations were identified within FOCA (Table 4.4). Of the seven COOP stations identified within 30 km of FOCA, six are active currently. The closest reliable data record to FOCA comes from the COOP station “Jacksonville Craig Muni. Arpt.,” located 5 km south of FOCA. This station has been active since 1970. The longest record of the COOP stations identified for FOCA comes from “Fernandina Beach,” which is 30 km north of FOCA, This station was discussed previously. Another very complete data record comes from the COOP station “Jacksonville Intl. Arpt.,” located 22 km northwest of FOCA. This station was also discussed previously.

At least five active SAO stations provide near-real-time data within 30 km of FOCA (Table 4.4). Most of these are associated with airports in the Jacksonville area (Figure 4.2). The longest record comes from the SAO station “Jacksonville Intl. Arpt.” Numerous CWOP stations also provide near-real-time data in the FOCA vicinity.

One NADP station has been identified within FOFR (Table 4.4). This is a historical station that was active in the 1980s. There are no currently active stations in FOFR.

Five of the six COOP stations we identified within 30 km of FOFR are active currently (Table 4.4). The closest COOP station to FOFR is “Brunswick Malcolm McKinnon Arpt.,” discussed previously. This station is located 1 km south of the park unit (Figure 4.2). The longest data record comes from the COOP station “Darien,” which is located 16 km north of FOFR. This station has been operating since 1892 yet the quality of its data record is uncertain. The COOP station “Brunswick,” discussed previously, is 11 km southwest of FOFR. The COOP station “Sapelo Island” provides a fourth climate record, having been active since 1957. This station’s data record has a gap from 1969 through 1971 but is otherwise quite complete.

The primary sources of near-real-time weather data outside of FOFR are two RAWS stations and three SAO stations (Table 4.4). The RAWS station "Stafford-CUIS" is located 27 km south of FOFR, while the RAWS station "Sterling" is located 27 km south of FOFR (Figure 4.2). The SAO stations are located south and west of FOFR. One station is at Brunswick Malcolm McKinnon Airport (1 km south), while the remaining two SAO stations ("Brunswick Glynco Jetport Arpt." and "Brunswick Glynn Co. Arpt.") are 7-8 km southwest of FOFR. Three CWOP stations within 30 km of FOFR also provide near-real-time data.

We have identified no stations within FOMA (Table 4.4). Of the seven COOP stations identified within 30 km of FOMA, five are active currently. The closest COOP station to FOMA is "Marineland," located 4 km south of FOMA. This station has been discussed previously. The longest record of the COOP stations identified for FOMA comes from "Federal Point," also discussed previously. This station is 29 km west of FOMA. Another useful climate record comes from the COOP station "St. Augustine Lighthouse," located 19 km north of FOMA.

The primary sources of near-real-time weather data outside of FOMA are a FAWN station (Hastings) and the SAO station at St. Augustine Airport. The FAWN station is 19 km west of FOMA. The SAO station is 28 km north of FOMA (Figure 4.2). Two CWOP stations within 30 km of FOMA also provide near-real-time data.

No weather/climate stations have been identified within TIMU (Table 4.4). Six of the eight COOP stations we have identified within 30 km of TIMU are active currently. The longest data record from these active stations comes from "Fernandina Beach," discussed previously. This station is located 11 km north of TIMU. The closest active COOP station to TIMU is "Mayport Pilot Stn.," immediately adjacent to the park unit. This station has a data record that extends back to 1955 and is largely complete.

Five SAO stations in the Jacksonville metropolitan area currently provide near-real-time weather data within 30 km of TIMU (Figure 4.2; Table 4.4). The closest of these stations is at Mayport Pilot Station, co-located with the COOP station. Twenty CWOP stations also provide near-real-time data for TIMU.

4.2.3. Alabama, Georgia, and South Carolina

We identified no weather/climate stations within HOBE (Table 4.5). The SAO station "Alexander City Thomas C Russel" provides the primary source of near-real-time weather data within 30 km of HOBE. This station is 21 km southwest of HOBE (Figure 4.3) and has been active since 1999. Two CWOP stations within 30 km of HOBE also provide near-real-time data.

The closest COOP station to HOBE is "Dadeville 2," located 11 km south of HOBE. This station has been active since 1948 (Table 4.5) but observations have been unreliable since 1983. The longest record of the COOP stations identified for HOBE comes from "Camp Hill 2 NW," which has been active since 1900. This station is 17 km south of HOBE. The COOP station "Lafayette 2 W" provides another long-term climate record for HOBE, going back to 1944. This station is 27 km southeast of HOBE. The data record at "Lafayette 2 W" is very complete with the exception of one large data gap from August 1991 to March 1994. This station is located 16 km northwest of HOBE. The COOP station “Folly Beach” is 8 km south of HOBE and has a data record that starts in 1958.

No weather/climate stations were identified within CHAT (Table 4.5). However, due to its location within the northwestern Atlanta metropolitan area, numerous stations are located within 30 km of CHAT (Figure 4.3).

Table 4.5. Weather/climate stations for the SECN park units in Alabama, Georgia, and South Carolina. Stations inside park units and within 30 km of the park unit boundary are included. Missing entries are indicated by “M”.

