National Park Service
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Natural Resource Program Center
Fort Collins, Colorado

Weather and Climate Inventory
National Park Service
Mojave Desert Network

Natural Resource Technical Report NPS/MOJN/NRTR—2007/007

ON THE COVER
Inyo Mountains, looking southeast from near Manzanar National Historic Site

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WRCC Report 2007-03

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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
AZMET	The Arizona Meteorological Network
BLM	Bureau of Land Management
CARB	California Air Resources Board
CASTNet	Clean Air Status and Trends Network
CCRFCD	Clark County (Nevada) Regional Flood Control District
CDEC	California Data Exchange Center
CEMP	Community Environmental Monitoring Program
CIMIS	California Irrigation Management Information System
CLR	China Lake/Fort Irwin network
CLIM-MET	USGS Southwest Climate Impact Meteorological Stations network
COOP	Cooperative Observer Program
CRN	Climate Reference Network
CWOP	Citizen Weather Observer Program
DEVA	Death Valley National Park
DFIR	Double-Fence Intercomparison Reference
DOENTS	Department of Energy Nevada Test Site
DOERD	Department of Energy Office of Repository Development
DRI	Desert Research Institute
DST	daylight savings time
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FIPS	Federal Information Processing Standards
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GPMP	NPS Gaseous Pollutant Monitoring Program
GPS	Global Positioning System
GPS-MET	NOAA ground-based GPS meteorology
GRBA	Great Basin National Park
I&M	NPS Inventory and Monitoring Program
JOTR	Joshua Tree National Park
LAME	Lake Mead National Recreation Area
LEO	Low Earth Orbit
LST	local standard time
MANZ	Manzanar National Historic Site
MDN	Mercury Deposition Network
MOJA	Mojave National Preserve
MOJN	Mojave Desert Inventory and Monitoring Network
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
NRCS-SC	NRCS snowcourse network
NWS	National Weather Service
PARA	Grand Canyon – Parashant National Monument
PDO	Pacific Decadal Oscillation
POMS	Portable Ozone Monitoring System
PRISM	Parameter Regression on Independent Slopes Model
RAWS	Remote Automated Weather Station network
RCC	regional climate center
SAO	Surface Airways Observation network
Surfrad	Surface Radiation Budget network
SNOTEL	Snowfall Telemetry network
SOD	Summary Of the Day
T-REX	Sierra Rotors Project
UPR	Union Pacific Railroad network
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
WBAN	Weather Bureau Army Navy
WMO	World Meteorological Organization
WRCC	Western Regional Climate Center

Executive Summary

Climate is a dominant factor driving the physical and ecologic processes affecting the Mojave Desert Inventory and Monitoring Network (MOJN). The MOJN includes both hot desert environments and 'high desert' or cold desert environments. Wintertime temperature inversions strongly influence the structure of MOJN ecosystems, particularly to the south. Climate phenomena in the tropical Pacific, such as the El Niño Southern Oscillation (ENSO), and the northern Pacific Ocean, such as the Pacific Decadal Oscillation (PDO), are linked to interannual variations in temperature and precipitation across the MOJN. On top of the background of climate variability is superimposed the short- and long-term effects of climate change caused by human effects. Scientists and park managers are concerned about the potential impact of global warming on species extinctions in the MOJN and the ability of species to adapt to potential future climate conditions. Because of its influence on the ecology of MOJN park units and the surrounding areas, climate was identified as a high-priority vital sign for MOJN 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 the MOJN. In this report, we provide the following information:

- Overview of broad-scale climatic factors and zones important to MOJN park units.
- Inventory of weather and climate station locations in and near MOJN 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.

Much of the MOJN is in the rain shadow created by the Sierra Nevada and the Transverse Ranges of California, creating a moisture gradient with drier conditions prevailing in the west grading toward greater total annual precipitation in the east. Precipitation in western MOJN mostly results from Pacific Ocean winter storms, while locations to the east see more convective summer precipitation. Mean annual precipitation totals range from 50 mm at Death Valley National Park (DEVA), which has had years with no recorded rainfall, to well over 750 mm at higher elevations in Great Basin National Park (GRBA). The warm arid conditions that characterize much of the MOJN generally lead to mild winters and hot summers. However, winter temperatures can regularly get below -10°C in GRBA. Daytime summer temperatures routinely reach above 40°C in some MOJN units, including the nation's highest (and world's second highest) temperature (57°C) at DEVA. Long-term temperature trends in the MOJN indicate warming over the past century.

Through a search of national databases and inquiries to NPS staff, we have identified 58 weather and climate stations within MOJN park units. Lake Mead National Recreation Area (LAME) and Mojave National Preserve (MOJA) have the most stations within park boundaries (14 stations each). Most of the weather and climate stations identified for MOJN park units had metadata and

data records that are sufficiently complete and satisfactory in quality. Grand Canyon – Parashant National Monument (PARA) was not in MOJN at the time of this inventory.

Much of the desert environment within MOJN park units has little or no weather or climate station coverage, with most stations being near visitor centers and other high-traffic areas. Some park units, like Joshua Tree National Park (JOTR) and LAME, have nearby populated areas that provide denser weather and climate station coverage. Even Manzanar National Historic Site (MANZ) has a fairly dense coverage of nearby automated stations that are associated with the Sierra Rotors Project (T-REX).

The majority of stations we have identified for DEVA are concentrated along Highway 190, mostly near the main visitor center at Furnace Creek. Away from Highway 190, station coverage drops off considerably. NPS has been considering removing the RAWS (Remote Automated Weather Station) site "Panamint," located on the west side of the Panamint Range. We strongly urge the NPS to reconsider this plan, as this RAWS station is the only near-real-time weather station within the southern half of DEVA. Climate monitoring efforts in DEVA could benefit greatly by installing one remote near-real-time station, such as RAWS, in both the northwestern and southeastern portions of the park unit. Suitable locations for such sites could include Grapevine (north) and Ashford Mill (south).

Most of the weather/climate stations within GRBA are situated along the Lehman Creek and Baker Creek drainages in northern GRBA, including the visitor center. Elsewhere, there is no station coverage. If resources allow, climate monitoring efforts in GRBA could benefit by partnering with local agencies to install one remote near-real-time station such as a RAWS or SNOTEL (Snowfall Telemetry Network) station in the southern half of GRBA. A suitable location for this site would be along the Snake Creek drainage, due to its relatively easy access.

Lake Mead National Recreation Area (LAME) has very few active stations with long records (e.g., Willow Beach). NPS would benefit by continuing the operation of such stations, as these longer records provide valuable documentation of ongoing climate changes within LAME. There are even fewer automated weather stations within the park unit. As a result, weather monitoring efforts within LAME must rely fairly heavily on outside stations, such as RAWS stations near eastern LAME and stations in the Las Vegas metropolitan area. However, these stations may not always represent accurately the local weather conditions at LAME. Therefore, NPS may want to consider installing near-real-time stations at popular marinas such as Temple Bar Marina.

Both JOTR and MOJA have more coverage of active weather/climate stations in the central and western portions of the park units, compared to the eastern portions. This is particularly noticeable at JOTR. The only active station within the eastern two-thirds of the park unit is the Gaseous Pollutant Monitoring Program (GPMP) station "Cottonwood Canyon," in south-central JOTR. The NPS may want to consider installing a remote near-real-time station like a RAWS station along the main road that runs between Cottonwood and Twentynine Palms. Despite the relatively sparse station coverage in MOJA, the very nature of this park unit (a national preserve) implies that minimum station coverage is likely a satisfactory objective. There is at least one active long-term station in the park at Mitchell Caverns, for which continued operation should be encouraged and would benefit climate monitoring efforts in MOJA.

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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). Proper understanding of ecosystem dynamics requires an understanding of the roles of climate variability, hydrologic interactions with soils, and adaptive strategies of biota to capitalize on spatially and temporally variable moisture dynamics (Noy-Meir 1973; Bailey 1995; Rodriguez-Iturbe 2000; Reynolds et al. 2004). 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; Heister 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 Mojave Desert Inventory and Monitoring Network (MOJN) 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 MOJN (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 MOJN park units.
- Inventory of locations for all weather stations in and near MOJN 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 questions to be addressed by climate- and weather-monitoring activities in MOJN are as follows (Heister et al. 2005):

A. Is the timing, intensity, duration, and geographic distribution of precipitation events in network parks changing over time?
B. Is the annual average temperature, minimum temperature, and maximum temperature in network parks changing over time?

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.

Table 1.1. Park units in the Mojave Desert Network.

Acronym	Name
DEVA	Death Valley National Park
GRBA	Great Basin National Park
JOTR	Joshua Tree National Park
LAME	Lake Mead National Recreation Area
MANZ	Manzanar National Historic Site
MOJA	Mojave National Preserve

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 more and better inventory data and station-tracking procedures. Some national weather/climate networks are associated with the National Oceanic and Atmospheric Administration (NOAA), including the National Weather Service (NWS) Cooperative Observer Program (COOP). Other national networks include the interagency Remote Automated Weather Station (RAWS) network and the U.S. Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS) Snowfall Telemetry (SNOTEL) and snowcourse networks. Usually a single agency, but sometimes a consortium of interested parties, will jointly support a particular weather/climate network.

1.1.2. NPS I&M Networks

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

1.2. Weather versus Climate Definitions

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

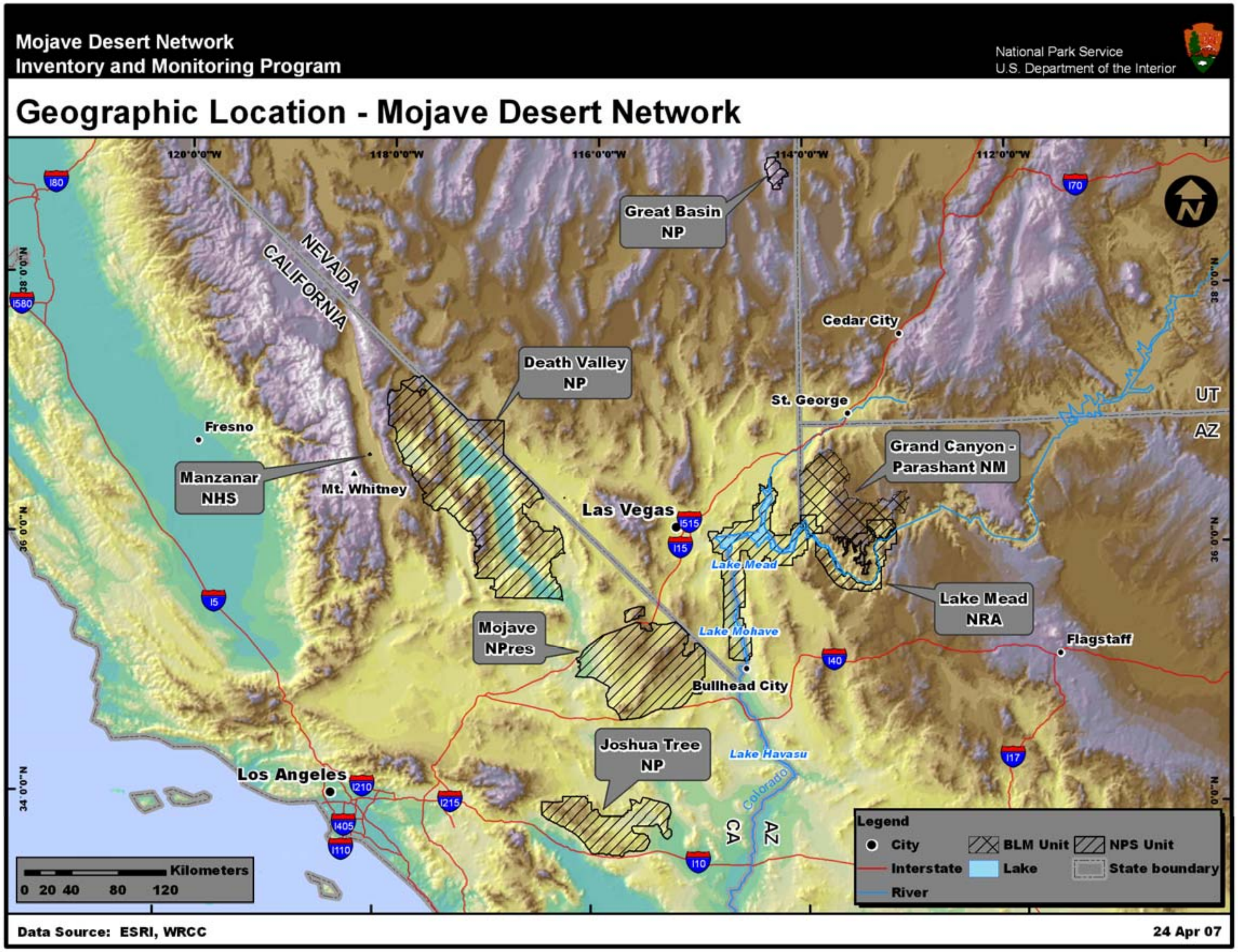


Figure 1.1. Map of the Mojave Desert Network.

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

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

1.3. Purpose of Measurements

Climate inventory and monitoring 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 MOJN climate is presented. However, this process is only one step in evaluating and designing a climate-monitoring program. The following steps must also be included:

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

Throughout the design process, there are various factors that require consideration in evaluating weather and climate measurements. Many of these factors have been summarized by Dr. Tom Karl, director of the NOAA National Climatic Data Center (NCDC), and widely distributed as the "Ten Principles for Climate Monitoring" (Karl et al. 1996; NRC 2001). These 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 preventive maintenance is effective but requires much planning and skilled technical staff. Changes in technology and products require retraining and continual re-education. Travel, logistics, scheduling, and seasonal access restrictions consume major amounts of time and budget but are absolutely necessary. Without such attention, data gradually become less credible and then often are misused or not used at all.

1.4.4. Automated versus Manual Stations

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

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

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 World Meteorological Organization (WMO 1983; 2005), the American Association of State Climatologists (AASC 1985), the U.S. Environmental Protection Agency (EPA 1987), Finklin and Fischer (1990), the RAWS program (Bureau of Land Management [BLM] 1997), and the National Wildfire Coordinating Group (2004). 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 nearby stations.

2.0. Climate Background

Climate is a primary factor controlling the structure and function of ecosystems in the MOJN. An understanding of both current climate patterns and climate history in the MOJN is important to understanding and interpreting change and patterns in ecosystem attributes (Davis et al. 1998; Heister et al. 2005). The modern distribution and ecology of plant and animal communities should be linked at a broad temporal scale to the climatic history of the Great Basin and Mojave Desert regions. This information provides significant power to the interpretation of other potential vital signs and provides a basis for understanding the response of desert ecosystems to future climate variation (Hereford et al. 2004). It is essential that the MOJN park units have an effective climate monitoring system to track climate changes and to aid in management decisions relating to these changes. In order to do this, it is essential to understand the climate characteristics of the MOJN, as discussed in this chapter.

2.1. Climate and the MOJN Environment

Climate across the MOJN is one of the most extreme and variable in the world with significant diurnal variation in temperature (Bailey 1995). The association between topography and climatic factors such as precipitation and temperature creates variable local climatic conditions within parks based on elevation. Most of the MOJN park units are located in a hot desert environment and include southern DEVA, JOTR, western LAME, and MOJA. Northern portions of DEVA, GRBA, and MANZ are located in a ‘high desert’ or cold desert climate more typically of the Great Basin region. Eastern portions of LAME, abutting Grand Canyon – Parashant National Monument (PARA), are part of the Colorado Plateau and its climate characteristics (see Davey et al. 2006a; 2006b) Desert conditions prevail across the MOJN because much of this region is in the rain shadow created by the Sierra Nevada and the Transverse Ranges of California. As air masses from coastal California meet the mountain ranges they rise and cool on the windward side of these mountains, and atmospheric moisture condenses and precipitates. On the leeward side of these mountain ranges, air masses descend and warm, reducing the potential for precipitation. The rain shadow created by Sierra Nevada and Transverse Ranges, in combination with other regional factors, creates a moisture gradient with drier conditions prevailing in the west grading toward greater total annual precipitation in the east. In the west, precipitation mostly results from regional winter storms originating over the Pacific Ocean. Toward the east, in LAME and PARA, there is increasing likelihood of summer precipitation resulting from localized convective storms. The rain and snow that precipitates on the mountains ultimately enters watersheds, some of which empty in desert basins; the Mojave River is an example of such a watershed. Runoff in the mountains creates surface flows that can transport large sediment loads, which are deposited downstream in the alluvial valleys and playas.

During winter, several gradients related to freezing temperatures are strong determinants of desert ecosystems. In general, winter temperatures decrease with increasing elevation and increasing latitude in the Mojave Desert and Great Basin, but this pattern is complicated by cold-air inversions that form in the closed basins characteristic of the Basin and Range physiographic province. These temperature inversions can affect the elevational distribution of plants in the MOJN, although this influence is weaker in northern portions of the MOJN due to stronger winter storms that mix the air more thoroughly and disrupt the inversions (Grayson 1993).

The topography characteristics of the MOJN also promote seasonal climatic phenomena. For example, during warm seasons, “dust devils” form when thermal energy in desert basins increases and rises in thermal columns causing large updrafts. When humidity is sufficient in the area, these thermal updrafts can also contribute to convective thunderstorms such as those common during summer monsoon rains. Other topographically-influenced climate phenomena include diurnal canyon circulations, which induce temperature fluctuations that create opportunities for plants to exceed their normal elevational limits. For example, in some areas ponderosa pines or firs may be found lower in canyons than they would be if on more-exposed slopes. At a broader scale, the increase of regional air pressure in the Great Basin during the fall and winter months influences air flows such as the Santa Ana winds that blow out of the deserts at high velocity toward the west coast.