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Chattahoochee River National Recreation Area – CHAT							
Alpharetta 2 NNW	34.117	-84.300	336	COOP	8/1/1948	11/30/1984	No
Alpharetta 4 SSW	34.000	-84.300	317	COOP	10/1/1901	4/1/1995	No
Atlanta 6 SW	33.717	-84.483	250	COOP	2/1/1974	3/20/1992	No
Atlanta Bolton	33.824	-84.498	270	COOP	3/1/1956	Present	No
Atlanta Hartsfield Intl. Arpt.	33.630	-84.442	308	COOP	9/1/1928	Present	No
Atlanta Hospital	33.696	-84.280	235	COOP	2/1/1974	Present	No
Atlanta Kirkwood	33.750	-84.317	305	COOP	7/9/1934	10/31/1951	No
Atlanta Tennis DARDC	33.817	-84.400	253	COOP	2/1/1974	Present	No
Atlanta WSO-City	33.750	-84.383	347	COOP	10/1/1878	12/31/1954	No
Atl-Peachtree Ck. LARC	33.817	-84.401	233	COOP	3/1/1970	12/7/2001	No
Austell 3 SE LARC	33.767	-84.600	261	COOP	2/1/1974	12/13/2001	No
Canton	34.236	-84.496	267	COOP	8/1/1891	Present	No
Cumming 1 ENE	34.221	-84.122	369	COOP	6/1/1937	Present	No
Cumming 1 WNW	34.217	-84.167	436	COOP	2/1/1984	4/24/1986	No
Dallas 7 NE	33.988	-84.748	335	COOP	2/1/1947	Present	No
Dawsonville	34.350	-84.133	338	COOP	7/1/1956	12/31/1960	No
Dawsonville	34.421	-84.104	409	COOP	4/21/1947	10/17/2003	No
Decatur	33.767	-84.367	314	COOP	10/1/1951	6/30/1953	No
Dekalb-Peachtree DARDC	33.883	-84.283	291	COOP	12/1/1967	3/26/1998	No
Doraville 2 NNE	33.936	-84.296	314	COOP	2/1/1960	Present	No
Douglasville 4 S	33.701	-84.730	305	COOP	6/13/1940	11/30/2004	No
Fairborn 9 NW Rvr.	33.650	-84.667	220	COOP	2/1/1974	3/20/1992	No
Gainesville	34.301	-83.860	357	COOP	10/1/1891	Present	No
Mableton 1 N	33.853	-84.578	299	COOP	1/1/1982	Present	No
Marietta 5 SW	33.917	-84.583	329	COOP	8/1/1960	Present	No
Norcross	33.948	-84.222	306	COOP	5/1/1910	12/31/2005	No
Suwanee 5 E	34.086	-83.983	334	COOP	1/27/1960	6/1/2003	No
Woodstock	34.110	-84.515	321	COOP	6/1/1937	7/11/2002	No
CW0361 Marietta	33.940	-84.434	300	CWOP	M	Present	No
CW0498 Powder Springs	33.885	-84.673	300	CWOP	M	Present	No
CW0544 Marietta	34.051	-84.521	287	CWOP	M	Present	No
CW0616 North Atlanta	33.949	-84.360	308	CWOP	M	Present	No
CW0634 Norcross	33.996	-84.221	305	CWOP	M	Present	No
CW0662 Dawsonville	34.365	-84.054	428	CWOP	M	Present	No
CW0842 Marietta	34.033	-84.436	315	CWOP	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
CW1007 Chestatee	34.313	-83.980	352	CWOP	M	Present	No
CW1851 Cumming	34.100	-84.226	323	CWOP	M	Present	No
CW2468 Smyrna	33.869	-84.503	305	CWOP	M	Present	No
CW2528 Marietta	34.029	-84.446	329	CWOP	M	Present	No
CW2540 Atlanta	33.753	-84.386	329	CWOP	M	Present	No
CW2770 Alpharetta	34.067	-84.191	300	CWOP	M	Present	No
CW2884 Sandy Plains	33.990	-84.436	305	CWOP	M	Present	No
CW3002 Atlanta	33.919	-84.356	297	CWOP	M	Present	No
CW3112 Atlanta	33.800	-84.300	292	CWOP	M	Present	No
CW3199 Marietta	33.967	-84.500	370	CWOP	M	Present	No
CW3344 Buford	34.093	-83.875	316	CWOP	M	Present	No
CW3454 Alpharetta	34.214	-84.280	357	CWOP	M	Present	No
CW4296 Atlanta	33.861	-84.339	333	CWOP	M	Present	No
CW4375 Cumming	34.167	-84.167	371	CWOP	M	Present	No
CW4978 Cumming	34.288	-84.200	358	CWOP	M	Present	No
CW5023 Roswell	34.016	-84.304	325	CWOP	M	Present	No
CW5487 Acworth	34.091	-84.620	314	CWOP	M	Present	No
CW5605 Looper Lake	34.139	-83.898	284	CWOP	M	Present	No
CW5715 Norcross	33.988	-84.216	300	CWOP	M	Present	No
CW5933 Marietta	34.023	-84.431	M	CWOP	M	Present	No
K4JCW Buford Dam	34.170	-84.001	335	CWOP	M	Present	No
K4KAL Marietta	33.888	-84.587	348	CWOP	M	Present	No
K4MET Sandy Springs	33.951	-84.422	308	CWOP	M	Present	No
K4SAH-1 Woodstock	34.144	-84.599	272	CWOP	M	Present	No
KC4CSX-9 Holly Springs	34.218	-84.548	304	CWOP	M	Present	No
KD4DKW Smyrna	33.865	-84.515	305	CWOP	M	Present	No
KD4K Cumming	34.146	-84.106	347	CWOP	M	Present	No
KF4OVF Atlanta	33.866	-84.425	274	CWOP	M	Present	No
KG4EYO Campbellton	33.724	-84.730	311	CWOP	M	Present	No
KG4PAN-1 Lawrenceville	34.021	-83.980	377	CWOP	M	Present	No
N1IP-4 Hog Mountain	34.083	-83.933	348	CWOP	M	Present	No
W4EPI-4 Snellville	33.864	-84.092	268	CWOP	M	Present	No
WA2EIU Marietta	33.956	-84.461	290	CWOP	M	Present	No
WA4DSY Mountain Park	34.088	-84.374	333	CWOP	M	Present	No
Jefferson Street	33.777	-84.414	265	NADP	6/11/2002	6/29/2004	No
Dallas	33.833	-84.740	276	RAWS	2/1/2003	Present	No
Dawsonville	34.376	-84.060	370	RAWS	2/1/2003	Present	No
Atlanta Bolton	33.824	-84.498	270	SAO	3/1/1956	Present	No
Atlanta Dekalb Peachtree Arpt.	33.875	-84.302	305	SAO	4/1/1963	Present	No
Atlanta Fulton Co. Arpt.	33.779	-84.521	256	SAO	2/1/1961	Present	No
Atlanta Hartsfield Intl. Arpt.	33.630	-84.442	308	SAO	9/1/1928	Present	No
Atlanta NAS	33.867	-84.300	302	SAO	6/1/1942	2/28/1959	No
Gainesville Lee Gilmer Mem. Arpt.	34.272	-83.830	389	SAO	10/17/1995	Present	No
Lawrencevillee. Gwinnet Co.	33.980	-83.963	323	SAO	7/1/1991	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
B.							
Marietta Cobb Co. McCollum	34.013	-84.599	317	SAO	9/12/1990	Present	No
Marietta Dobbins AFB	33.917	-84.517	330	SAO	9/1/1946	Present	No
Atlanta Georgia Tech	33.767	-84.383	M	WBAN	M	Present	No
Auburn	34.040	-83.830	281	WX4U	M	Present	No
KD4K Cumming	34.146	-84.107	348	WX4U	M	Present	No
Kennesaw	34.050	-84.550	320	WX4U	M	Present	No
Powder Spring	33.887	-84.673	305	WX4U	M	Present	No
Roswell	34.014	-84.357	313	WX4U	M	Present	No
Thornbrook Marietta	34.050	-84.520	287	WX4U	M	Present	No
Charles Pinckney National Historic Site – CHPI							
Charleston 8 W	32.800	-80.067	3	COOP	8/1/1956	1/31/1970	No
Charleston City	32.780	-79.932	3	COOP	1/1/1871	Present	No
Charleston Intl. Arpt.	32.899	-80.040	12	COOP	1/1/1930	Present	No
Folly Beach	32.683	-79.883	3	COOP	5/1/1958	Present	No
Isle Of Palms	32.783	-79.800	3	COOP	7/1/1950	7/31/1951	No
James Island	32.700	-79.967	3	COOP	12/1/1942	10/31/1965	No
Johns Island	32.700	-80.000	6	COOP	4/1/1964	10/31/1964	No
Sullivans Island	32.760	-79.849	2	COOP	7/1/1951	Present	No
Sullivans Island Lig.	32.767	-79.850	3	COOP	8/1/1935	12/31/1975	No
K4LXF Charleston	32.857	-80.010	5	CWOP	M	Present	No
KE4KUR-2 Mt Pleasant	32.829	-79.878	5	CWOP	M	Present	No
Cape Romain NWR	32.942	-79.659	M	NADP	3/2/2004	Present	No
Fort Johnson	32.751	-79.898	2	NADP	3/19/2002	Present	No
Charleston	32.767	-79.850	3	SAO	M	Present	No
Charleston Intl. Arpt.	32.899	-80.040	12	SAO	1/1/1930	Present	No
Charleston NS	32.850	-79.950	1	SAO	M	Present	No
Folly Beach	32.683	-79.883	3	SAO	5/1/1958	Present	No
Charleston	32.900	-80.033	16	WBAN	9/1/1953	3/31/1964	No
Charleston NAS	32.850	-79.933	2	WBAN	7/1/1940	6/30/1980	No
Congaree National Park – CONG							
Congaree Bluff	33.815	-80.781	34	GPMP	3/1/2000	Present	Yes
Congaree Swamp	33.816	-80.827	30	GPMP	3/1/1981	12/1/2000	Yes
Congaree Swamp	33.815	-80.781	145	NADP	3/5/1996	Present	Yes
Congaree	33.815	-80.781	37	RAWS	11/1/2003	Present	Yes
Buckingham Landing	33.683	-80.583	M	COOP	6/7/1978	11/1/1989	No
Columbia	34.000	-81.050	34	COOP	1/1/1892	Present	No
Columbia	34.000	-81.050	118	COOP	1/1/1899	12/31/1954	No
Columbia Ft. Jackson	34.017	-80.933	76	COOP	11/1/1956	6/30/1958	No
Columbia Metro. Arpt.	33.946	-81.122	65	COOP	11/1/1941	Present	No
Columbia Univ. Of SC	33.983	-81.017	74	COOP	9/1/1954	Present	No
Hopkins 2 E	33.900	-80.833	61	COOP	8/1/1964	9/30/1973	No
Pinewood 4 SE	33.717	-80.417	55	COOP	6/1/1978	8/13/1982	No
Rimini 2 SSW	33.649	-80.531	24	COOP	2/20/1914	Present	No
Sandy Run 3 ENE	33.809	-80.902	23	COOP	1/2/2000	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
St. Matthews	33.653	-80.781	85	COOP	10/1/1898	Present	No
Summerton 5 WNW	33.617	-80.433	43	COOP	11/1/1965	11/30/1968	No
Wedgefield	33.893	-80.519	76	COOP	9/1/1922	Present	No
Wedgefield 6 S	33.817	-80.500	55	COOP	5/1/1942	7/31/1967	No
CW1313 Wedgefield	33.900	-80.500	71	CWOP	M	Present	No
N4BAM Springdale	33.951	-81.094	57	CWOP	M	Present	No
N5CWH Columbia	34.000	-81.073	90	CWOP	M	Present	No
WS4P-5 Sumter	33.919	-80.408	55	CWOP	M	Present	No
Weir Tower	34.022	-80.868	166	RAWS	M	12/12/9999	No
Columbia Metro. Arpt.	33.946	-81.122	65	SAO	11/1/1941	Present	No
Columbia Owens Downtown Arpt.	33.971	-80.996	65	SAO	6/1/1939	Present	No
Fort Jackson Rng. GWC	34.067	-80.800	M	SAO	M	Present	No
Mc Entire Ang. Columbia	33.917	-80.800	77	SAO	M	12/31/1975	No
Mcentire Ang.	33.967	-80.800	90	SAO	2/1/1959	Present	No
Poinsett Range AF	33.850	-80.483	68	SAO	6/1/1970	Present	No
Sumter Shaw AFB	33.967	-80.467	74	SAO	11/1/1941	Present	No
Columbia Congaree Field MCAF	33.917	-80.800	74	WBAN	3/1/1945	9/30/1945	No
North AF	33.600	-81.083	98	WBAN	4/1/1954	7/31/1954	No
Fort Pulaski National Monument – FOPU							
Hilton Head	32.217	-80.750	5	COOP	6/1/1953	Present	No
Isle Of Hope 2	31.983	-81.050	0	COOP	12/1/1961	1/31/1967	No
Ossabaw Island	31.833	-81.083	3	COOP	7/1/1957	5/31/1965	No
Savannah AFB	32.017	-81.133	12	COOP	1/1/1871	Present	No
Savannah Beach	32.000	-80.850	3	COOP	9/27/1938	3/31/1977	No