Events in the tropical Pacific and northern Pacific Ocean are linked to variations in temperature and precipitation across the MOJN. Interannual climate variations in the MOJN are influenced strongly by the El Niño Southern Oscillation, or ENSO (Heister et al. 2005). El Niño events produce above normal precipitation more frequently and result in significantly higher precipitation amounts compared to La Niña events. Multi-decadal climate variation across the desert region follows a pattern best expressed by the Pacific Decadal Oscillation, or PDO (Mantua 2000; Mantua and Hare 2002; Hereford et al. 2002; Hereford et al. 2004). These variations multiply and combine in complex patterns that affect entire populations, species, and ecosystems at the regional level. Desert plant and animal communities are highly adaptable to the short-term variability in climate but respond on the scale of millennia to large swings in climate variability, which ultimately drives change in the plant and animal communities in the deserts. On top of the background of climate variability is superimposed the short- and long-term effects of climate change caused by human effects such as heat islands in and near cities, insulating effects of increased carbon dioxide and aerosols, and decreased insolation by haze blankets (Heister et al. 2005)

Climate affects the water resources of the MOJN, which are critical in determining distributions of plant and animal species in the region. These water resources are very sensitive to climate variability and change. Small changes in mean annual temperature, for instance, can greatly change winter snowfall, altering snowpack and the streams and recharge that are dependent on snowmelt. Changes to stream and lake temperature from changed flow volume or changes in air temperature can affect aquatic species, as can water chemistry, volume, and duration of water in ephemeral systems. Even small changes in climate parameters can have great affects in soil moisture, since a delicate temperature-precipitation-plant transpiration balance governs the availability of this tiny fraction of the water budget, the fraction that is essential to plant life over most of the desert landscape.

Some studies suggest that in response to climate changes over time the vegetation in the Great Basin and Mojave Desert has been in continual geographic and altitudinal movement for thousands of years (Tausch et al. 1995; Thompson et al. 2004). Many scientists suggest that we are currently in another interglacial period and to understand how plant and animal communities may respond to future climate change (glaciation or global warming) communities must be examined with history in mind (Gould 1991). Conservation biologists across the Great Basin-Mojave Desert Region are concerned about the potential impact of global warming on species extinctions and the ability of species to re-colonize in suitable locations under current and potential future climate conditions. As temperatures warm and montane habitats shrink, local extinction of some species is considered likely (Brussard et al. 1998; Wagner et al. 2003).

2.2. Spatial Variability

Much of the MOJN is in a dry, hot desert environment, including DEVA, JOTR, LAME, and MOJA. As a result, annual precipitation totals are generally very low across the MOJN (Figure 2.1). This precipitation generally falls in the form of rain, except for GRBA, where significant snowfall occurs during the winter months. The least amount of precipitation occurs in DEVA, where annual precipitation is approximately 50 mm and there have been years with no recorded rainfall. In fact, the valley floor at DEVA receives the least precipitation in the U.S. (NPS 2001). At nearby MANZ, the Owens Valley is well protected from ocean air masses by the Sierra crest and thus experiences a predominantly high-desert climate. Most precipitation at MANZ falls as a mix of rain and snow during the months from December through March, while a limited amount of precipitation falls from summer thunderstorms. Mean annual precipitation at MANZ totals about 100 mm per year (NPS 1996). At JOTR, precipitation occurs primarily in the form of rainfall, also averaging 100 mm per year, although this average varies widely across the park unit. The Pinto Basin average is under 50 mm of precipitation per year while higher elevations areas may receive up to 200 mm of rain per year (NPS 1995). At LAME, precipitation averages 110 mm annually (Heister et al. 2005) but, like JOTR, these values vary widely across the park unit. Precipitation at MOJA averages about 220 mm per year (NPS 2000). The wettest park unit in the MOJN is GRBA, where higher elevations generally receive well over 750 mm of precipitation each year. Precipitation in GRBA occurs primarily in the form of winter snows and summer thunderstorms. While valley locations in GRBA generally receive less than 150 mm of precipitation each year, the highest mountain locations in GRBA have been known to receive over 2000 mm (NPS 1992a).

It is interesting to note that the MOJN spans a transition zone regarding the influence of summer convective precipitation, particularly the southwest monsoon, on its park units. Mean July precipitation across the MOJN (Figure 2.2) shows that the influence of summer convective precipitation is greatest in eastern portions of MOJN, dropping off dramatically at and just west of the Sierra crest and the mountains of southern California. More specifically, GRBA and portions of LAME are strongly influenced by summer convective precipitation and receive upwards of 50 mm of precipitation in July. In contrast, park units like DEVA and MANZ see little if any summer precipitation. Other park units like JOTR and MOJA show a moderate influence from summer convective precipitation, particularly at higher elevations.

The seasonal timing of precipitation varies greatly across MOJN park units (Figure 2.3). For instance, much of the precipitation at DEVA (Figure 2.3a) occurs during the winter months. This winter maximum in precipitation is also evident at JOTR (Figure 2.3b); however, a second maximum occurs in August, tied to summer convective precipitation. Precipitation falls fairly consistently through the year in GRBA (Figure 2.3c), with slight increases during the spring and fall months.

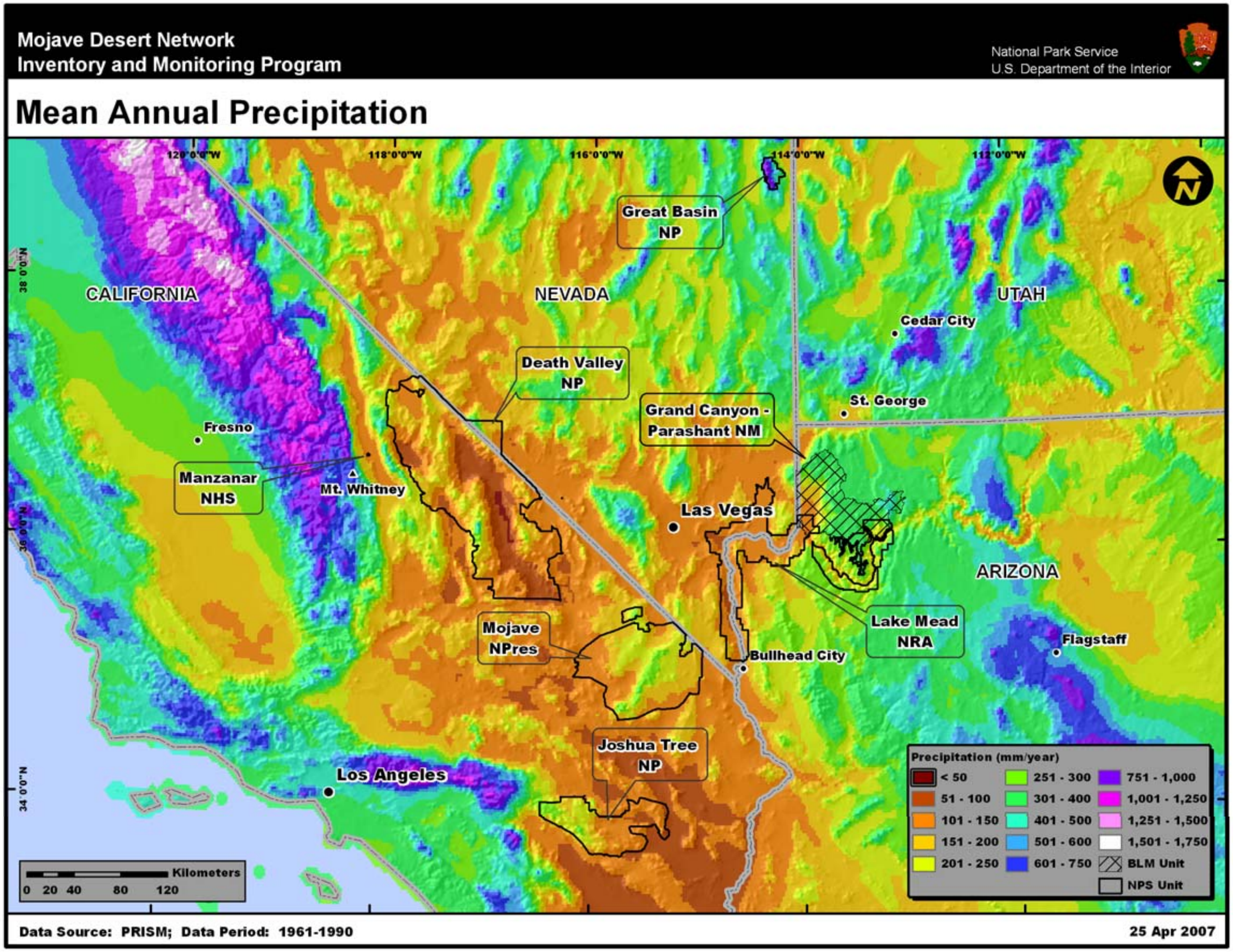


Figure 2.1. Mean annual precipitation, 1961-1990, for the MOJN.

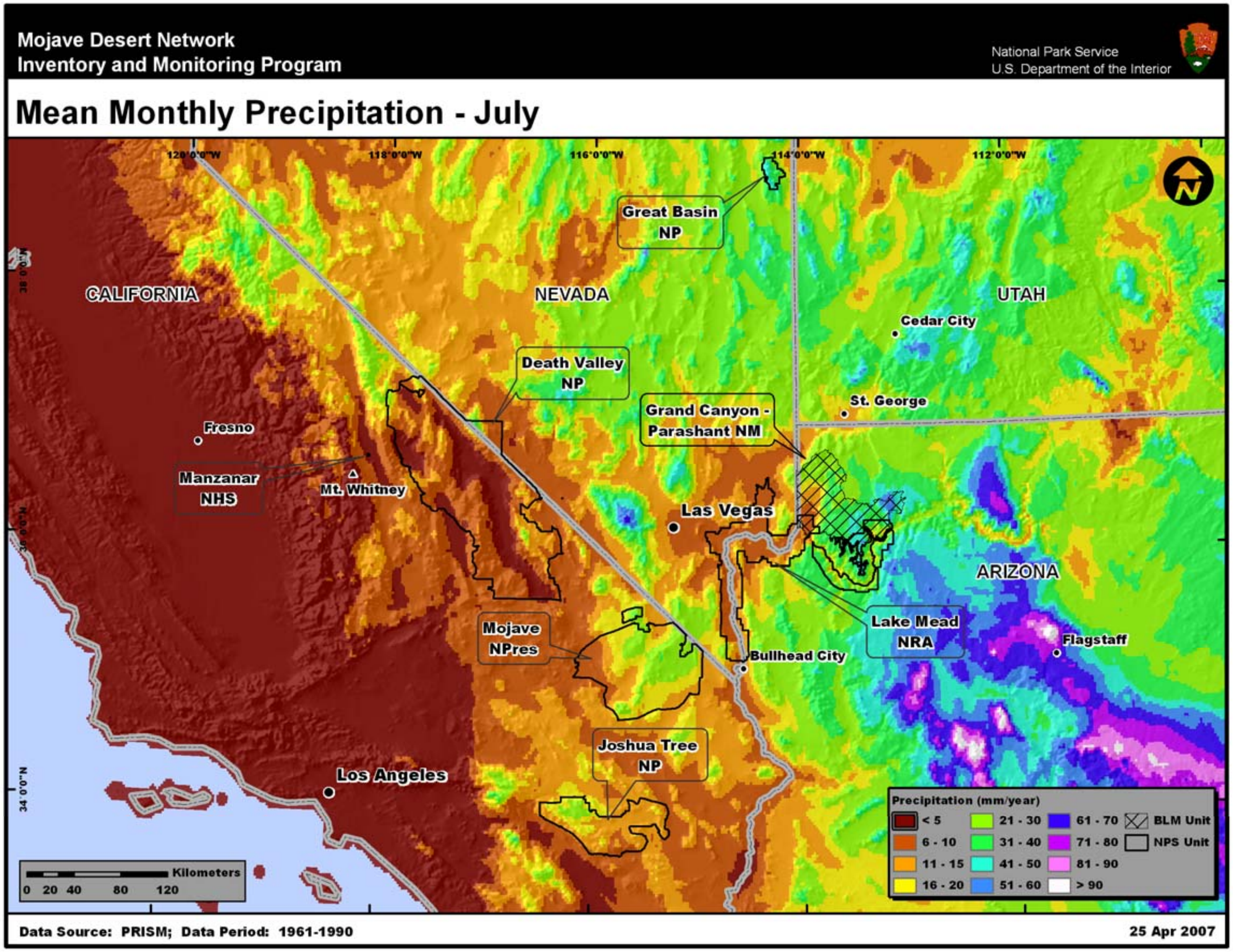


Figure 2.2. Mean July precipitation, 1961-1990, for the MOJN.

a)
b)
c)

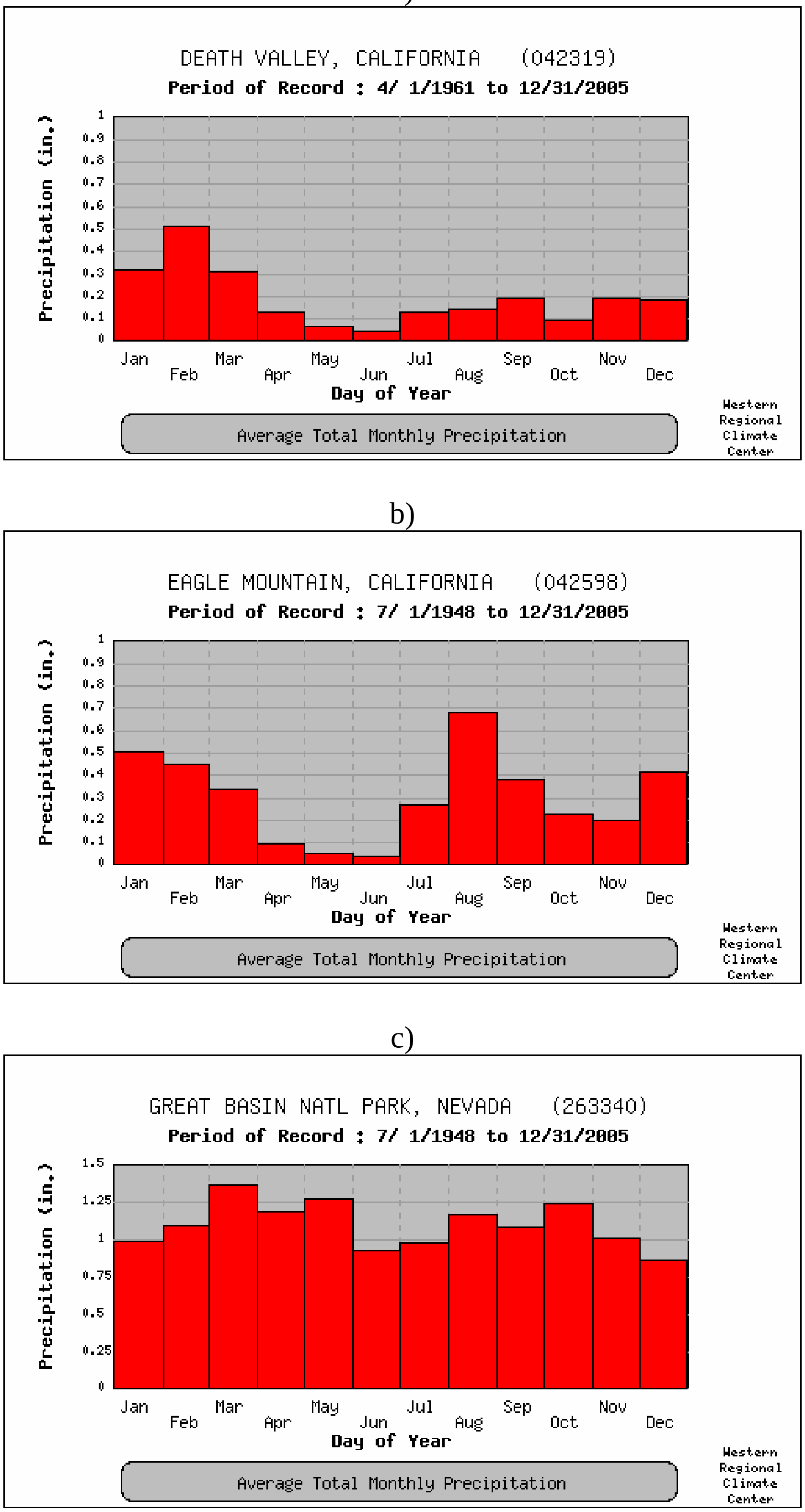


Figure 2.3. Mean monthly precipitation at selected locations in the MOJN. Locations include DEVA (a); Eagle Mountain, near JOTR (b); and GRBA (c).

The warm arid conditions that characterize much of the MOJN generally lead to mild winters and hot summers across the network. Mean annual temperatures in the MOJN (Figure 2.4) are as low as 1-3°C in GRBA but are quite warm across southern MOJN park units, staying well above 20°C in some portions of DEVA and JOTR. At DEVA, nighttime temperatures within most sections of the park unit rarely drop below freezing, even during the winter (e.g., Figure 2.5) while daytime summer temperatures routinely reach above 40°C (e.g., Figure 2.6). In fact, DEVA has recorded the nation's highest (and world's second highest) temperature, at 57°C, or 134°F (NPS 2001). Like DEVA, many of the other southern park units of the MOJN exhibit mild winter temperatures. For instance, MOJA sees winter temperatures ranging from 1-16°C, JOTR sees winter temperatures between 4-18°C, and LAME sees winter temperatures ranging from 12-19°C (Heister et al. 2005). This is in stark contrast to the Basin and Range province to the north, where minimum temperatures can regularly reach below -10°C. At GRBA, January temperatures can vary from -23°C up to 4°C.