Savannah Beach Coast	32.017	-80.850	3	COOP	6/1/1967	Present	No
Savannah Intl. Arpt.	32.130	-81.210	14	COOP	10/1/1950	Present	No
Savannah Radio WTOC	32.000	-81.267	12	COOP	9/1/1961	9/30/1974	No
Savannah USDA Plant	32.000	-81.267	6	COOP	3/1/1928	4/20/1977	No
Savannah WBO	32.083	-81.083	25	COOP	6/1/1888	6/30/1949	No
Tybee Island	32.017	-80.850	2	COOP	7/22/1994	Present	No
CW1443 Savannah	32.038	-81.098	2	CWOP	M	Present	No
CW3308 Bluffton	32.230	-80.926	5	CWOP	M	Present	No
CW4805 Bluffton	32.242	-80.876	8	CWOP	M	Present	No
CW4925 Hilton head	32.189	-80.701	3	CWOP	M	Present	No
Skidaway	31.996	-81.019	3	NADP	6/18/2002	5/24/2005	No
Savannah NWR	32.100	-81.083	3	RAWS	12/1/2002	Present	No
Hilton Head Island Hilton Head	32.217	-80.700	7	SAO	8/1/1972	Present	No
Hunter AAF	32.017	-81.050	13	SAO	M	Present	No
Savannah AFB	32.017	-81.133	12	SAO	1/1/1871	Present	No
Savannah Intl. Arpt.	32.130	-81.210	14	SAO	10/1/1950	Present	No
Tybee Lighthouse Stn.	32.017	-80.850	3	SAO	6/1/1967	Present	No
Savannah Chatham Field AAF	32.133	-81.200	16	WBAN	3/1/1944	12/31/1956	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Savannah Lightship	31.950	-80.667	5	WBAN	7/1/1936	12/10/1964	No
WSAV Studios Savannah	32.080	-81.100	2	WX4U	M	Present	No
Fort Sumter National Monument – FOSU							
Charleston 8 W	32.800	-80.067	3	COOP	8/1/1956	1/31/1970	No
Charleston City	32.780	-79.932	3	COOP	1/1/1871	Present	No
Charleston Intl. Arpt.	32.899	-80.040	12	COOP	1/1/1930	Present	No
Folly Beach	32.683	-79.883	3	COOP	5/1/1958	Present	No
Isle Of Palms	32.783	-79.800	3	COOP	7/1/1950	7/31/1951	No
James Island	32.700	-79.967	3	COOP	12/1/1942	10/31/1965	No
Johns Island	32.700	-80.000	6	COOP	4/1/1964	10/31/1964	No
Ladson Oakbrook	32.964	-80.153	21	COOP	8/1/1997	Present	No
Sullivans Island	32.760	-79.849	2	COOP	7/1/1951	Present	No
Sullivans Island Lig.	32.767	-79.850	3	COOP	8/1/1935	12/31/1975	No
K4LXF Charleston	32.857	-80.010	5	CWOP	M	Present	No
KE4KUR-2 Mt Pleasant	32.829	-79.878	5	CWOP	M	Present	No
Cape Romain NWR	32.942	-79.659	M	NADP	3/2/2004	Present	No
Fort Johnson	32.751	-79.898	2	NADP	3/19/2002	Present	No
Charleston	32.767	-79.850	3	SAO	M	Present	No
Charleston Intl. Arpt.	32.899	-80.040	12	SAO	1/1/1930	Present	No
Charleston NS	32.850	-79.950	1	SAO	M	Present	No
Folly Beach	32.683	-79.883	3	SAO	5/1/1958	Present	No
Charleston	32.900	-80.033	16	WBAN	9/1/1953	3/31/1964	No
Charleston NAS	32.850	-79.933	2	WBAN	7/1/1940	6/30/1980	No
Horseshoe Bend National Military Park – HOBE							
Alexander City	32.945	-85.948	195	COOP	10/1/1969	Present	No
Alexander City 2	32.917	-85.950	204	COOP	3/1/1976	8/31/1986	No
Alexander City 6 NE	32.983	-85.867	201	COOP	11/1/1942	10/5/1969	No
Camp Hill 2 NW	32.824	-85.656	207	COOP	12/25/1900	Present	No
Dadeville	32.817	-85.750	198	COOP	7/12/1904	3/31/1984	No
Dadeville 2	32.862	-85.736	223	COOP	3/1/1948	Present	No
Goodwater	33.067	-86.050	308	COOP	11/1/1895	6/30/1954	No
Lafayette 2 W	32.907	-85.434	226	COOP	10/19/1944	Present	No
Milltown	33.033	-85.483	213	COOP	1/1/1926	6/30/1944	No
Wadley	33.117	-85.567	206	COOP	2/1/1933	10/1/1992	No
Wadley NR 2	33.136	-85.587	216	COOP	9/26/2003	Present	No
N4BCB-2 Roanoke	32.733	-85.819	152	CWOP	M	Present	No
WD4KTY Wedowee	32.868	-86.055	207	CWOP	M	Present	No
Alexander City Thomas C Russel	32.915	-85.963	209	SAO	1/7/1999	Present	No
Kennesaw Mountain National Battlefield Park – KEMO							
Allatoona Dam 2	34.165	-84.730	297	COOP	9/1/1946	Present	No
Alpharetta 2 NNW	34.117	-84.300	336	COOP	8/1/1948	11/30/1984	No
Alpharetta 4 SSW	34.000	-84.300	317	COOP	10/1/1901	4/1/1995	No
Americus 3 SW	32.050	-84.275	149	COOP	5/1/1876	12/1/2005	No
Americus Exp. Stn. Nrsy.	32.103	-84.267	137	COOP	8/1/1948	3/31/2004	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Atlanta 6 SW	33.717	-84.483	250	COOP	2/1/1974	3/20/1992	No
Atlanta Bolton	33.824	-84.498	270	COOP	3/1/1956	Present	No
Atlanta Tennis DARDC	33.817	-84.400	253	COOP	2/1/1974	Present	No
Atlanta WSO-City	33.750	-84.383	347	COOP	10/1/1878	12/31/1954	No
Atl-Peachtree Ck. LARC	33.817	-84.401	233	COOP	3/1/1970	12/7/2001	No
Austell 3 SE LARC	33.767	-84.600	261	COOP	2/1/1974	12/13/2001	No
Canton	34.236	-84.496	267	COOP	8/1/1891	Present	No
Cartersville # 2	34.183	-84.796	235	COOP	5/28/1937	Present	No
Dallas 7 NE	33.988	-84.748	335	COOP	2/1/1947	Present	No
Dawson	31.782	-84.450	108	COOP	1/27/1903	Present	No
Decatur	33.767	-84.367	314	COOP	10/1/1951	6/30/1953	No
Dekalb-Peachtree DARDC	33.883	-84.283	291	COOP	12/1/1967	3/26/1998	No
Doraville 2 NNE	33.936	-84.296	314	COOP	2/1/1960	Present	No
Douglasville 4 S	33.701	-84.730	305	COOP	6/13/1940	11/30/2004	No
Fairborn 9 NW Rvr.	33.650	-84.667	220	COOP	2/1/1974	3/20/1992	No
Mableton 1 N	33.853	-84.578	299	COOP	1/1/1982	Present	No
Marietta 5 SW	33.917	-84.583	329	COOP	8/1/1960	Present	No
Plains SW GA Exp. Stn.	32.047	-84.371	152	COOP	1/1/1956	Present	No
Preston	32.055	-84.524	123	COOP	2/1/1956	Present	No
Preston 1 SW-DARDC G.	32.050	-84.550	104	COOP	4/1/1976	11/30/1977	No
Woodstock	34.110	-84.515	321	COOP	6/1/1937	7/11/2002	No
CW0361 Marietta	33.940	-84.434	300	CWOP	M	Present	No
CW0498 Powder Springs	33.885	-84.673	300	CWOP	M	Present	No
CW0544 Marietta	34.051	-84.521	287	CWOP	M	Present	No
CW0616 North Atlanta	33.949	-84.360	308	CWOP	M	Present	No
CW0842 Marietta	34.033	-84.436	315	CWOP	M	Present	No
CW2468 Smyrna	33.869	-84.503	305	CWOP	M	Present	No
CW2528 Marietta	34.029	-84.446	329	CWOP	M	Present	No
CW2540 Atlanta	33.753	-84.386	329	CWOP	M	Present	No
CW2884 Sandy Plains	33.990	-84.436	305	CWOP	M	Present	No
CW3002 Atlanta	33.919	-84.356	297	CWOP	M	Present	No
CW3112 Atlanta	33.800	-84.300	292	CWOP	M	Present	No
CW3199 Marietta	33.967	-84.500	370	CWOP	M	Present	No
CW4296 Atlanta	33.861	-84.339	333	CWOP	M	Present	No
CW5023 Roswell	34.016	-84.304	325	CWOP	M	Present	No
CW5487 Acworth	34.091	-84.620	314	CWOP	M	Present	No
CW5933 Marietta	34.023	-84.431	M	CWOP	M	Present	No
K4KAL Marietta	33.888	-84.587	348	CWOP	M	Present	No
K4MET Sandy Springs	33.951	-84.422	308	CWOP	M	Present	No
K4SAH-1 Woodstock	34.144	-84.599	272	CWOP	M	Present	No
KC4CSX-9 Holly Springs	34.218	-84.548	304	CWOP	M	Present	No
KD4DKW Smyrna	33.865	-84.515	305	CWOP	M	Present	No
KF4OVF Atlanta	33.866	-84.425	274	CWOP	M	Present	No
KG4EYO Campbellton	33.724	-84.730	311	CWOP	M	Present	No
N8PXE Andersonville	31.879	-84.276	88	CWOP	M	Present	No
N8PXE Andersonville	31.879	-84.276	88	CWOP	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
WA2EIU Marietta	33.956	-84.461	290	CWOP	M	Present	No
WA4DSY Mountain Park	34.088	-84.374	333	CWOP	M	Present	No
Jefferson Street	33.777	-84.414	265	NADP	6/11/2002	6/29/2004	No
Dallas	33.833	-84.740	276	RAWS	2/1/2003	Present	No
Plains/Sumter	32.010	-84.330	160	RAWS	2/1/2003	Present	No
Atlanta Bolton	33.824	-84.498	270	SAO	3/1/1956	Present	No
Atlanta Dekalb Peachtree Arpt.	33.875	-84.302	305	SAO	4/1/1963	Present	No
Atlanta Fulton Co. Arpt.	33.779	-84.521	256	SAO	2/1/1961	Present	No
Atlanta NAS	33.867	-84.300	302	SAO	6/1/1942	2/28/1959	No
Cartersville Arpt.	34.123	-84.849	233	SAO	3/22/2000	Present	No
Marietta Cobb Co. McCollum	34.013	-84.599	317	SAO	9/12/1990	Present	No
Marietta Dobbins AFB	33.917	-84.517	330	SAO	9/1/1946	Present	No
Plains Peterson Field	32.083	-84.367	160	SAO	1/4/1977	7/31/1981	No
Americus	32.050	-84.233	139	WBAN	10/1/1938	8/31/1941	No
Atlanta Georgia Tech	33.767	-84.383	M	WBAN	M	Present	No
Kennesaw	34.050	-84.550	320	WX4U	M	Present	No
Powder Spring	33.887	-84.673	305	WX4U	M	Present	No
Roswell	34.014	-84.357	313	WX4U	M	Present	No
Thornbrook Marietta	34.050	-84.520	287	WX4U	M	Present	No
Ocmulgee National Monument – OCMU							
Byron Experiment Stn.	32.669	-83.745	149	COOP	10/1/1977	8/1/2000	No
Lizella	32.809	-83.820	171	COOP	7/1/1970	2/23/2000	No
Macon	32.839	-83.620	82	COOP	4/18-1892	9/14/2005	No
Macon DARDC	32.827	-83.609	84	COOP	2/1/1974	Present	No
Macon Middle GA Regl. Arpt.	32.685	-83.653	105	COOP	12/1/1948	Present	No
Macon WB Arpt.	32.833	-83.567	141	COOP	12/1/1928	12/31/1948	No
Macon WB City	32.833	-83.633	114	COOP	4/1/1899	3/31/1954	No
Warner Robins	32.636	-83.651	158	COOP	2/13/1997	Present	No
CW1457 Macon	32.922	-83.675	120	CWOP	M	Present	No
CW2041 Warner Robins	32.628	-83.631	112	CWOP	M	Present	No
CW2779 Macon	32.859	-83.660	114	CWOP	M	Present	No
CW3069 Macon	32.926	-83.681	150	CWOP	M	Present	No
NA4V-4 Warner Robins	32.572	-83.642	120	CWOP	M	Present	No
Macon	32.700	-83.560	87	GPS-MET	M	Present	No
Brender	33.010	-83.740	91	RAWS	2/1/2003	Present	No
Macon Middle GA Regl. Arpt.	32.685	-83.653	105	SAO	12/1/1948	Present	No
Macon WB Arpt	32.833	-83.567	141	SAO	12/1/1928	12/31/1948	No
Warner Robins AFB	32.633	-83.600	92	SAO	8/1/1942	Present	No
Macon Cochran Field AAF	32.700	-83.650	110	WBAN	8/1/1941	4/30/1945	No