With the exception of highest elevations in the MOJN, summer temperatures are very hot. Summer daytime temperatures are generally between 13-18°C on the mountain ridges of GRBA. For the rest of the MOJN, summer maximum temperatures are generally between 20-30°C at the higher elevations, such as in GRBA, and easily reach above 40°C at the lower elevations of the southern MOJN park units (Heister et al. 2005).

2.3. Temporal Variability

Multi-decadal climate variation across the MOJN region appears to follow variations in the Pacific Decadal Oscillation, or PDO (Mantua and Hare 2002; Hereford et al. 2002; Hereford et al. 2004). Climate trend analyses across the Mojave Desert suggest that for the next 2-3 decades, climate in the region may become drier in a pattern similar to mid-century conditions (Hereford et al. 2002; Hereford et al. 2004). ENSO cycles strongly influence interannual precipitation variations throughout the MOJN as well, with wetter conditions generally occurring during warm ENSO (El Niño) phases. Some of the wetter winters in the MOJN are particularly notable, such as the winter of 2004-2005 that contributed to the memorable wildflower blooms across DEVA and the other MOJN park units in the spring of 2005.

An investigation of daily precipitation amounts around the MOJN region over the last century (Figure 2.7) reveals several multi-decadal precipitation regimes that are largely consistent with well-known droughts across the Southwest (Heister et al. 2005). The 1890s were dry years, followed by wet years from the early 1900s through the 1920s. The early 1940s were also somewhat wet, followed by 2-3 decades of dry conditions. After this dry period, the 1970s and 1980s were generally wet across the MOJN. In fact, some studies (e.g., Hereford et al. 2002; Hereford et al. 2004) have found that the period between 1976 and 1998 was the wettest period of the last century for the MOJN region. Similar patterns have been observed in annual precipitation at GRBA between 1952 and 2004 (DuBois and Green 2005).

Long-term trends in ambient temperature (Figure 2.8) are difficult to detect due to the high variability in daily and annual temperatures. It is generally apparent, however, that temperatures have become warmer over the past century (NAST 2001). For example, DuBois and Green (2005), in an analysis of average maximum and minimum temperatures at GRBA between 1952 and 2004, found a significant warming trend for annual average minimum temperature. The

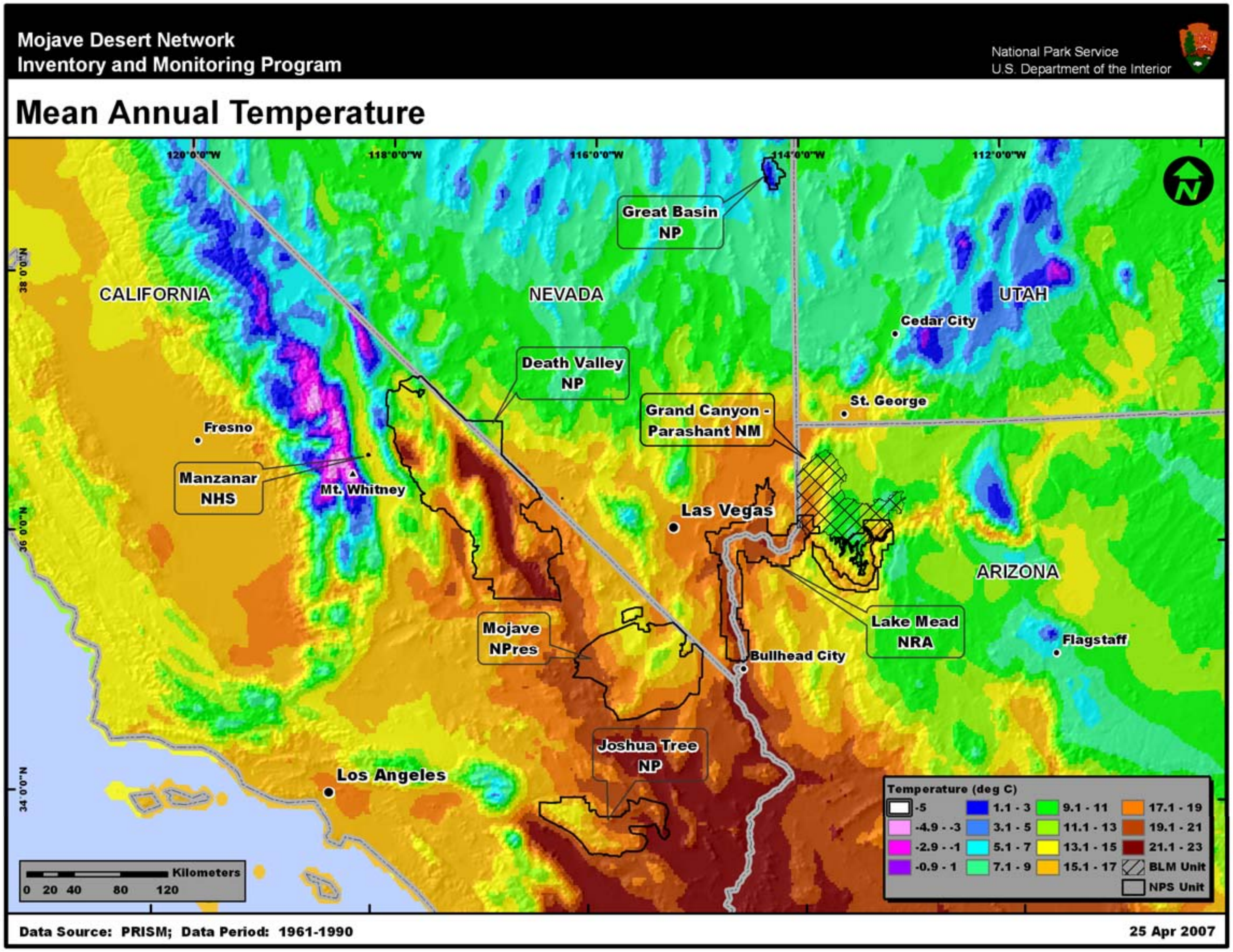


Figure 2.4. Mean annual temperature, 1961-1990, for the MOJN.

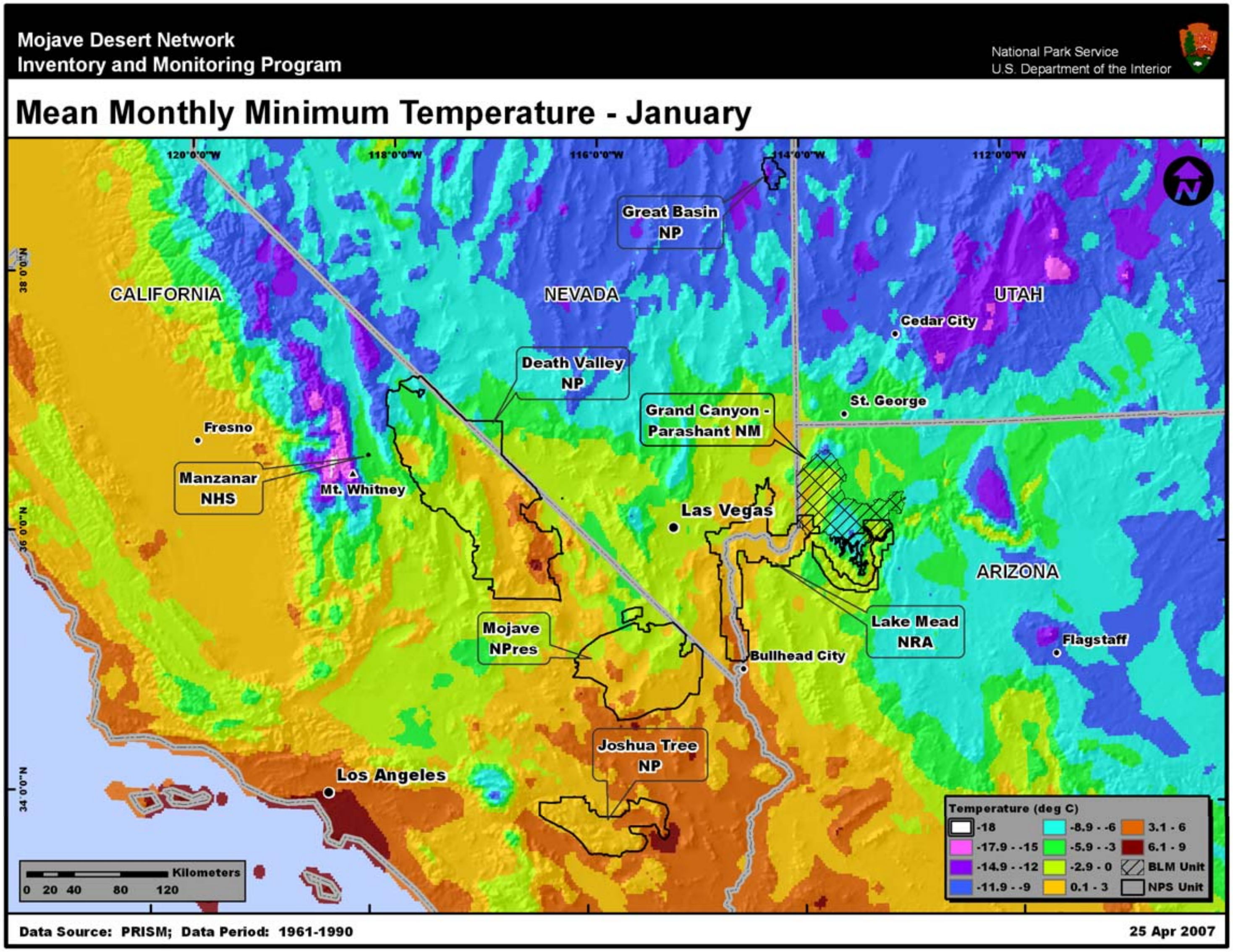


Figure 2.5. Mean January minimum temperature, 1961-1990, for the MOJN.

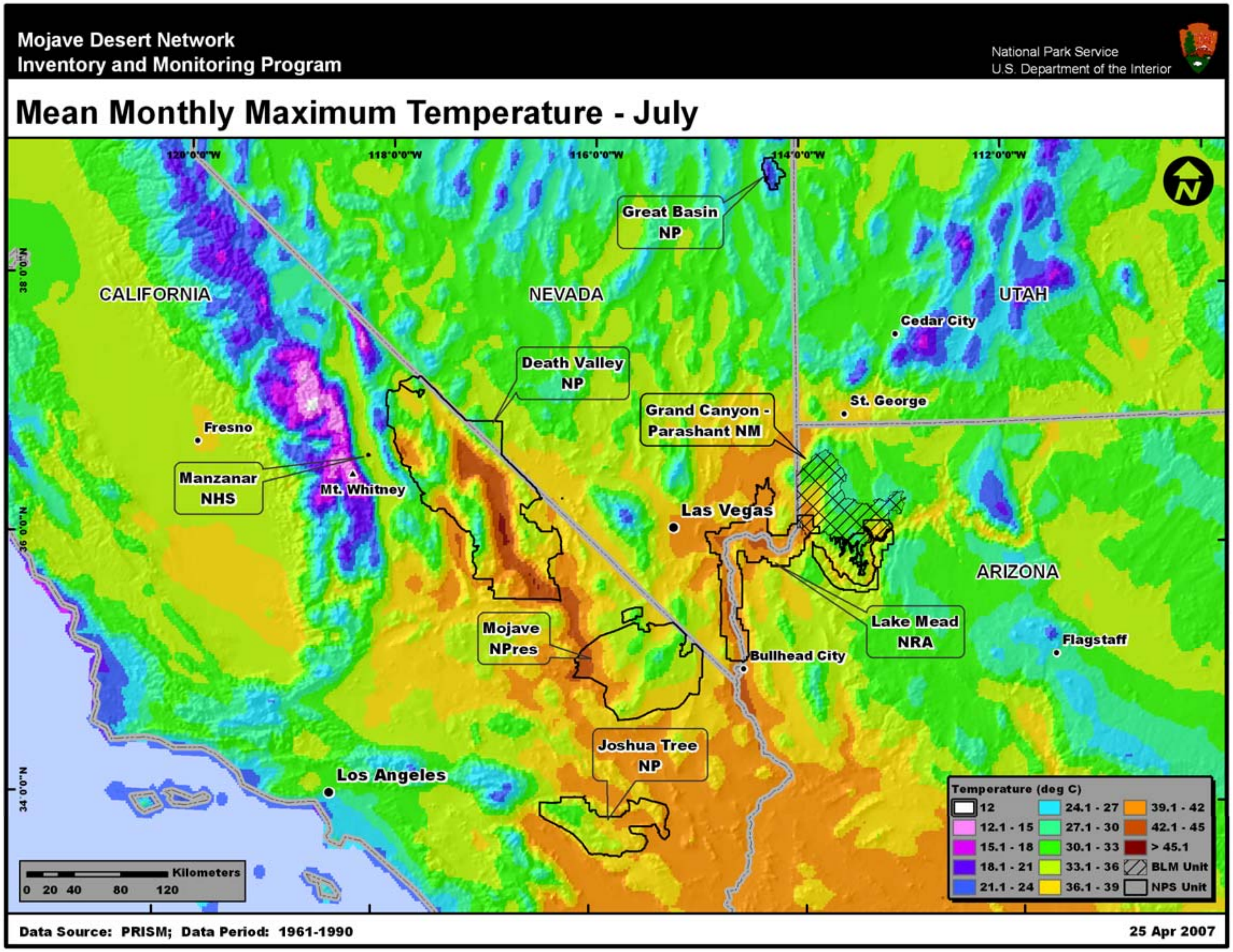
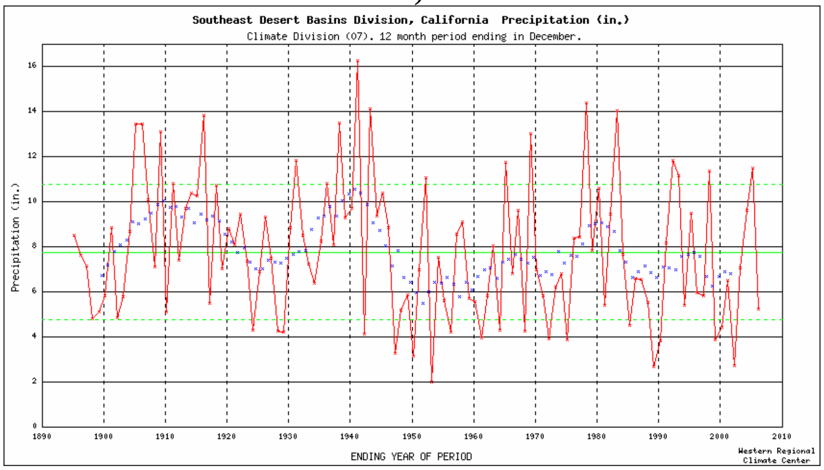
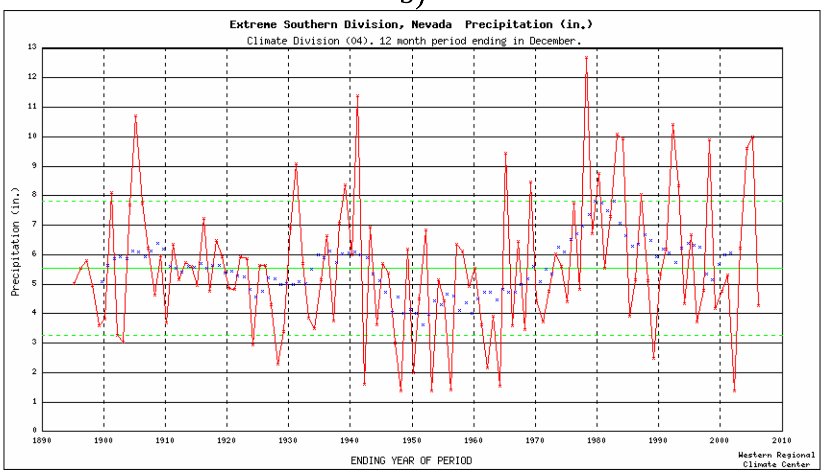


Figure 2.6. Mean July maximum temperature, 1961-1990, for the MOJN.

a)



b)



c)

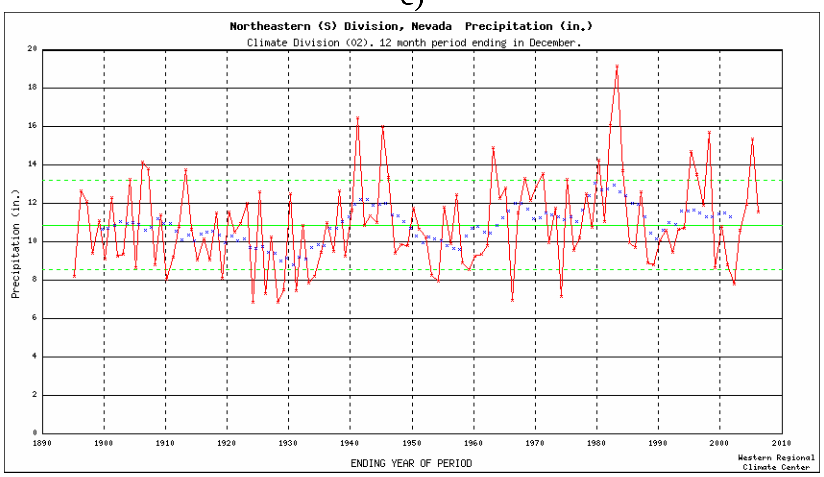


Figure 2.7. Precipitation time series, 1895-2005, for selected regions in the MOJN. These include twelve-month precipitation (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include southeastern California (a), southernmost Nevada (b), and northeastern Nevada (c).