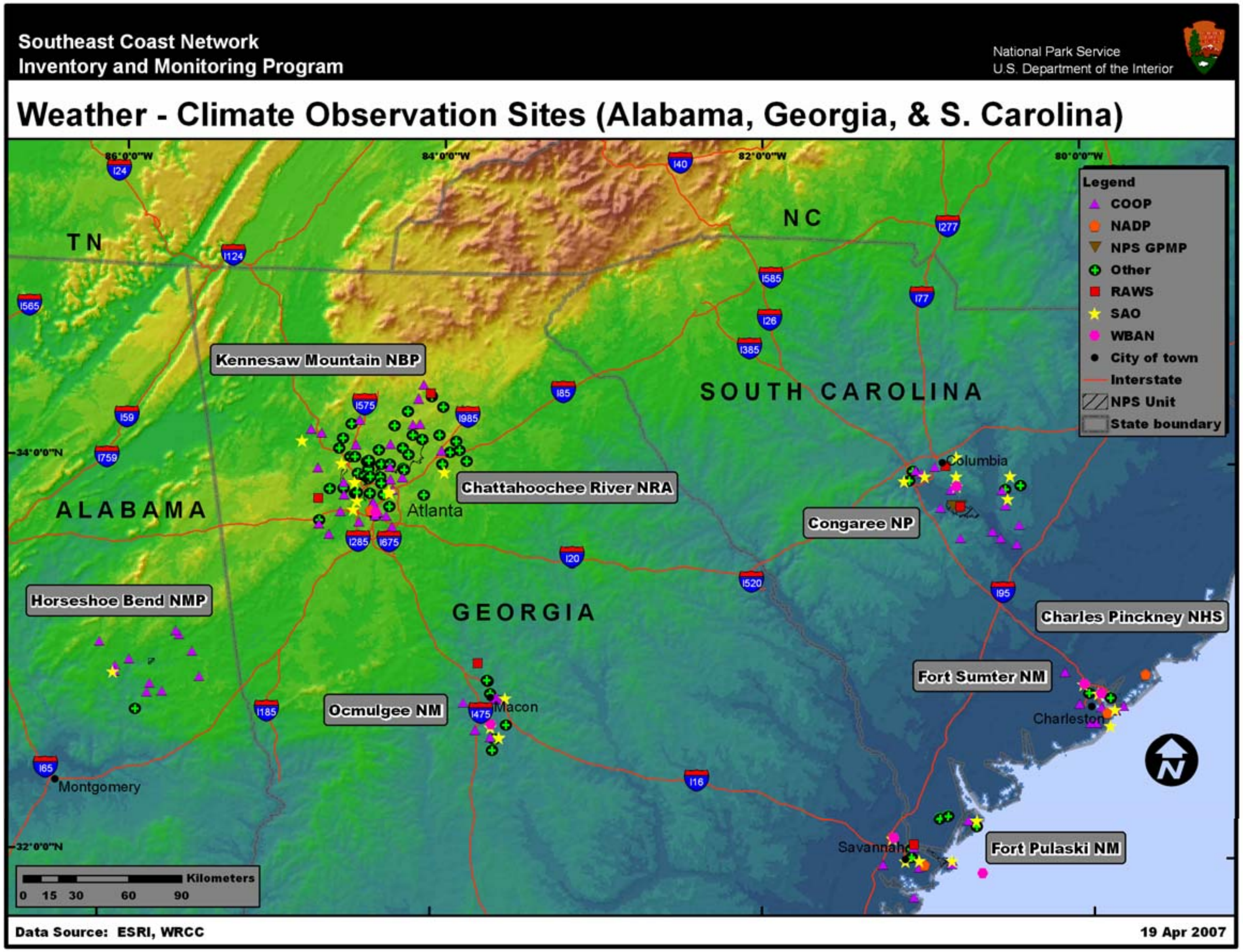


Figure 4.3. Station locations for SECN park units in Alabama, Georgia, and South Carolina.

Of the 28 COOP sites we identified within 30 km of CHAT (Table 4.5), 11 are currently active. The closest active COOP site to CHAT is “Atlanta Bolton,” located 4 km southwest of the south end of CHAT. The longest data record comes from the COOP station “Canton” (1891-present). This station is 27 km northwest of CHAT and has a very complete data record, although this station measures precipitation only. “Gainesville” is another COOP station with a long data record going back to 1891. This station is 25 km northeast of CHAT. Unlike “Canton,” the COOP station at Gainesville measures both temperature and precipitation. Its data record is very complete. Atlanta’s Hartsfield International Airport has a COOP station which has a very complete data record starting in 1928. This station is located 22 km south of CHAT. The COOP station “Cumming 1 ENE,” located 10 km northwest of CHAT, has been operating since 1937. This station measures precipitation primarily; however, temperatures have been observed since June 2001. A significant data gap occurred at “Cumming 1 ENE” from February 1984 to May 1986. The COOP station “Dallas 7 NE” is located 28 km west of CHAT and has a very complete data record extending to 1947, at least for precipitation. Temperatures were not measured at “Dallas 7 NE” until November 1957.

Several weather/climate networks currently provide near-real-time data within 30 km of CHAT. Two active RAWS sites have been identified within 30 km of CHAT (Table 4.5). “Dallas” is located 26 km west of CHAT, while “Dawsonville” is 24 km north of CHAT (Figure 4.3). At least eight active SAO stations were identified within 30 km of CHAT. The closest SAO station to CHAT is “Atlanta Bolton,” 4 km southwest of the park unit. “Atlanta Fulton Co. Arpt.” and “Marietta Dobbins AFB” also provide near-real-time weather data within 10 km of CHAT. In addition to these, numerous CWOP and WX4U stations also provide near-real-time weather data in the vicinity of CHAT.

Of the 19 COOP sites we identified for KEMO, nine are currently active (Table 4.5). The closest active COOP site to KEMO is “Marietta 5 SW,” located less than a kilometer southeast of KEMO. The data at this station are of unknown quality. The longest data record comes from the COOP station “Canton” (1891-present), discussed previously. This station is 29 km north of KEMO. “Cartersville # 2” (1937-present) is located 29 km northwest of KEMO. Although the data record at “Cartersville # 2” is very complete, precipitation is the only variable measured. “Dallas 7 NE” is another COOP station with a long data record. This station, discussed previously, is 13 km west of KEMO.

Several weather/climate networks currently provide near-real-time data within 30 km of KEMO. One active RAWS station (Dallas) has been identified. This station is located 15 km southwest of KEMO (Figure 4.3). Six active SAO stations were identified within 30 km of KEMO (Table 4.5). The closest SAO station to KEMO is “Marietta Cobb Co. McCollum,” 3 km east of the park unit. The longest SAO record is provided at “Marietta Dobbins AFB” (6 km from KEMO), with a record going back to 1946. In addition to these, numerous CWOP and WX4U stations also provide near-real-time weather data in the vicinity of KEMO.

We identified no weather/climate stations within OCMU (Table 4.5). Only three of the eight COOP stations we have identified within 30 km of OCMU are active currently. The longest data record from these active stations comes from “Macon Middle GA Regl. Arpt.,” located 15 km south of OCMU. This station’s data record is very complete. A longer climate record is available from a nearby COOP station (Macon) that unfortunately ended in 2005. This station began taking observations in 1892. The data record at “Macon” was not as reliable as the record from the regional airport COOP station. The closest active COOP station to OCMU is “Macon DARDC,” which is located just south of OCMU and has been active since 1974.

One RAWS station and two SAO stations currently are the primary sources of near-real-time weather data within 30 km of OCMU (Figure 4.3; Table 4.5). Five CWOP stations also provide near-real-time data. The RAWS station “Brender” is 22 km northwest of OCMU and has been taking observations since 2003. The SAO station “Warner Robins AFB” is located 20 km south of OCMU and has been active since 1942. The other active SAO station is co-located with the COOP station at Macon Middle Georgia Regional Airport.

No weather/climate stations were identified within CHPI (Table 4.5). The closest reliable data record to CHPI comes from the COOP station “Sullivans Island,” located 9 km south of CHPI. This station has been active since 1951. The data record at “Sullivans Island” is largely complete although there are occasional gaps scattered throughout the record. The longest record of the COOP stations identified for CHPI comes from “Charleston City,” which is 12 km southwest of CHPI and started taking observations in 1871. The data record at this station is very complete. Another very complete data record comes from the COOP station “Charleston Intl. Arpt.,” located 21 km west of CHPI.

Two NADP stations were identified within 30 km of CHPI (Table 4.5). “Cape Romain NWR” is located 19 km northeast of CHPI while “Fort Johnson” is located 12 km south of CHPI (Figure 4.3).

At least four active SAO stations provide near-real-time data within 30 km of CHPI (Table 4.5). Most of these are co-located with COOP stations and are south and west of CHPI (Figure 4.3). The longest record comes from the SAO station “Charleston Intl. Arpt.” Two CWOP stations also provide near-real-time data in the CHPI vicinity.

Four weather/climate stations have been identified within CONG. Three of these stations are active currently (Table 4.5). A GPMP station (Congaree Bluff) has been operating in CONG since 2000. A NADP station (Congaree Swamp) has been operating in CONG since 1996.The RAWS station “Congaree” has provided near-real-time weather information in CONG since 2003. No long-term climate records exist within CONG.

We have identified 14 COOP stations outside of CONG that are within 30 km of the park unit. Sevenof these are active (Table 4.5). The closest active COOP station, “Sandy Run 3 ENE,” is 3 km southwest of the park unit and has been operating since 2000. The COOP station “Columbia”, 25 km northwest of CONG, has the longest data record of these stations, with observations starting in 1892. However, its data are of unknown quality. Data from this station may have been merged with data from the COOP station “Columbia Metro. Arpt.,” which is 27 km northwest of CONG and has a very complete data record starting in 1941. “St. Matthews,” 12 km south of CONG, has a data record extending to 1898 but its data, like “Columbia,” are of unknown quality. The COOP station “Wedgefield” (1922-present) is located 19 km northeast of CONG and provides a data record that is largely complete.

The SAO stations identified within 30 km of CONG are the primary source of near-real-time weather data for the park unit and they are all generally located 20-30 km north and west of CONG. The longest records come from the airport sites near Columbia, South Carolina.

No weather/climate stations have been identified within FOPU (Table 4.5). A NADP station was active at Skidaway from 2002 until 2005. The closest COOP station to FOPU is “Savannah Beach Coast,” located 3 km east of FOPU. This station has been active since 1967. The longest record of the COOP stations identified for FOPU comes from “Savannah AFB,” located 14 km west of FOPU. This station’s data record goes back to 1871 and is largely complete, with only occasional small gaps. Another useful climate record comes from the COOP station “Hilton Head.” This station is located 24 km northeast of FOPU and its record is very complete. The COOP station “Savannah Intl. Arpt,” 20 km west of FOPU, has observations starting in 1950 but has a significant data gap from 1969 through 1971.

One RAWS station and five SAO stations provide the primary sources of near-real-time weather data within 30 km of FOPU. Four CWOP stations and one WX4U station also provide near-real-time data. The RAWS station “Savannah NWR” is located 8 km west of FOPU and has been taking observations since December 2002. The closest SAO to FOPU is “Tybee Lighthouse Stn.,” located 3 km east of the park unit. The other SAO stations identified here are located at Hilton Head Island or in the Savannah vicinity. The U.S. Geological Survey (USGS) has a hydrologic station at the Coast Guard station adjacent to FOPU but access to this station’s data feed was not verifiable at the time of this report so it was not specifically included in this inventory.

No weather/climate stations have been identified within FOSU (Table 4.5). Two NADP stations have been identified within 30 km of FOSU. “Cape Romain NWR” is 27 km northeast of the park unit and “Fort Johnson” is 1 km west of the park unit (Figure 4.3). The closest COOP station to FOSU is “Sullivans Island,” located less than a kilometer east of FOSU. This station has been discussed previously. The longest record of the COOP stations identified for FOSU comes from “Charleston City,” also discussed previously. “Charleston City” is located about 1 km northwest of FOSU. Other useful climate records come from the COOP station “Charleston Intl. Arpt.,” discussed previously. This station is located 16 km northwest of FOSU. The COOP station “Folly Beach” is 8 km south of FOSU and has a data record that starts in 1958.

Four SAO stations provide the primary sources of near-real-time weather data within 30 km of FOSU. Most of these SAO stations are in the Charleston metropolitan area, north and west of FOSU. The closest SAO to FOSU is “Charleston,” 1 km north of the park unit.
Kennesaw Mountain National Battlefield (KEMO) has no weather/climate stations inside its park unit boundaries (Table 4.5). However, due to its location within the northwestern Atlanta metropolitan area (Figure 4.3), numerous stations are located within 30 km of KEMO.

5.0. Conclusions and Recommendations

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

5.1. Southeast Coast Inventory and Monitoring Network

The SECN office was very instrumental in identifying weather/climate stations within SECN park units. Many of these park units have no weather/climate stations at or within park boundaries. Most of the SECN park units are historical sites or other memorials. As a result, these park units are generally quite small and therefore must rely heavily on stations outside of the park units for their weather and climate data. Fortunately, each of these park units have numerous near-real-time and long-term weather/climate stations nearby. For those park units that do have weather/climate stations inside their boundaries, very few of these stations have verifiable long-term data records. It is therefore important that NPS work with local agencies to ensure that any active long-term sites be retained in order to continue their valuable long-term records.

The national seashore park units in the SECN, CAHA and CALO in particular, have large stretches of barrier islands that currently have no weather/climate stations and must therefore rely on ocean buoys or stations further inland for their weather and climate data. These stations are usually a significant distance away from the barrier islands. The stations that are located on these barrier islands are often located at the island edges, near inlets or other significant shipping lanes. As resources allow, climate monitoring efforts in these park units may benefit from a concerted effort to install new near-real-time stations on some of the previously-unsampled barrier islands. This could be especially helpful in monitoring sharp coast-interior climate gradients, along with other climate dynamics that work to shape the coastal ecosystems of the SECN.

5.2. Spatial Variations in Mean Climate

Land-use heterogeneity, particularly land uses introduced by human settlement, and significant coastal-interior climate gradients influence heavily the park units within SECN, leading to systematic spatial variations in mean surface climate. This is true at local scales in particular. With local variations over short horizontal distances, land use patterns introduce considerable fine-scale structure to mean climate (temperature and precipitation). Issues encountered in mapping mean climate are discussed in Appendix D and in Redmond et al. (2005).

If only a few stations will be emplaced, the primary goal should be overall characterization of the main climate elements (temperature and precipitation, and snow). This level of characterization generally requires that the stations should be distributed spatially in the major biomes of each park, located in those land uses/land covers that most truly represent the local area. If such stations already are present in the vicinity, then additional stations would be best used for two important and somewhat competing purposes: (a) add redundancy as backup for loss of data from current stations (or loss of the physical stations) or (b) provide added information on spatial heterogeneity in climate arising from land use variations, particularly local wind patterns.

5.3. Climate Change Detection

There is much interest in the adaptation of SECN ecosystems in response to possible future climate change. For inland locations, this particularly includes climate influences from land use changes, impacts on air quality and water quantity and quality, and the introduction of non-native plant and animal communities. Along coastal SECN park units, the impacts of possible sea level rises on coastal ecosystems are of great importance.

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.

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

- Most SECN park units have no weather/climate stations. Fortunately, coverage of both near-real-time stations and long-term climate stations is generally satisfactory in the immediate vicinity of SECN park units.
- Few SECN park units have verifiable long-term records.
- Weather conditions are currently undersampled for large portions of the barrier islands in the SECN park units. Any new installations intended to address this situation would be beneficial for SECN climate monitoring efforts.

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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)

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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 (Parameter Regression on Independent Slopes Model) maps (Daly et al. 1994; 2002; Gibson et al. 2002; Doggett et al. 2004) were probably the best available. An analysis by Simpson et al. (2005) further discussed many issues in the mapping of Alaska's climate and resulted in the same conclusion about PRISM.