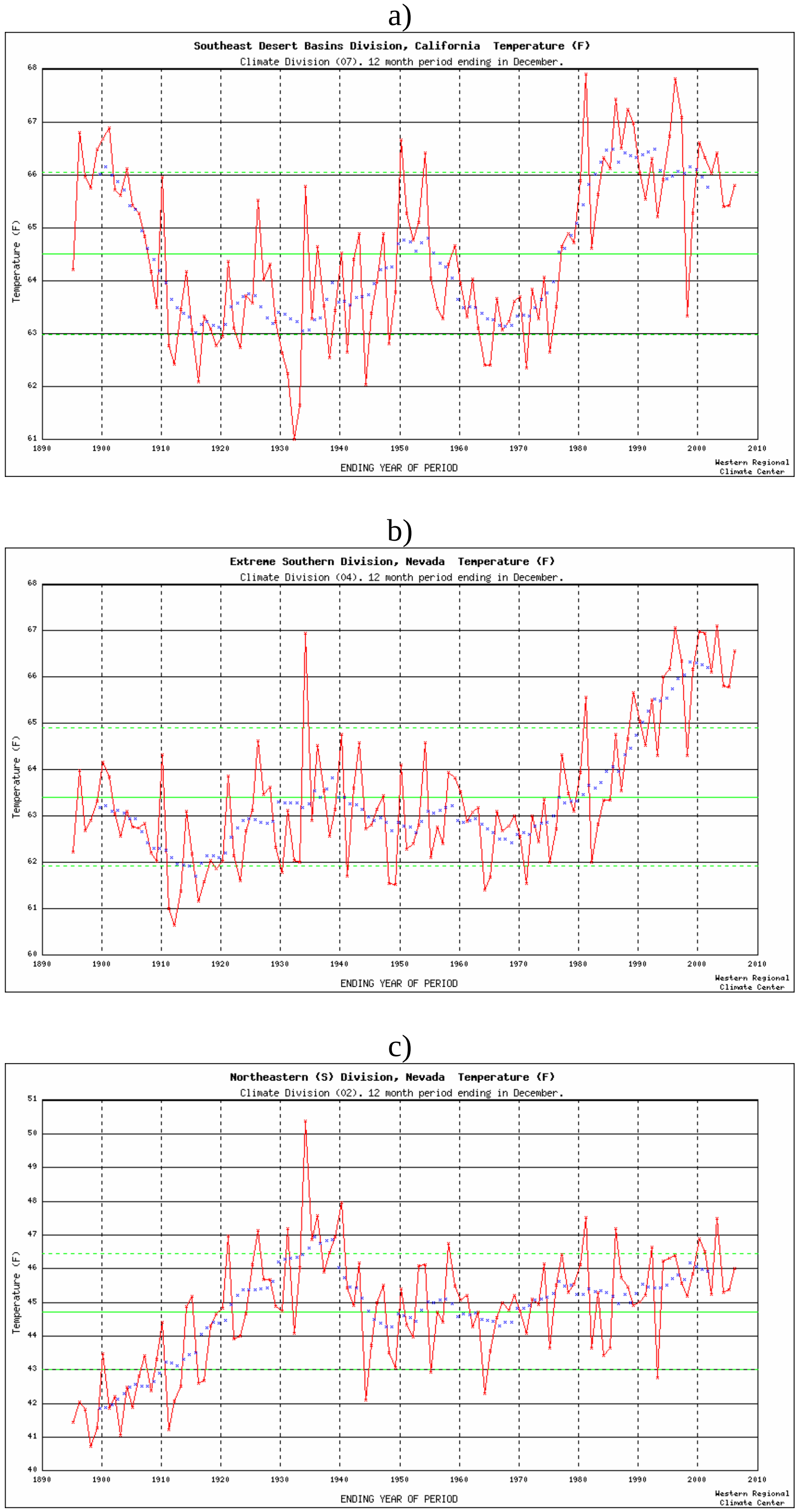


Figure 2.8. Temperature time series, 1895-2005, for selected regions in the MOJN. These include twelve-month average temperature (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include southeastern California (a), southernmost Nevada (b), and northeastern Nevada (c).

signature of this net warming varies quite dramatically across the MOJN. Some regions, like northeastern Nevada (Figure 2.8c), have shown more warming during the early part of the past century. In the remaining portions of the MOJN, however, most of the warming appears to have occurred in the past few decades (e.g., Figures 2.8a,b). Short-term interannual temperature changes in the MOJN can generally be related to ENSO cycles (Heister et al. 2005). Trends toward increasing temperatures are generally reflected in available data from across the MOJN, potentially suggesting a regional warming trend. However, 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 station moves. These patterns highlight the emphasis on measurement consistency that is needed in order to properly detect long-term climatic changes.

2.4. Parameter Regression on Independent Slopes Model (PRISM)

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

3.0. Methods

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

3.1. Metadata Retrieval

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

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

The primary source of metadata at WRCC is the Applied Climate Information System (ACIS), a joint effort among RCCs and other NOAA entities. Metadata for MOJN weather/climate stations identified from the ACIS database are available in file “MOJN_from_ACIS.tar.gz” (see Appendix F). Historic metadata pertaining to major climate- and weather-observing systems in the U.S. are stored in ACIS where metadata are linked to the observed data. A distributed system, ACIS is synchronized among the RCCs. Mainstream software is utilized, including Postgress, Python™, and Java™ programming languages; CORBA®-compliant network software; and industry-standard, nonproprietary hardware and software. Metadata and data for all major national climate and weather networks have been entered into the ACIS database. For this project, the available metadata from many smaller networks also have been entered but in most cases the actual data have not yet been entered. Data sets are in the NetCDF (Network Common Data Form) format, but the design allows for integration with legacy systems, including non-NetCDF files (used at WRCC) and additional metadata (added for this project). The ACIS also supports a suite of products to visualize or summarize data from these data sets. National climate-monitoring maps are updated daily using the ACIS data feed. The developmental phases of ACIS have utilized metadata supplied by the NCDC and NWS with many tens of thousands of entries, screened as well as possible for duplications, mistakes, and omissions.

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

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

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

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

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

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

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

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

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

3.2. Criteria for Locating Stations

To identify weather and climate stations for each park unit in the MOJN we selected only those stations located within 40 km of the MOJN park units. This buffer distance was selected in an attempt to include at least a few automated stations from major networks such as SAO, but also to keep the size of the stations lists 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 MOJN. 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 MOJN region in relation to the boundaries of the NPS park units within the MOJN. 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 MOJN region are associated with at least one of 23 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 MOJN.

Acronym	Name
AZMET	The Arizona Meteorological Network
CARB	California Air Resources Board network
CASTNet	Clean Air Status and Trends Network
CCRFCD	Clark County Regional Flood Control District network
CEMP	Community Environmental Monitoring Program
CIMIS	California Irrigation Management Information System
CLR	China Lake/Fort Irwin Network
COOP	NWS Cooperative Observer Program
CRN	Climate Reference Network
CWOP	Citizen Weather Observer Program
DOENTS	Department of Energy Nevada Test Site network
DOERD	Department of Energy Office of Repository Development network
DRI	Desert Research Institute network
GPMP	NPS Gaseous Pollutant Monitoring Program
GPS-MET	NOAA ground-based GPS meteorology network
NADP	National Atmospheric Deposition Program
NRCS-SC	USDA/NRCS snowcourse network
POMS	Portable Ozone Monitoring System
RAWS	Remote Automated Weather Station network
SAO	NWS/FAA Surface Airways Observation network
SNOTEL	USDA/NRCS SNOTEL network
UPR	Union Pacific Railroad network
USGS	U.S. Geological Survey

4.1.1. The Arizona Meteorological Network (AZMET)

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

4.1.2. California Air Resources Board (CARB) Network

Meteorological measurements are taken at CARB sites in support of their overall mission of promoting and protecting public health, welfare, and ecological resources in California through the reduction of air pollutants, while accounting for economical effects of such measures. Measured elements include temperature, relative humidity, precipitation, and wind speed and direction.

4.1.3. 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.

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

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

4.1.5. Community Environmental Monitoring Program (CEMP)

The CEMP network has 26 monitoring stations. Most CEMP sites have operated since 1999. These sites are intended primarily to monitor airborne levels of manmade radioactivity from activities at the Nevada Test Site. This program is a joint effort between the Nevada Operations office of the Department of Energy and the Desert Research Institute. Standard meteorological elements are measured including temperature, precipitation, wind, barometric pressure, humidity, and solar radiation.

4.1.6. California Irrigation Management Information System (CIMIS)

The California Irrigation Management Information System (CIMIS), operated through the California Department of Water Resources, is a network of over 120 automated weather stations in the state of California. CIMIS stations are used to assist irrigators in managing their water resources efficiently. Measured meteorological elements at CIMIS stations generally include temperature, precipitation, wind, and solar radiation. Some stations measure additional parameters such as soil temperature and moisture.

4.1.7. China Lake/Fort Irwin Network (CLR)

This network of 29 weather stations is located around the China Lake Naval Air Weapons Station and the Fort Irwin National Training Center, providing weather data in support of operations at these bases. This network is located between Death Valley and the Mojave Desert, at the south end of the Owens Valley in east-central California. Stations in CLR generally provide observations of wind direction, wind speed, wind gust, temperature, relative humidity and barometric pressure. Some stations also provide precipitation and solar radiation measurements.

4.1.8. 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.

4.1.9. Climate Reference Network (CRN)

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

4.1.10. 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 standard meteorological elements such as temperature, precipitation, and wind are measured at all CWOP stations, station characteristics do vary, including sensor types and site exposure.

4.1.11. Department of Energy Nevada Test Site (DOENTS) Network

The NOAA/Air Resources Laboratory/Special Operations and Research Division operates this network that provides weather data in support of activities at the Nevada Test Site in southwestern Nevada. The network provides observations of air temperature, relative humidity, wind speed, wind direction, barometric pressure, and precipitation.

4.1.12. Department of Energy Office Of Repository Development (DOERD) Network

This network provides weather data in support of activities at the Yucca Mountain Site in southwestern Nevada. Hourly meteorology elements are measured and include temperature, wind, humidity, barometric pressure, precipitation, and solar radiation.

4.1.13. Desert Research Institute (DRI) Network

The Desert Research Institute (DRI) operates this network of automated weather stations, located primarily in California and Western Nevada. Many of these stations are located in remote mountain and desert locations and provide data that are often used in support of various mountain- and desert-based environmental studies in the region. Meteorology elements are measured every 10 minutes and include temperature, wind, humidity, barometric pressure, precipitation, and solar radiation.

4.1.14. 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 two decades in length.

4.1.15. NOAA Ground-Based GPS Meteorology (GPS-MET) Network
The GPS-MET network is the first network of its kind dedicated to GPS (Global Positioning System) meteorology (see Duan et al. 1996), which utilizes the radio signals broadcast by the satellite 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 barometric pressure.

4.1.16. 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.

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

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

4.1.19. Remote Automated Weather Station (RAWS) Network
The RAWS network is administered through many land management agencies, particularly the BLM and the Forest Service. Hourly meteorology elements are measured and include temperature, wind, humidity, solar radiation, barometric pressure, fuel temperature, and precipitation (when temperatures are above freezing). The fire community is the primary client

for RAWS data. These sites are remote and data typically are transmitted via GOES (Geostationary Operational Environmental Satellite). Some sites operate all winter. Most data records for RAWS sites began during or after the mid-1980s.

4.1.20. NWS Surface Airways Observation (SAO) Network
These stations are located usually at major airports and military bases. Almost all SAO sites are automated. The hourly data measured at these sites include temperature, precipitation, humidity, wind, barometric 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.

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

4.1.22. Union Pacific Railroad Network (UPR)
This is a network of weather stations managed by UPR to support their shipping and transport activities, primarily in the central and western U.S. These stations are generally located along the UPR's main railroad lines. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

4.1.23. U.S. Geological Survey (USGS) Network
These stations are associated with the USGS Southwest Climate Impact Meteorological Stations network (CLIM-MET), which is operated under the American Drylands Project. This project investigates the connection between climate properties and geologic processes in the southwestern U.S. Climate data from this project are being input into regional climate models that simulate future climatic conditions for the region.

4.1.24. California Data Exchange Center (CDEC)
Some stations are identified in this report as CDEC stations. This is a data repository for a variety of California stations from agencies which include but are not limited to the California Department of Water Resources, BLM, and various power and other utility companies. Despite the variety of agencies involved, these stations are all still referred to as CDEC stations. Measured meteorological elements vary widely depending on agency. Data from CDEC stations are usually hourly.

4.1.25. Weather Bureau Army Navy (WBAN)
Some stations are identified in this report as WBAN stations. 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 COOP and SAO networks.

4.1.26. 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. These networks could be present within MOJN 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 MOJN (discussed in Section 4.1) have at most several stations at or inside each park unit (Table 4.2). Most of these are COOP stations.

Table 4.2. Number of stations within or nearby MOJN 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	**DEVA**	**GRBA**	**JOTR**	**LAME**	**MANZ**	**MOJA**
AZMET	**0**(0)	**0**(0)	**0**(0)	**2**(0)	**0**(0)	**2**(0)
CARB	**2**(1)	**0**(0)	**5**(1)	**0**(0)	**0**(0)	**0**(0)
CASTNet	**1**(1)	**1**(1)	**1**(1)	**0**(0)	**0**(0)	**0**(0)
CCRFCD	**0**(0)	**0**(0)	**0**(0)	**31**(1)	**0**(0)	**8**(0)
CDEC	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**5**(0)	**0**(0)
CEMP	**5**(0)	**0**(0)	**0**(0)	**5**(0)	**0**(0)	**0**(0)
CIMIS	**3**(0)	**0**(0)	**11**(0)	**0**(0)	**1**(0)	**0**(0)
CLR	**12**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**5**(1)
COOP	**31**(4)	**7**(1)	**33**(0)	**44**(9)	**10**(0)	**24**(5)
CRN	**1**(1)	**1**(1)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
CWOP	**0**(0)	**0**(0)	**9**(0)	**25**(0)	**0**(0)	**3**(0)
DOENTS	**6**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
DOERD	**9**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
DRI	**20**(0)	**0**(0)	**0**(0)	**2**(0)	**17**(0)	**0**(0)
GPMP	**0**(0)	**1**(1)	**3**(3)	**0**(0)	**0**(0)	**0**(0)
GPS-MET	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)
NADP	**2**(1)	**1**(1)	**1**(1)	**0**(0)	**0**(0)	**0**(0)
NRCS-SC	**0**(0)	**4**(3)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
POMS	**0**(0)	**0**(0)	**0**(0)	**2**(1)	**0**(0)	**0**(0)
RAWS	**6**(2)	**5**(3)	**5**(2)	**15**(1)	**0**(0)	**5**(2)
SAO	**3**(0)	**0**(0)	**5**(0)	**8**(0)	**0**(0)	**3**(0)
SNOTEL	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
UPR	**0**(0)	**0**(0)	**0**(0)	**4**(0)	**0**(0)	**6**(3)
USGS	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**3**(3)
Other	**9**(1)	**0**(0)	**5**(0)	**3**(2)	**5**(0)	**4**(0)
Total	**110**(11)	**21**(11)	**78**(8)	**142**(14)	**33**(0)	**63**(14)

Lists of stations have been compiled for the MOJN. As previously noted, a station does not have to be within park boundaries to provide useful data and information regarding any 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. Northwestern park units (DEVA and MANZ)

Out of the 11 weather and climate stations identified within the boundaries of DEVA (Table 4.3; Figure 4.1), six are active. One of these is a long-term COOP station, while the remaining five stations provide automated weather data. Half of the active stations we identified (three) are near the Furnace Creek visitor center, in east-central DEVA. The COOP station “Death Valley” is located at the Furnace Creek visitor center and provides the longest climate record in the park. This is a manual station that has been active since 1911 and has a very complete data record. Two stations have been identified about 5 km north of Furnace Creek. These include the CASTNet station “Nevares Spring,” which has been operating since 1993, and the CARB station “Death Valley Natl. Park.” The CRN climate station “Stovepipe Wells 1 SW” is located just outside of Stovepipe Wells. About 30 km to the west of Stovepipe Wells is a RAWS station (Hunter Mountain), which has been active since 1989. A second RAWS station (Panamint) is located in the Panamint Range in southwestern DEVA. This second weather station has been active since 1988. A NADP station (Death Valley NP-Cow Creek) operated until 2005.

Table 4.3. Weather/climate stations for northwestern MOJN park units. Stations inside park units and within 40 km of the park unit boundary are included. Missing entries are indicated by “M”.

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Death Valley National Park (DEVA)							
Death Valley Natl. Park	36.507	-116.848	125	CARB	M	Present	Yes
Nevares Spring	36.509	-116.848	125	CASTNet	12/1/1993	Present	Yes
Cow Creek	36.533	-116.883	-46	COOP	7/1/1934	12/31/1961	Yes
Death Valley	36.462	-116.867	-59	COOP	6/1/1911	Present	Yes
Panamint City	36.117	-117.100	1903	COOP	3/25/1965	11/14/1972	Yes
Wildrose R.S.	36.266	-117.185	1250	COOP	12/1/1966	5/1/2000	Yes
Stovepipe Wells 1 SW	36.602	-117.145	24	CRN	5/5/2004	Present	Yes
Death Valley NP-Cow Creek	36.589	-116.978	125	NADP	2/8/2000	5/31/2005	Yes
Hunter Mountain	36.563	-117.474	2097	RAWS	2/1/1989	Present	Yes
Panamint	36.120	-117.088	2097	RAWS	3/1/1988	Present	Yes
Furnace Creek	36.467	-116.883	-67	WBAN	2/1/1955	3/31/1955	Yes
Trona-Athol & Telegraph	35.774	-117.372	498	CARB	M	Present	No
Cottonwood Lakes	36.483	-118.177	3094	CDEC	1/1/1986	Present	No
Amargosa Valley	36.569	-116.459	610	CEMP	9/1/1999	Present	No
Beatty	36.913	-116.756	980	CEMP	10/1/1999	Present	No
Pahrump	36.221	-115.995	777	CEMP	8/1/1999	Present	No
Sarcobatus Flats	37.279	-117.023	1224	CEMP	9/1/1999	Present	No
Tecopa/Shoshone	35.960	-116.262	462	CEMP	2/1/2006	Present	No
Bishop	37.358	-118.404	1271	CIMIS	2/1/1983	Present	No
Owens Lake North	36.489	-117.919	1123	CIMIS	12/1/2002	Present	No
Owens Lake South	36.359	-117.946	1122	CIMIS	4/1/2003	Present	No
4-Corners	35.349	-116.594	757	CLR	M	Present	No
Avawatz	35.526	-116.367	1742	CLR	M	Present	No
East-Gate	35.384	-116.361	782	CLR	M	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Gary-Owens	35.513	-116.760	1232	CLR	M	Present	No
Goldstone	35.304	-116.803	1027	CLR	M	Present	No
Granite-Pass	35.429	-116.550	1190	CLR	M	Present	No
JR	36.047	-117.505	1725	CLR	M	Present	No
LFA-12.5	35.364	-116.548	1452	CLR	M	Present	No
Live-Fire	35.492	-116.486	1075	CLR	M	Present	No
Nelson-Lake	35.420	-116.760	947	CLR	M	Present	No
Parrot	36.083	-117.482	2554	CLR	M	Present	No
RBW	35.511	-117.272	730	CLR	M	Present	No
Amargosa Farms Garey	36.572	-116.462	747	COOP	11/1/1965	8/25/2006	No
Baker 9 NNW	35.383	-116.117	320	COOP	11/1/1953	4/22/1971	No
Beatty	36.917	-116.750	1007	COOP	11/1/1917	11/16/1972	No
Beatty 8 N	36.995	-116.719	1082	COOP	11/1/1972	Present	No
Bishop Airport	37.371	-118.358	1250	COOP	8/1/1930	Present	No
Bishop F.S.	37.368	-118.365	1252	COOP	11/21/1996	8/25/2005	No
Clay City	36.433	-116.400	668	COOP	7/22/1926	12/31/1937	No
Cottonwood Creek	36.483	-118.183	3099	COOP	7/1/1948	9/30/1976	No
Deep Springs 11 NW	37.433	-118.167	3203	COOP	7/1/1948	10/31/1954	No
Deep Springs College	37.374	-117.980	1593	COOP	7/1/1948	Present	No
Dyer	37.615	-118.011	1494	COOP	2/1/1903	Present	No
Goldstone Echo	35.300	-116.800	982	COOP	3/16/1965	11/14/1972	No
Haiwee	36.139	-117.953	1166	COOP	5/1/1923	Present	No
Independence	36.798	-118.204	1204	COOP	1/1/1893	Present	No
Independence Onion V	36.767	-118.333	2800	COOP	12/1/1948	2/25/1971	No
Lathrop Wells	36.650	-116.400	814	COOP	1/1/1942	2/28/1964	No
Lathrop Wells 16 SSE	36.417	-116.350	665	COOP	11/1/1970	3/19/1978	No
Lone Pine Cottonwood Ph.	36.443	-118.043	1155	COOP	7/1/1948	Present	No
Mercury Desert Rock Arpt.	36.621	-116.028	1006	COOP	5/1/1978	Present	No
Pahrump	36.279	-116.003	815	COOP	3/1/1914	Present	No
Pahrump Ranch	36.200	-115.983	814	COOP	7/1/1948	5/31/1952	No
Palmetto	37.467	-117.767	1800	COOP	2/1/1890	3/31/1954	No
Sarcobatus	37.267	-117.017	1226	COOP	10/1/1941	7/31/1961	No
Shoshone	35.972	-116.270	479	COOP	11/1/1972	Present	No
Silver Lake CAA Arpt.	35.333	-116.083	281	COOP	4/1/1931	11/30/1953	No
Trona	35.764	-117.391	517	COOP	1/1/1920	Present	No
White Mountain 1	37.500	-118.183	3094	COOP	3/1/1951	12/31/1977	No
A-23 Mercury bld525 (NTS)	36.658	-115.996	1137	DOENTS	1/1/1983	12/31/2004	No
A-25 Army Gun Site	36.704	-116.355	884	DOENTS	5/1/1998	12/31/2004	No
A-25 Army Target	36.704	-116.346	899	DOENTS	4/1/1998	8/31/1999	No
A-25 S Gate 510	36.671	-116.404	846	DOENTS	1/1/1983	12/31/2004	No
A-25 X Tunnel	36.722	-116.377	878	DOENTS	12/1/1996	3/31/1998	No
Yucca Mountain	36.839	-116.469	1500	DOENTS	6/1/1987	12/31/2004	No
Alice Hill (YMP 4)	36.864	-116.404	1234	DOERD	12/1/1985	1/31/2005	No
Coyote Wash (YMP 3)	36.855	-116.452	1279	DOERD	12/1/1985	1/31/2005	No
Fortymile Wash (YMP 5)	36.764	-116.391	952	DOERD	12/1/1985	1/31/2005	No
Gate 510 (YMP 9)	36.671	-116.402	838	DOERD	1/1/1993	1/31/2005	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Knothead Gap (YMP 8)	36.828	-116.426	1131	DOERD	1/1/1992	1/31/2005	No
NTS-60 (YMP 1)	36.843	-116.431	1143	DOERD	12/1/1985	1/31/2005	No
Sever Wash (YMP 7)	36.847	-116.408	1081	DOERD	4/1/1992	1/31/2005	No
WT-6 (YMP 6)	36.894	-116.446	1315	DOERD	1/1/1992	1/31/2005	No
Yucca Mountain (YMP 2)	36.855	-116.466	1478	DOERD	12/1/1985	1/31/2005	No
Crooked Creel (WMRS)	37.543	-118.204	3094	DRI	3/1/2003	Present	No
Devils Hole	36.424	-116.306	704	DRI	5/1/2003	Present	No
Dyer	37.606	-117.989	1488	DRI	3/1/2003	Present	No
Independence	36.802	-118.196	1201	DRI	2/1/2004	Present	No
Independence 1 SSW #03	36.786	-118.208	1274	DRI	1/1/2004	Present	No
Independence 2 ESE #04	36.795	-118.166	1170	DRI	1/1/2004	Present	No
Independence 3 S #09	36.766	-118.190	1238	DRI	1/1/2004	Present	No
Independence 3 SE #10	36.773	-118.163	1179	DRI	1/1/2004	Present	No
Independence 3 SSW #08	36.761	-118.229	1440	DRI	1/1/2004	Present	No
Independence 3 SW #02	36.778	-118.243	1476	DRI	1/1/2004	Present	No
Independence 4 E #05	36.801	-118.133	1145	DRI	1/1/2004	Present	No
Independence 4 ESE #11	36.781	-118.128	1146	DRI	1/1/2004	Present	No
Independence 4 SW #07	36.754	-118.254	1575	DRI	1/1/2004	Present	No
Independence 5 ESE #12	36.785	-118.107	1137	DRI	1/1/2004	Present	No
Independence 5 SSE #14	36.729	-118.171	1233	DRI	1/1/2004	Present	No
Independence 5 WSW #01	36.768	-118.276	1736	DRI	1/1/2004	Present	No
Independence 6 E #06	36.811	-118.091	1216	DRI	1/1/2004	Present	No
Independence 6 S #13	36.719	-118.204	1440	DRI	1/1/2004	Present	No
Independence 6 SE #15	36.741	-118.116	1136	DRI	1/1/2004	Present	No
Independence 7 SE #16	36.740	-118.088	1136	DRI	1/1/2004	Present	No
Bishop	37.371	-118.366	1252	NADP	4/15/1980	6/22/1982	No
Horse Thief Springs	35.771	-115.909	1524	RAWS	9/1/1991	Present	No
Oak Creek	36.843	-118.259	1480	RAWS	10/1/1994	Present	No
Oriental Wash	37.235	-117.496	1250	RAWS	9/1/1986	Present	No
Pahrump	36.166	-116.102	792	RAWS	11/1/1986	2/28/1997	No
Bishop Airport	37.371	-118.358	1250	SAO	8/1/1930	Present	No
Goat Mountain TOC	35.517	-116.450	1254	SAO	2/1/1988	Present	No
Mercury Desert Rock Arpt.	36.621	-116.028	1006	SAO	5/1/1978	Present	No
Barstow Camp Irwin	35.300	-116.650	764	WBAN	11/1/1944	7/31/1945	No
Beatty	36.900	-116.767	1008	WBAN	2/1/1944	12/31/1958	No
Beatty Team 6	36.933	-116.733	1034	WBAN	1/1/1951	9/30/1957	No
Bishop AAF	37.350	-118.400	1256	WBAN	1/1/1943	1/31/1944	No
Shoshone	35.967	-116.283	982	WBAN	9/1/1958	10/31/1958	No
Shoshone Team 5	35.967	-116.267	482	WBAN	7/1/1957	9/30/1957	No
Superior Valley Aggr.	35.333	-117.100	M	WBAN	4/1/1982	Present	No
Manzanar National Historic Site (MANZ)							
Chagoopa Plateau	36.497	-118.442	3139	CDEC	10/1/1986	Present	No
Charlotte Lake	36.797	-118.422	3170	CDEC	10/1/1985	Present	No
Cottonwood Lakes	36.483	-118.177	3094	CDEC	1/1/1986	Present	No
Crabtree Meadow	36.563	-118.345	3261	CDEC	10/1/1985	Present	No
Upper Tyndall Creek	36.650	-118.397	3475	CDEC	8/1/1988	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Owens Lake North	36.489	-117.919	1123	CIMIS	12/1/2002	Present	No
Bullfrog Lake	36.767	-118.400	3264	COOP	7/1/1948	7/31/1955	No
Chagoopa	36.500	-118.450	3154	COOP	7/1/1964	11/30/1972	No
Cottonwood Creek	36.483	-118.183	3099	COOP	7/1/1948	9/30/1976	No
Crabtree Meadow	36.567	-118.350	3264	COOP	7/1/1948	9/30/1976	No
East Vidette Meadow	36.733	-118.383	3172	COOP	4/28/1949	8/31/1964	No
Independence	36.798	-118.204	1204	COOP	1/1/1893	Present	No
Independence Onion V	36.767	-118.333	2800	COOP	12/1/1948	2/25/1971	No
Lone Pine Cottonwood Ph.	36.443	-118.043	1155	COOP	7/1/1948	Present	No
Moraine Creek	36.717	-118.567	2696	COOP	8/1/1964	9/30/1974	No
Vidette Meadow	36.750	-118.417	2898	COOP	8/1/1964	9/30/1974	No
Independence	36.802	-118.196	1201	DRI	2/1/2004	Present	No
Independence 1 SSW #03	36.786	-118.208	1274	DRI	1/1/2004	Present	No
Independence 2 ESE #04	36.795	-118.166	1170	DRI	1/1/2004	Present	No
Independence 3 S #09	36.766	-118.190	1238	DRI	1/1/2004	Present	No
Independence 3 SE #10	36.773	-118.163	1179	DRI	1/1/2004	Present	No
Independence 3 SSW #08	36.761	-118.229	1440	DRI	1/1/2004	Present	No
Independence 3 SW #02	36.778	-118.243	1476	DRI	1/1/2004	Present	No
Independence 4 E #05	36.801	-118.133	1145	DRI	1/1/2004	Present	No
Independence 4 ESE #11	36.781	-118.128	1146	DRI	1/1/2004	Present	No
Independence 4 SW #07	36.754	-118.254	1575	DRI	1/1/2004	Present	No
Independence 5 ESE #12	36.785	-118.107	1137	DRI	1/1/2004	Present	No
Independence 5 SSE #14	36.729	-118.171	1233	DRI	1/1/2004	Present	No
Independence 5 WSW #01	36.768	-118.276	1736	DRI	1/1/2004	Present	No
Independence 6 E #06	36.811	-118.091	1216	DRI	1/1/2004	Present	No
Independence 6 S #13	36.719	-118.204	1440	DRI	1/1/2004	Present	No
Independence 6 SE #15	36.741	-118.116	1136	DRI	1/1/2004	Present	No
Independence 7 SE #16	36.740	-118.088	1136	DRI	1/1/2004	Present	No

Out of the 27 COOP stations identified within 40 km of the boundaries of DEVA, 11 are active (Table 4.3). The longest record we identified was from the COOP station “Independence,” which is 26 km west of DEVA and has been active since 1893. The record at this climate station is very complete with a couple of exceptions. First, there were no weekend observations at “Independence” between 1948 and 1970. Second, a significant data gap occurred between March 1946 and June 1948. Another reliable long-term record was identified at the COOP station “Dyer,” which is located 37 km northwest of DEVA in Nevada. This station has been active since 1903. The COOP station “Haiwee” is 39 km southwest of DEVA and has a reliable data record that goes back to 1923. Bishop Airport, 37 km northwest of DEVA, operates both a COOP station and a SAO station, with observations going back to 1930. These data records are very complete. The COOP station “Pahrump,” located 30 km east of DEVA in Nevada, has a data record that goes back to 1914, but its data have only been reliable since the 1960s. The COOP station “Trona” is 24 km southwest of DEVA and has a data record that goes back to 1920. The data record from “Trona” has several multi-month gaps during the 1990s. Two other

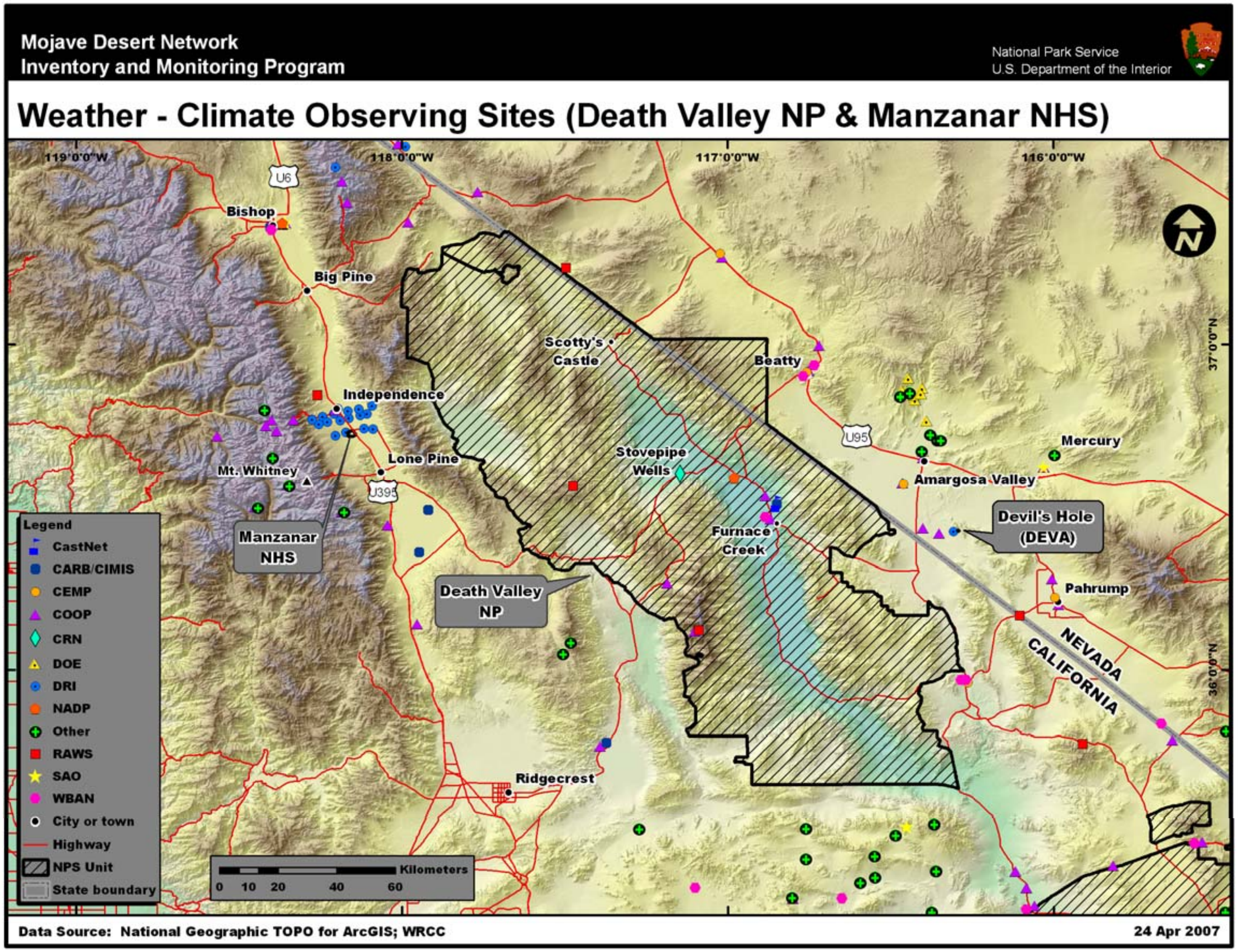


Figure 4.1. Station locations for northwestern MOJN park units.