D.2.3. Climate-Change Detection

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

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

D.2.4. Element-Specific Differences

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

D.2.5. Logistics and Practical Factors

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

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

D.2.6. Personnel Factors

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

D.3. Site Selection

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

D.3.1. Equipment and Exposure Factors

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

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

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

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

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

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

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

D.3.2. Element-Specific Factors

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

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

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

Near the 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 SECN: http://www.wrcc.dri.edu/nps/pub/SECN/metadata/SECN_from_ACIS.tar.gz.

F.2. SECN metadata files for weather and climate stations associated with the SECN: http://www.wrcc.dri.edu/nps/pub/SECN/metadata/SECN_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. Florida Automated Weather Network (FAWN)

- Purpose of network: provide localized weather information, including frost and freeze warnings, for agricultural management decisions.
- Primary management agency: University of Florida Institute of Food and Agricultural Sciences.
- Data Website: http://fawn.ifas.ufl.edu.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
  - Solar radiation.
- Sampling frequency: 15 minutes or less.
- Reporting frequency: 15 minutes.
- Estimated station cost: unknown.
- Network strengths:
  - Near-real-time data.
  - Easy data access.
  - Site maintenance is excellent.
- Network weaknesses:
  - Coverage limited to Florida.
  - Record lengths are limited (1990s and later).

The FAWN network was initiated in Florida in the late 1990s in response to funding cutbacks at NWS in the area of localized weather information for agriculture, including frost and freeze warnings. Today FAWN provides useful weather data for Florida farmers and growers, primarily for daily management decisions. FAWN is also being used as a source of weather information for the general public.

G.6. NPS Gaseous Pollutant Monitoring Program (GPMP)

- Purpose of network: measurement of ozone and related meteorological elements.
- Primary management agency: NPS.
- Data website: http://www2.nature.nps.gov/air/monitoring.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
  - Solar radiation.
  - Surface wetness.
- Sampling frequency: continuous.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:

- Stations are located within NPS park units.
  - Data quality is excellent, with high data standards.
  - Provides unique measurements that are not available elsewhere.
  - Records are up to 2 decades in length.
  - Site maintenance is excellent.
  - Thermometers are aspirated.
- Network weaknesses:
  - Not easy to download the entire data set or to ingest live data.
  - Period of record is short compared to other automated networks. Earliest sites date from 2004.
  - Station spacing and coverage: station installation is episodic, driven by opportunistic situations.

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

G.7. NOAA Ground-Based GPS Meteorology (GPS-MET)

- Purpose of network:
  - Measure atmospheric water vapor using ground-based GPS receivers.
  - Facilitate use of these data operational and in other research and applications.
  - Provides data for weather forecasting, atmospheric modeling and prediction, climate monitoring, calibrating and validation other observing systems including radiosondes and satellites, and research.
- Primary management agency: NOAA Earth System Research Laboratory.
- Data website: http://gpsmet.noaa.gov/jsp/index.jsp.
- Measurements:
  - Dual frequency carrier phase measurements every 30 seconds.
- Ancillary weather/climate observations:
  - Air temperature.
  - Relative humidity.
  - Pressure.
- Reporting frequency: currently 30 min.
- Estimated station cost: $0-$10000, depending on approach. Data from dual frequency GPS receivers installed for conventional applications (e.g. high accuracy surveying) can be used without modification.
- Network strengths:
  - Frequent, high-quality measurements.
  - High reliability.
  - All-weather operability.
  - Many uses.
  - Highly leveraged.

  - Requires no calibration.
  - Measurement accuracy improves with time.
- Network weakness:
  - Point measurement.
  - Provides no direct information about the vertical distribution of water vapor.

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

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

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

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

G.8. 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 includes MDN sites and is a collaborative effort among several agencies including USGS and USDA. Precipitation is the primary climate parameter measured at NADP sites. This network includes the Mercury Deposition Network (MDN).

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

- Purpose of network: provide near-real-time (hourly or near hourly) measurements of meteorological variables for use in fire weather forecasts and climatology. Data from RAWS also are used for natural resource management, flood forecasting, natural hazard management, and air-quality monitoring.
- Primary management agency: WRCC, National Interagency Fire Center.
- Data website: http://www.raws.dri.edu/index.html.
- Measured weather/climate elements:
    - Air temperature.
    - Precipitation.
    - Relative humidity.
    - Wind speed.
    - Wind direction.
    - Wind gust.
    - Gust direction.
    - Solar radiation.
    - Soil moisture and temperature.
- Sampling frequency: 1 or 10 minutes, element-dependent.
- Reporting frequency: generally hourly. Some stations report every 15 or 30 minutes.
- Estimated station cost: $12000 with satellite telemetry ($8000 without satellite telemetry); maintenance costs are around $2000/year.
- Network strengths:
    - Metadata records are usually complete.
    - Sites are located in remote areas.

    - Sites are generally well-maintained.
    - Entire period of record available on-line.
- Network weaknesses:
    - RAWS network is focused largely on fire management needs (formerly focused only on fire needs).
    - Frozen precipitation is not measured reliably.
    - Station operation is not always continuous.
    - Data transmission is completed via one-way telemetry. Data are therefore recoverable either in real-time or not at all.

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

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

- Purpose of network: provide near-real-time measurements of meteorological variables and are used both for airport operations and weather forecasting.
- Primary management agency: NOAA, FAA.
- Data website: data are available from state climate offices, RCCs (e.g., WRCC, http://www.wrcc.dri.edu), and NCDC (http://www.ncdc.noaa.gov).
- Measured weather/climate elements:
    - Air temperature.
    - Dewpoint and/or relative humidity.
    - Wind speed.
    - Wind direction.
    - Wind gust.
    - Gust direction.
    - Barometric pressure.
    - Precipitation (not at many FAA sites).
    - Sky cover.
    - Ceiling (cloud height).
    - Visibility.
- Sampling frequency: element-dependent.
- Reporting frequency: element-dependent.
- Estimated station cost: $100000–$200000, with maintenance costs approximately $10000/year.
- Network strengths:
    - Records generally extend over several decades.
    - Consistent maintenance and station operations.

  - Data record is reasonably complete and usually high quality.
  - Hourly or sub-hourly data.
- Network weaknesses:
  - Nearly all sites are located at airports.
  - Data quality can be related to size of airport—smaller airports tend to have poorer datasets.
  - Influences from urbanization and other land-use changes.

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

G.11. Weather For You Network (WX4U)

- Purpose of network: allow volunteer weather enthusiasts around the U.S. to observe and share weather data.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Precipitation.
  - Wind speed and direction.
  - Wind gust and direction.
  - Pressure.
- Sampling frequency: 10 minutes.
- Reporting frequency: 10 minutes.
- Estimated station cost: unknown.
- Network strengths:
  - Stations are located throughout the U.S.
  - Stations provide near-real-time observations.
- Network weaknesses:
  - Instrumentation platforms can be variable.
  - Data are sometimes of questionable quality.

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

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NPS/SECN/NRTR—2007/010, April 2007

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