COOP stations we identified have data records starting in the 1940s. These stations are “Deep Springs College” and “Lone Pine Cottonwood Ph.”

Several local and regional weather station networks have sites within 40 km of DEVA, providing near-real-time weather observations for the region. The CARB station “Trona-Athol & Telegraph” is located southwest of DEVA (Figure 4.1). A CDEC weather station (Cottonwood Lakes) is located on the eastern Sierra front, 37 km west of DEVA. Several CEMP stations have been identified (Table 4.3), primarily north and east of DEVA. Three CIMIS stations have been identified in the Owens Valley and near Bishop, California. The CLR weather stations identified with this report are located mostly to the south of DEVA. Stations with the DOENTS and DOERD networks have been identified with the Yucca Mountain site and the Nevada Test Site, both east of DEVA. The DRI network has an automated weather station at Devils Hole and 16 stations associated with the Sierra Rotors Project (T-REX) near Independence, California. The T-REX project is designed to study mountain-wave induced rotors in Owens Valley, on the east side of the Sierra Nevada.

Other national weather and climate networks have stations within 40 km of DEVA. A NADP station operated at Bishop between April 1980 and June 1982 (Table 4.3). Four RAWS stations provide near-real-time weather observations within 40 km of DEVA; three of these weather stations are still active. The oldest RAWS station we identified was “Oriental Wash,” about 2 km north of DEVA (Figure 4.1), which has operated since 1986. “Horse Thief Springs” is 37 km southeast of DEVA and has been active since 1991. “Oak Creek” has been active since 1994 and is 5 km northwest of Independence (about 28 km W of DEVA). Three active SAO stations have also been identified. The longest record is from “Bishop Airport,” 37 km northwest of DEVA, with data going back to 1930. Other SAO sites include “Mercury Desert Rock Arpt.,” 32 km east of DEVA, and “Goat Mountain TOC,” 15 km south of DEVA.

No stations were identified within MANZ (Table 4.3). Five CDEC stations were identified within 40 km of MANZ, mostly south and west of the park unit (Figure 4.1). A CIMIS station (Owens Lake North) is currently operating 33 km southeast of MANZ. The RAWS station “Oak Creek” is located 15 km northwest of MANZ. All of these stations provide near-real-time weather data for MANZ.

We identified 10 COOP stations within 40 km of MANZ (Table 4.3). Only two of these climate stations are currently active. The COOP station “Independence,” discussed previously, provides the longest data record in the area and is 8 km north of MANZ. The COOP station “Lone Pine Cottonwood. Ph.” is 32 km south of MANZ and has been taking measurements since 1948. Another valuable source of weather data within 40 km of MANZ is the T-REX project, mentioned previously.

4.2.2. Great Basin National Park

Like DEVA, eleven weather and climate stations were identified within the boundaries of GRBA (Table 4.4; Figure 4.2). All but two of these stations are active. Stations from at least four different weather/climate networks are currently operating at the main visitor center for GRBA, including a CASTNet site (Great Basin NP), a COOP site (Great Basin Natl. Prk.), a CRN site (Baker 5 W), and a NADP site (Great Basin NP – Lehman Caves). The CASTNet and CRN sites

Table 4.4. Weather/climate stations for Great Basin National Park (GRBA). Stations inside GRBA and within 40 km of GRBA are included. Missing entries are indicated by "M".

Great Basin National Park (GRBA)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Great Basin NP	39.005	-114.216	2060	CASTNet	8/24/1993	Present	Yes
Great Basin National Park	39.009	-114.227	2082	COOP	10/1/1937	Present	Yes
Baker 5 W	39.012	-114.217	2010	CRN	5/9/2004	Present	Yes
Great Basin NP	39.005	-114.216	2060	GPMP	8/24/1993	3/31/1995	Yes
Great Basin NP-Lehman Caves	39.005	-114.216	2067	NADP	1/15/1985	Present	Yes
Baker Creek #1	38.967	-114.250	2423	NRCS-SC	1/1/1942	Present	Yes
Baker Creek #2	38.967	-114.267	2728	NRCS-SC	1/1/1942	Present	Yes
Baker Creek #3	38.967	-114.267	2819	NRCS-SC	1/1/1942	Present	Yes
Baker Creek	38.979	-114.244	2408	RAWS	8/1/2002	10/31/2003	Yes
Baker Flat	39.002	-114.218	2085	RAWS	4/1/2000	Present	Yes
Mather	39.023	-114.272	2825	RAWS	6/1/1998	Present	Yes
Connors Pass	39.033	-114.650	2233	COOP	10/1/1953	7/31/1976	No
Eskdale	39.109	-113.954	1518	COOP	3/1/1966	Present	No
Garrison	38.933	-114.033	1603	COOP	1/1/1903	8/1/1990	No
Geyser Ranch	38.668	-114.636	1835	COOP	2/1/1904	5/18/2002	No
Major's Place	39.017	-114.617	1981	COOP	5/1/1988	8/31/1988	No
Shoshone 5 N	38.916	-114.402	1807	COOP	10/1/1988	Present	No
Silver Creek #2	39.233	-114.250	2438	NRCS-SC	1/1/1957	Present	No
Cattle Camp	38.904	-114.814	2225	RAWS	2/1/1994	Present	No
Dale	38.911	-114.633	1957	RAWS	1/1/2004	8/31/2004	No
Berry Creek	39.319	-114.623	M	SNOTEL	M	Present	No

provide near-real-time weather information. A GPMP station operated in the early 1990s near the visitor center.

The COOP station we identified (Great Basin Natl. Prk.) has the longest data record among the visitor center stations, with data available as early as 1937. However, caution should be exercised when using this site. This station also went by the name "Lehman Caves NM" from 1948-1987, which may cause confusion when interpreting its climate records.

Several stations also have been identified in other parts of GRBA (Figure 4.2). Two of the three RAWS weather stations we identified within GRBA are currently active (Table 4.4). The RAWS station "Baker Creek," south of Baker Creek Campground, operated for a short time in 2002 and 2003. "Baker Flat" is located along Wheeler Peak Scenic Drive, west of the visitor center, while "Mather" is along Road 446, northwest of the visitor center. Finally, the NRCS-SC network operates a transect of three snowcourses in the upper Baker Creek basin.

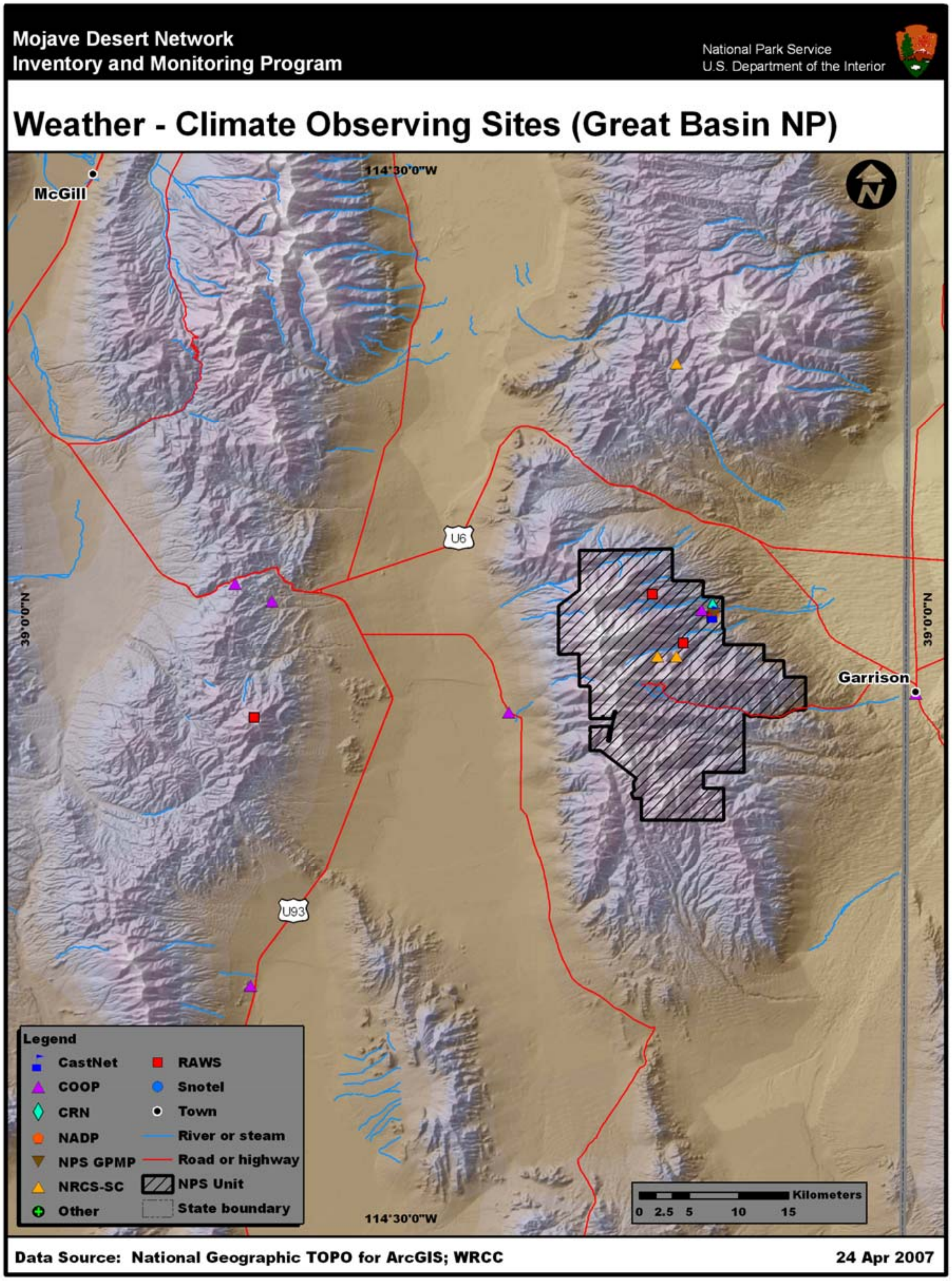


Figure 4.2. Station locations for Great Basin National Park.

Six COOP stations have been identified within 40 km of the boundaries of GRBA (Table 4.4). However, only two of these climate stations are still active. The COOP station “Eskdale,” located 24 km northeast of GRBA, has operated since 1966 with a very reliable data record. The COOP station “Shoshone 5 N” is located 6 km west of GRBA, on Highway 894, and has been operating since 1988. A long-term COOP station 36 km southwest of GRBA (Geyser Ranch) recently stopped taking measurements (2002). This is unfortunate, particularly in an area where so few long-term climate records are available to begin with. In addition to these stations, one NRCS-SC station (Silver Creek #2) has been identified 19 km north of GRBA, an active RAWS station (Cattle Camp) has been identified in the Egan Range, 40 km west of GRBA (Figure 4.2), and a SNOTEL station (Berry Creek) is located just under 40 km northwest of GRBA.

4.2.3. Joshua Tree National Park

Eight weather and climate stations were identified within the boundaries of JOTR (Figure 4.3; Table 4.5). Five of these stations are active. None of these active stations provide long-term climate records. The longest known record we could fine comes from the RAWS station “Lost Horse,” which has been active since 1991. This weather station is located in northwestern JOTR, along Park Boulevard. The CASTNet station “Black Rock” provides a comparable data record, starting in 1993. This station is located in extreme northwestern JOTR, just southeast of Yucca Valley. A CARB station (Joshua Tree-National Monument) and a NADP station (Joshua Tree NP-Black Rock) are operating in this general area. The GPMP station “Cottonwood Canyon” has been operating since 2005 in south-central JOTR, just south of Cottonwood Campground.

Stations from the CARB and CIMIS networks have been identified within 40 km of JOTR. These stations are located primarily south and west of JOTR, in the populated areas around Palm Springs, Indio, and the rest of the Coachella Valley (Figure 4.3).

Many COOP stations have been identified within 40 km of the boundaries of JOTR (Table 4.5). These are located primarily south and west of JOTR, with a few exceptions (Figure 4.3). Fifteen of these climate stations are currently active. The closest COOP station to JOTR is “Hayfield Pump Plant,” just 1 km southeast of JOTR along the Colorado Aqueduct. This station has a reliable data record beginning in 1933. “Eagle Mountain” is just east of JOTR and is another COOP station containing a reliable climate record (1933-present). The longest data record we identified was from the COOP station “Indio Fire Station,” located 15 km southwest of JOTR, has been operating since 1894. Before 1982, this station’s data record was very reliable; however, this station experienced a large data gap from June 1982 to June 1985, and there have been scattered gaps throughout the record after 1985. Another long term record is available from the COOP station “Palm Springs,” located 17 km southwest of JOTR (1906-present). The data record for “Palm Springs” is very complete. The COOP station “Mecca Fire Station” provides a third very long data record (1905-present). Located 15 km south of JOTR, this station’s record was very complete until 2000, since when it has become more unreliable. The COOP station “Twentynine Palms” is 2 km north of JOTR and has a very reliable data record starting in 1935. The COOP station “Iron Mountain” is 18 km northeast of JOTR and also has a very reliable data record starting in 1935. Several additional COOP stations within 40 km of JOTR have data records that begin in the 1930s and 1940s.

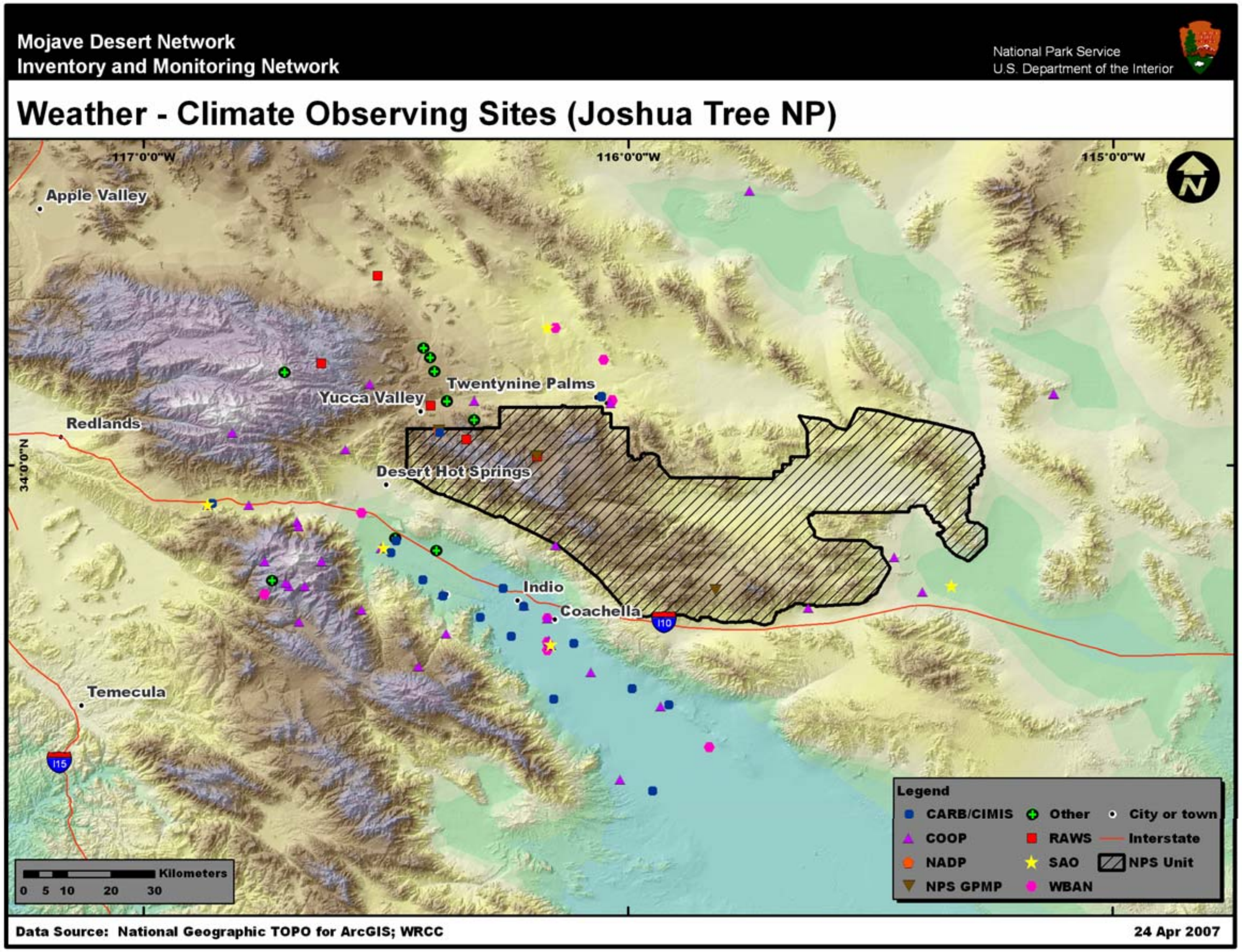


Figure 4.3. Station locations for Joshua Tree National Park.

Table 4.5. Weather/climate stations for Joshua Tree National Park (JOTR). Stations inside JOTR and within 40 km of the JOTR boundary are included. Missing entries are indicated by "M".

Joshua Tree National Park (JOTR)

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Joshua Tree-National Monument	34.068	-116.389	1240	CARB	M	Present	Yes
Black Rock	34.071	-116.391	1244	CASTNet	9/1/1993	Present	Yes
Black Rock	34.071	-116.391	1244	GPMP	9/1/1993	1/31/1995	Yes
Cottonwood Canyon	33.741	-115.821	984	GPMP	12/15/2005	Present	Yes
Lost Horse R.S.	34.018	-116.189	1265	GPMP	5/1/1987	6/1/1997	Yes
Joshua Tree NP-Black Rock	34.072	-116.391	-3048	NADP	9/19/2000	Present	Yes
Covington	34.053	-116.334	1416	RAWS	7/1/2001	2/29/2004	Yes
Lost Horse	34.018	-116.188	1280	RAWS	9/1/1991	Present	Yes
Banning-Airport	33.921	-116.858	473	CARB	M	Present	No
Indio-Jackson Street	33.708	-116.216	-4	CARB	M	Present	No
Palm Springs-Fire Station	33.819	-116.490	171	CARB	M	Present	No
Twentynine Palms-Adobe RD #2	34.142	-116.055	652	CARB	M	Present	No
Cathedral City	33.843	-116.479	119	CIMIS	12/1/1995	Present	No
Indio	33.746	-116.258	12	CIMIS	12/1/1999	Present	No
La Quinta	33.686	-116.306	13	CIMIS	11/1/2000	Present	No
Mecca	33.538	-115.992	55	CIMIS	5/1/1998	Present	No
Oasis	33.516	-116.154	4	CIMIS	1/1/1997	Present	No
Palm Desert	33.730	-116.382	61	CIMIS	5/1/1987	4/30/1994	No
Rancho Mirage	33.764	-116.424	73	CIMIS	M	Present	No
Salton Sea North	33.504	-115.916	61	CIMIS	10/1/1998	Present	No
Salton Sea West	33.327	-115.950	69	CIMIS	11/1/1994	Present	No
Thermal	33.631	-116.112	37	CIMIS	M	Present	No
Thermal	33.646	-116.242	9	CIMIS	M	Present	No
Banning Municipal	33.917	-116.867	676	COOP	1/1/1933	Present	No
Berdoo Camp	33.833	-116.150	549	COOP	7/1/1933	12/31/1937	No
Cabazon	33.917	-116.783	549	COOP	3/1/1906	4/24/1974	No
Deckers Ranch	33.800	-116.750	1693	COOP	8/1/1920	12/23/1941	No
Deep Canyon Laboratory	33.651	-116.376	366	COOP	1/1/1963	Present	No
Desert Center 2 NNE	33.738	-115.393	228	COOP	2/1/2004	Present	No
Eagle Mountain	33.809	-115.451	297	COOP	9/1/1933	Present	No
Habitat	33.350	-116.017	-25	COOP	3/1/1987	12/20/1988	No
Hayfield Pump Plant	33.704	-115.629	418	COOP	7/1/1933	Present	No
Hurkey Creek Park	33.676	-116.679	1338	COOP	10/1/1939	Present	No
Idyllwild 1 NE	33.750	-116.700	1647	COOP	1/6/1901	6/30/1967	No
Idyllwild Fire Dept	33.757	-116.707	1640	COOP	10/1/1943	Present	No
Indio Coachella	33.683	-116.167	-20	COOP	8/1/1903	5/31/1950	No
Indio Fire Station	33.709	-116.215	-6	COOP	3/1/1894	Present	No
Iron Mountain	34.147	-115.122	281	COOP	1/1/1935	Present	No

Joshua Tree National Park (JOTR)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Joshua Tree	34.133	-116.317	830	COOP	6/1/1959	3/1/1972	No
Joshua Tree 3 S	34.100	-116.317	1064	COOP	3/1/1972	6/30/1977	No
Kee Ranch	34.167	-116.533	1321	COOP	7/1/1948	4/18/1979	No
Mecca Fire Station	33.571	-116.077	-55	COOP	9/1/1905	Present	No
Morongo Valley	34.033	-116.583	781	COOP	1/1/1942	3/1/1972	No
Mount San Jacinto W.S.	33.800	-116.633	2568	COOP	7/1/1965	12/31/1978	No
Nightingale	33.583	-116.433	1229	COOP	5/1/1963	6/1/1969	No
Palm Desert	33.733	-116.383	59	COOP	6/11/1982	6/14/1985	No
Palm Springs	33.828	-116.510	130	COOP	3/1/1906	Present	No
Palm Springs Thermal Arpt.	33.628	-116.160	-34	COOP	5/1/1950	8/16/2002	No
Palm Springs Tramway	33.700	-116.550	2596	COOP	1/1/1964	7/13/1965	No
Salton Sea State Park	33.500	-115.933	-70	COOP	1/1/1967	12/31/1969	No
Snow Creek	33.883	-116.683	390	COOP	3/1/1919	1/31/1957	No
Snow Creek Upper	33.873	-116.680	591	COOP	1/1/1939	Present	No
South Fork Cabin	34.067	-116.817	2172	COOP	1/1/1919	11/7/1967	No
Tahquitz Peak	33.750	-116.667	2693	COOP	5/1/1953	Present	No
Thermal Fire Stn. 39	33.636	-116.164	-35	COOP	11/1/1972	Present	No
Twentynine Palms	34.128	-116.037	602	COOP	5/1/1935	Present	No
AA6HF-5 Cathedral City	33.849	-116.481	134	CWOP	M	Present	No
CW1828 Joshua Tree	34.095	-116.318	1036	CWOP	M	Present	No
CW2285 Thousand Palms	33.824	-116.396	84	CWOP	M	Present	No
CW2900 Yucca Valley	34.194	-116.400	1100	CWOP	M	Present	No
CW3300 Yucca Valley	34.133	-116.375	902	CWOP	M	Present	No
CW4878 Idyllwild	33.763	-116.735	1920	CWOP	M	Present	No
CW5809 Yucca Valley	34.242	-116.423	981	CWOP	M	Present	No
N6GIW Landers	34.223	-116.409	1040	CWOP	M	Present	No
ONYX Onyx Peak	34.192	-116.710	2778	CWOP	M	Present	No
Burns Canyon	34.210	-116.634	1829	RAWS	9/1/1991	Present	No
Means Lake	34.391	-116.517	884	RAWS	11/1/1995	Present	No
Yucca Valley	34.123	-116.408	994	RAWS	5/1/1990	Present	No
Banning Municipal	33.917	-116.867	676	SAO	1/1/1933	Present	No
Desert Center AAF	33.750	-115.333	165	SAO	6/1/1943	3/31/1944	No
Palm Springs Regional Arpt.	33.828	-116.505	128	SAO	4/1/1930	Present	No
Palm Springs Thermal Arpt.	33.628	-116.160	-34	SAO	5/1/1950	8/16/2002	No
Twentynine Palms MC	34.283	-116.167	643	SAO	M	Present	No
Condor Field AAF	34.133	-116.033	542	WBAN	7/1/1942	4/30/1943	No
Indio	33.683	-116.167	-19	WBAN	1/1/1931	3/31/1938	No
Los Pinos Peak	33.733	-116.750	1491	WBAN	9/1/1941	11/30/1944	No
Needles AF	34.767	-114.617	229	WBAN	2/1/1955	5/31/1955	No
Palm Springs	33.900	-116.550	128	WBAN	5/1/1942	2/28/1946	No

Three RAWS stations have been identified within 40 km of JOTR. All of these stations are northwest of the park unit and have been active since the early- or mid-1990s. The most distant station is “Means Lake” (35 km away) while the closest station is “Yucca Valley” (7 km away).

Two active SAO stations were identified outside of JOTR. These stations are found at the Palm Springs and Twentynine Palms airports. In addition, two WBAN records were identified in the Twentynine Palms area.

4.2.4. Lake Mead National Recreation Area

Fourteen weather/climate stations were identified within the boundaries of LAME (Table 4.6; Figure 4.4). Eight of these stations are active. The CCRFCD station “Overton Beach” provides near-real-time weather data in northernmost LAME. The RAWS station “Twin West” also provides near-real-time weather data and is located in eastern LAME. A POMS station (Meadview) is located in southeastern LAME. Five active COOP stations are located in LAME. The longest record from these stations is found at “Willow Beach.” This COOP has been operating since 1967 and its data record is largely complete, with the exception of the last 1-2 years. “Callville Bay” is a COOP station located in northwestern LAME, 40 km east of Las Vegas. The COOP station “Echo Bay” is in northern LAME. The COOP station “Meadview 1 SE” is in extreme southeastern LAME. Temple Bar also has a COOP station that has been operating since 1987.

Table 4.6. Weather/climate stations for Lake Mead National Recreation Area (LAME). Stations inside LAME and within 40 km of the LAME boundary are included. Missing entries are indicated by “M”.

Lake Mead National Recreation Area (LAME)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Overton Beach	36.440	-114.360	390	CCRFCD	M	Present	Yes
Callville Bay	36.141	-114.728	387	COOP	7/1/1989	Present	Yes
Davis Dam # 2	35.200	-114.567	201	COOP	7/1/1948	7/7/1977	Yes
Echo Bay	36.309	-114.426	381	COOP	7/1/1989	Present	Yes
Katherine Ranger Stn.	35.233	-114.567	204	COOP	7/7/1977	2/3/1978	Yes
Lake Mead Evaporation	36.017	-114.817	525	COOP	3/1/1969	12/31/1976	Yes
Meadview 1 SE	36.003	-114.051	975	COOP	9/30/1996	Present	Yes
Pierce Ferry	36.117	-114.000	418	COOP	10/1/1948	6/30/1952	Yes
Temple Bar	36.030	-114.329	390	COOP	11/18/1987	Present	Yes
Willow Beach	35.869	-114.661	226	COOP	10/1/1967	Present	Yes
Meadview	36.019	-114.069	881	POMS	5/1/2003	Present	Yes
Twin West	36.101	-113.634	1809	RAWS	5/1/1999	Present	Yes
Overton Team 2	36.400	-114.433	409	WBAN	5/1/1957	9/30/1957	Yes
Pierces Ferry	36.033	-114.200	869	WBAN	6/1/1936	10/31/1937	Yes
Mohave	34.970	-114.610	146	AZMET	M	Present	No
Mojave #2	34.931	-114.564	151	AZMET	M	Present	No
Angel Park	36.170	-115.310	866	CCRFCD	M	Present	No
Angel Park DB	36.187	-115.281	808	CCRFCD	M	Present	No
Boulder City	36.000	-114.860	1049	CCRFCD	M	Present	No
Bullhead City	35.108	-114.608	172	CCRFCD	M	Present	No

Lake Mead National Recreation Area (LAME)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Bunkerville	36.710	-114.080	870	CCRFCD	M	Present	No
California Wash	36.480	-114.710	634	CCRFCD	M	Present	No
Calnevari	35.320	-114.800	899	CCRFCD	M	Present	No
Desert Tortoise	35.980	-115.250	802	CCRFCD	M	Present	No
Dolan Springs	35.582	-114.278	1014	CCRFCD	M	Present	No
Downtown Las Vegas	36.170	-115.140	658	CCRFCD	M	Present	No
Henderson	36.050	-115.000	561	CCRFCD	M	Present	No
Lake Mead City	35.962	-114.092	1028	CCRFCD	M	Present	No
Laughlin	35.180	-114.680	738	CCRFCD	M	Present	No
Meadview	36.002	-114.006	910	CCRFCD	M	Present	No
Mesquite	36.840	-114.060	600	CCRFCD	M	Present	No
Mohave Valley	34.868	-114.561	141	CCRFCD	M	Present	No
Mormon Mesa	36.660	-114.420	610	CCRFCD	M	Present	No
Nelson Peak	35.700	-114.890	1508	CCRFCD	M	Present	No
North Nellis	36.250	-115.040	579	CCRFCD	M	Present	No
North Valley	36.340	-115.170	805	CCRFCD	M	Present	No
NWS Las Vegas	36.050	-115.190	693	CCRFCD	M	Present	No
Overton Airport	36.570	-114.440	414	CCRFCD	M	Present	No
Sacramento Valley	35.032	-114.175	689	CCRFCD	M	Present	No
Santa Claus	35.344	-114.196	1079	CCRFCD	M	Present	No
Searchlight	35.400	-115.030	1131	CCRFCD	M	Present	No
Sloan	35.930	-115.190	831	CCRFCD	M	Present	No
Sunrise Landfill	36.144	-114.996	683	CCRFCD	M	Present	No
The Lakes	36.124	-115.286	799	CCRFCD	M	Present	No
Valle Vista	35.419	-113.865	951	CCRFCD	M	Present	No
Valley Of Fire	36.460	-114.500	667	CCRFCD	M	Present	No
Boulder City	35.985	-114.841	722	CEMP	7/1/1999	Present	No
Henderson	36.008	-114.966	668	CEMP	7/1/1999	Present	No
Las Vegas	36.114	-115.148	622	CEMP	7/1/1999	Present	No
Mesquite	36.814	-114.050	540	CEMP	11/1/2005	Present	No
Overton	36.546	-114.446	366	CEMP	7/1/1999	Present	No
Boulder City	35.980	-114.846	762	COOP	9/1/1931	1/18/2005	No
Boulder City Arpt.	35.967	-114.833	736	COOP	6/1/1936	6/30/1950	No
Bullhead City	35.141	-114.568	165	COOP	11/1/1977	Present	No
Bunkerville	36.767	-114.133	470	COOP	2/1/1898	11/30/1953	No
Bunkerville	36.773	-114.124	472	COOP	11/1/1979	Present	No
Bunkerville Mountain	36.617	-114.200	991	COOP	7/1/1966	7/31/1976	No
Chloride	35.417	-114.200	1226	COOP	4/1/1965	9/27/1967	No
Diamond Bar Ranch	35.883	-114.000	1098	COOP	7/1/1952	7/31/1956	No
Frazier Well 4 NE	35.833	-113.033	2001	COOP	10/1/1950	7/31/1976	No
Fraziers Well	35.783	-113.067	1830	COOP	4/1/1940	10/31/1944	No
Las Vegas	36.167	-115.133	613	COOP	6/1/1895	12/31/1956	No

Lake Mead National Recreation Area (LAME)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Las Vegas McCarran Intl. Arpt.	36.079	-115.155	648	COOP	9/6/1948	Present	No
Las Vegas NWFO	36.047	-115.185	661	COOP	9/1/1996	Present	No
Las Vegas WB Arpt.	36.233	-115.033	574	COOP	7/1/1928	1/31/1949	No
Laughlin	35.169	-114.581	184	COOP	10/23/1983	Present	No
Littlefield 25 SSW	36.533	-114.033	1220	COOP	6/1/1946	10/31/1951	No
Logandale	36.600	-114.483	427	COOP	4/18/1906	12/31/1938	No
Logandale	36.617	-114.483	430	COOP	1/1/1968	12/1/1991	No
Mccullough Pass	35.733	-115.167	1147	COOP	7/1/1965	7/31/1976	No
Mesquite	36.803	-114.074	479	COOP	7/1/1928	6/15/2006	No
Mount Trumbull	36.417	-113.350	1708	COOP	10/1/1919	6/30/1978	No
Needles	34.830	-114.594	146	COOP	1/1/1917	Present	No
Needles A	34.833	-114.600	166	COOP	10/1/1977	7/1/1978	No
North Las Vegas	36.235	-115.116	579	COOP	1/17/1990	Present	No
Overton	36.551	-114.458	381	COOP	5/1/1939	Present	No
Peach Springs	35.541	-113.424	1473	COOP	7/1/1948	Present	No
Perner Ranch	35.367	-113.283	1708	COOP	3/1/1952	11/20/1969	No
Pierce Ferry 17 SSW	35.883	-114.083	1176	COOP	6/1/1963	8/1/1984	No
Searchlight	35.466	-114.922	1079	COOP	12/1/1913	Present	No
Sunrise Manor Las Vegas	36.200	-115.083	555	COOP	2/1/1951	11/1/1989	No
Supai	36.200	-112.700	977	COOP	9/1/1899	6/1/1987	No
Truxton Canyon	35.388	-113.659	1164	COOP	5/16/1901	Present	No
Tuweep	36.286	-113.064	1455	COOP	6/1/1941	Present	No
Valley Of Fire St. Park	36.430	-114.513	610	COOP	11/1/1972	Present	No
White Hills 5 WSW	35.700	-114.483	741	COOP	4/1/1962	10/1/1967	No
AA5QJ Las Vegas	36.202	-115.260	735	CWOP	M	Present	No
AA5QJ-1 Las Vegas	36.202	-115.260	740	CWOP	M	Present	No
CW0363 Henderson	35.974	-115.085	775	CWOP	M	Present	No
CW0673 Moapa	36.672	-114.624	510	CWOP	M	Present	No
CW0686 Mesquite	36.800	-114.079	486	CWOP	M	Present	No
CW0693 Henderson	35.987	-114.989	780	CWOP	M	Present	No
CW1191 Laughlin	35.148	-114.616	634	CWOP	M	Present	No
CW3037 Las Vegas	36.100	-115.200	679	CWOP	M	Present	No
CW3178 Las Vegas	36.272	-115.248	713	CWOP	M	Present	No
CW3256 Las Vegas	36.136	-115.301	851	CWOP	M	Present	No
CW3549 Las Vegas	36.167	-115.233	664	CWOP	M	Present	No
CW3746 Las Vegas	36.113	-115.054	515	CWOP	M	Present	No
CW3809 North Las Vegas	36.243	-115.124	614	CWOP	M	Present	No
CW4139 Moapa	36.700	-114.600	40	CWOP	M	Present	No
CW4221 North Las Vegas	36.244	-115.205	671	CWOP	M	Present	No
CW4367 Bullhead City	35.188	-114.531	321	CWOP	M	Present	No
CW4587 Las Vegas	36.048	-115.200	767	CWOP	M	Present	No

Lake Mead National Recreation Area (LAME)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
CW4951 Fort Mohave	34.984	-114.587	154	CWOP	M	Present	No
K0QMS Mesquite	36.816	-114.104	561	CWOP	M	Present	No
K2TCO Las Vegas	36.201	-115.125	573	CWOP	M	Present	No
K6YDW Henderson	36.032	-115.020	586	CWOP	M	Present	No
KA7GOO Henderson	36.001	-115.083	718	CWOP	M	Present	No
KD7LVX-13 Las Vegas	36.184	-115.021	594	CWOP	M	Present	No
NK7I Las Vegas	36.150	-115.109	577	CWOP	M	Present	No
WA4PDM Henderson SCMR	35.995	-115.070	721	CWOP	M	Present	No
Henderson Fire Stn. 82	36.060	-115.023	518	DRI	3/1/2004	6/30/2004	No
Las Vegas (DOE-LV)	36.245	-115.119	594	DRI	2/1/2006	Present	No
Las Vegas	36.160	-115.190	660	GPS-MET	M	Present	No
Tuweep	36.283	-113.096	1433	POMS	5/1/2003	Present	No
Arizona Strip Portable L1	36.150	-113.700	1829	RAWS	7/1/1987	6/30/1990	No
Big Bend	35.119	-114.693	305	RAWS	11/1/1986	12/31/1995	No
Christmas Tree Pass	35.232	-114.777	1052	RAWS	6/1/1990	3/31/1995	No
Frazier Wells	35.846	-113.055	2063	RAWS	11/1/1999	Present	No
Mount Logan	36.347	-113.199	2195	RAWS	1/1/1985	Present	No
Music Mountain Arizona	35.615	-113.794	1652	RAWS	3/1/1996	Present	No
Nixon Flats	36.390	-113.152	1981	RAWS	1/1/1992	Present	No
Olaf Knolls	36.507	-113.816	884	RAWS	5/1/1985	Present	No
Robinson Tank	36.471	-112.841	1695	RAWS	4/1/1986	Present	No
Toquop Wash	36.913	-114.195	746	RAWS	6/1/1990	2/28/1998	No
Truxton Canyon	35.783	-113.794	1631	RAWS	8/1/2002	Present	No
Tweeds Point	36.582	-113.732	1585	RAWS	1/1/1985	Present	No
Union Pass	35.225	-114.375	1073	RAWS	5/1/1994	Present	No
Yellow John Mtn	36.154	-113.542	1878	RAWS	12/1/1987	Present	No
Boulder City Arpt.	35.967	-114.833	736	SAO	6/1/1936	6/30/1950	No
Goffs	34.833	-114.717	791	SAO	3/1/1932	5/31/1935	No
Las Vegas	36.250	-115.033	569	SAO	3/1/1942	Present	No
Las Vegas Air Terminal	36.212	-115.196	671	SAO	7/31/2000	Present	No
Las Vegas Henderson Arpt.	35.976	-115.133	749	SAO	M	Present	No
Las Vegas McCarran Intl. Arpt.	36.079	-115.155	648	SAO	9/6/1948	Present	No
Laughlin Bullhead Intl. Arpt.	35.157	-114.559	212	SAO	4/7/2005	Present	No
Nellis AFB	36.250	-115.033	574	SAO	3/1/1942	Present	No
Apex	36.341	-114.918	733	UPR	M	Present	No
Arden	36.029	-115.226	740	UPR	M	Present	No
Dry Lake	36.503	-114.764	617	UPR	M	Present	No
Moapa	36.763	-114.656	531	UPR	M	Present	No
Mormon Mesa	36.717	-114.467	632	WBAN	11/1/1939	8/31/1942	No

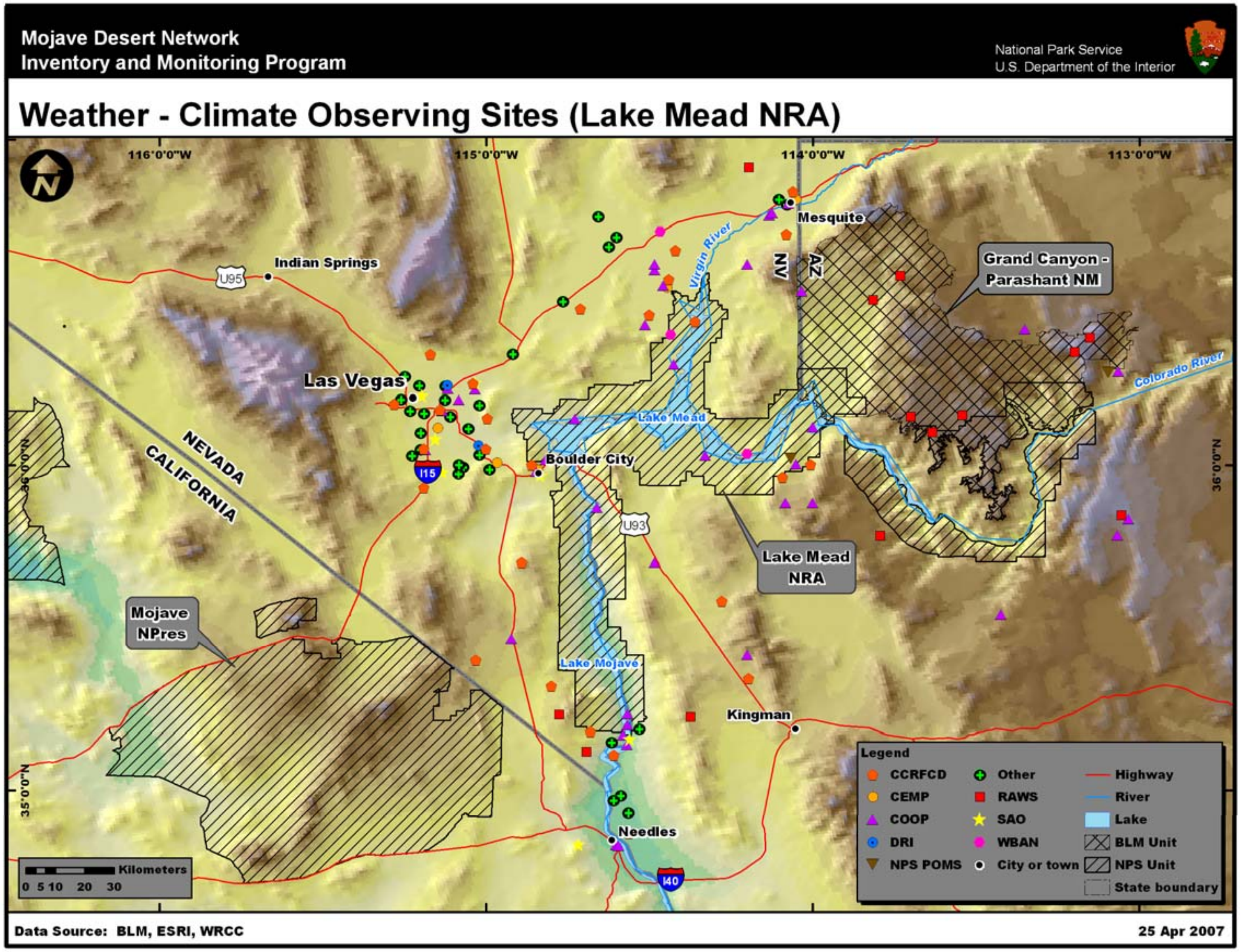


Figure 4.4. Station locations for Lake Mead National Recreation Area.

Many weather and climate stations have been identified within 40 km of the boundaries of LAME (Table 4.6). The AZMET stations “Mohave” and “Mojave #2” are located about 25 km south of LAME. Numerous CCRFCD stations were identified in the Las Vegas metropolitan area (Figure 4.4). Five CEMP stations and numerous CWOP stations also were identified, primarily in the Las Vegas area. Four UPR stations were identified, mostly north of LAME.

Other national networks have a presence in the LAME area. The GPS-MET station “Las Vegas” is located 24 km northwest of LAME (Figure 4.4) and provides near-real-time data. A POMS station (Tuweep) is about 10 km east of LAME. Ten active RAWS stations have been identified within 40 km of LAME (Table 4.6). The closest of these weather stations to LAME is “Yellow John Mtn.,” which is 2 km east of LAME and has been active since 1987. The longest data records go back to 1985 and are found at three stations. “Mount Logan” is 11 km north of LAME, “Olaf Knolls” is 25 km north of LAME, and “Tweeds Point” is 35 km northeast of LAME. Five active SAO stations provide near-real-time data within 40 km of LAME. Most of these stations are located in the Las Vegas area, north and west of LAME. McCarron International Airport, in particular, has a reliable data record for the area.

Thirteen active COOP stations have been identified within 40 km of the boundaries of LAME (Table 4.6). The longest data record we identified was from the COOP station “Truxton Canyon,” 37 km southeast of LAME. This climate station has been operating since 1901. This station’s data record was very reliable before 1980 but has been very sporadic since. Another long term record is available from the COOP station “Needles,” located 38 km southwest of LAME (1917-present). However, the data record for “Needles” is of uncertain quality. “Searchlight” is a COOP station 13 km west of LAME and has been active since 1913. The data record at this climate station is largely complete except for a multi-year gap in the early 1940s. “Overton” is located 3 km north of LAME. This station had no data between the late 1960s and the early 1990s. “Peach Springs” (1948-present) is a COOP station that measures precipitation only. It has had numerous gaps since 1980. “Tuweep” (1941-present) is located 10 km east of LAME. This climate station has had unreliable data since 1985. A reliable long term record is available from the COOP station “Las Vegas McCarron Intl. Arpt.,” located 22 km west of LAME (1948-present).

4.2.5. Mojave National Preserve

Fourteen weather and climate stations were identified in MOJA (Table 4.7; Figure 4.5). Ten of these stations are active. The CLR station “Langford-Lake” is located in northwestern MOJA. One active COOP station is located in MOJA. This climate station (Mitchell Caverns) is located in southern MOJA and has a very complete data record going back to 1958. Two RAWS stations provide near-real-time data for the park unit. “Mid Hills” is located in central MOJA and “Mojave River Sink” is located in far western MOJA. Both of these weather stations have records that are greater than 15 years in length. Three UPR stations have been identified in MOJA, located in the central part of the park unit. The USGS CLIM-MET network has three weather stations operating in western MOJA.

Outside of MOJA, 19 COOP stations were identified within 40 km of the park unit boundaries. The longest record among these climate stations comes from “Searchlight,” in southern Nevada. This station is 19 km northeast of MOJA and has been discussed previously. Needles Airport,

Table 4.7. Weather/climate stations for Mojave National Preserve (MOJA). Stations inside MOJA and within 40 km of the MOJA boundary are included. Missing entries are indicated by "M".

Mojave National Preserve (MOJA)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Langford-Lake	35.206	-116.001	668	CLR	M	Present	Yes
Goffs	34.933	-115.067	824	COOP	5/1/1916	10/31/1919	Yes
Mitchell Caverns	34.944	-115.547	1326	COOP	3/1/1958	Present	Yes
New York Mountains	35.250	-115.300	1830	COOP	7/1/1965	11/30/1972	Yes
O X Ranch	35.200	-115.200	1281	COOP	3/1/1965	11/30/1972	Yes
Vulcan Mine	34.933	-115.567	1162	COOP	3/1/1943	5/31/1947	Yes
Mid Hills	35.123	-115.411	1650	RAWS	9/1/1991	Present	Yes
Mojave River Sink	35.053	-116.079	290	RAWS	3/1/1988	Present	Yes
Cima	35.259	-115.474	1248	UPR	M	Present	Yes
Kelso	34.996	-115.682	611	UPR	M	Present	Yes
Moore	35.412	-115.260	980	UPR	M	Present	Yes
Balch	35.032	-115.970	353	USGS	11/9/1999	Present	Yes
Crucero	35.050	-116.152	308	USGS	3/1/2000	Present	Yes
North Soda Lake	35.225	-116.069	282	USGS	11/8/1999	Present	Yes
Mohave	34.970	-114.610	146	AZMET	M	Present	No
Mojave #2	34.931	-114.564	151	AZMET	M	Present	No
Bullhead City	35.108	-114.608	172	CCRFCD	M	Present	No
Calnevari	35.320	-114.800	899	CCRFCD	M	Present	No
Goodsprings	35.810	-115.470	1536	CCRFCD	M	Present	No
Jean	35.770	-115.330	864	CCRFCD	M	Present	No
Laughlin	35.180	-114.680	738	CCRFCD	M	Present	No
Mohave Valley	34.868	-114.561	141	CCRFCD	M	Present	No
Nelson Peak	35.700	-114.890	1508	CCRFCD	M	Present	No
Searchlight	35.400	-115.030	1131	CCRFCD	M	Present	No
Avawatz	35.526	-116.367	1742	CLR	M	Present	No
East-Gate	35.384	-116.361	782	CLR	M	Present	No
Hill-831	35.231	-116.564	827	CLR	M	Present	No
Red-Pass-Lake	35.259	-116.374	683	CLR	M	Present	No
Afton Canyon	35.033	-116.383	427	COOP	6/1/1959	7/31/1959	No
Amboy	34.567	-115.750	195	COOP	7/1/1948	11/13/1974	No
Baker	35.278	-116.059	290	COOP	4/1/1931	Present	No
Baker 9 NNW	35.383	-116.117	320	COOP	11/1/1953	4/22/1971	No
Bullhead City	35.141	-114.568	165	COOP	11/1/1977	Present	No
Davis Dam # 2	35.200	-114.567	201	COOP	7/1/1948	7/7/1977	No
Dunn Siding	35.050	-116.433	491	COOP	7/1/1959	9/21/1971	No
Goodsprings	35.839	-115.427	1219	COOP	2/19/1999	Present	No
Katherine R.S.	35.233	-114.567	204	COOP	7/7/1977	2/3/1978	No
Kingston	35.783	-115.633	753	COOP	2/1/1925	9/30/1942	No
Laughlin	35.169	-114.581	184	COOP	10/23/1983	Present	No
McCullough Pass	35.733	-115.167	1147	COOP	7/1/1965	7/31/1976	No

Mojave National Preserve (MOJA)							
Name	**Lat.**	**Lon.**	**Elev. (m)**	**Network**	**Start**	**End**	**In Park?**
Mountain Pass	35.471	-115.544	1442	COOP	2/1/1955	Present	No
Needles	34.830	-114.594	146	COOP	1/1/1917	Present	No
Needles A	34.833	-114.600	166	COOP	10/1/1977	7/1/1978	No
Searchlight	35.466	-114.922	1079	COOP	12/1/1913	Present	No
Silver Lake CAA Arpt.	35.333	-116.083	281	COOP	4/1/1931	11/30/1953	No
Yucca Grove	35.400	-115.817	1205	COOP	1/1/1931	2/28/1955	No
Needles Arpt.	34.768	-114.619	271	COOP	3/10/1942	Present	No
CW1191 Laughlin	35.148	-114.616	634	CWOP	M	Present	No
CW4367 Bullhead City	35.188	-114.531	321	CWOP	M	Present	No
CW4951 Fort Mohave	34.984	-114.587	154	CWOP	M	Present	No
Big Bend	35.119	-114.693	305	RAWS	11/1/1986	12/31/1995	No
Christmas Tree Pass	35.232	-114.777	1052	RAWS	6/1/1990	3/31/1995	No
Horse Thief Springs	35.771	-115.909	1524	RAWS	9/1/1991	Present	No
Goffs	34.833	-114.717	791	SAO	3/1/1932	5/31/1935	No
Laughlin Bullhead Intl. Arpt.	35.157	-114.559	212	SAO	4/7/2005	Present	No
Needles Arpt.	34.768	-114.619	271	SAO	3/10/1942	Present	No
Balch	35.044	-116.077	293	UPR	M	Present	No
Borax	35.662	-115.355	795	UPR	M	Present	No
Dunn	35.036	-116.322	450	UPR	M	Present	No
Baker Team 19	35.267	-116.083	281	WBAN	4/1/1957	9/30/1957	No
Mojave Flt E 4	35.833	-115.667	24	WBAN	5/1/1964	5/31/1964	No
Mountain Pass	35.467	-115.567	1463	WBAN	12/1/1930	12/31/1937	No
Needles AF	34.767	-114.617	229	WBAN	2/1/1955	5/31/1955	No

about 38 km southeast of MOJA, has a COOP station that has been operating since 1942 and has a very complete data record. A SAO station is also located here, providing near-real-time weather data. The COOP station "Needles," located 37 km southeast of MOJA, has been taking measurements since 1917, but the data record at this site is of uncertain quality.

The AZMET network currently operates two weather stations within 40 km of MOJA (Table 4.7). These stations ("Mojave" and "Mojave #2") are both located east of MOJA. Several stations have been identified with the CCRFCD network; these weather stations are primarily north or northeast of MOJA. The four CLR stations we identified are all northwest of MOJA. The only active RAWS station within 40 km of MOJA boundaries is "Horse Thief Springs," located 30 km north of MOJA. This weather station has been operating since 1991. Besides the aforementioned SAO station at Needles Airport, a SAO station began operating in 2005 at Laughlin Bullhead International Airport, about 36 km east of MOJA (Figure 4.5). Three weather stations with the UPR network were also identified outside of MOJA. "Balch" and "Dunn" are both west of MOJA, while "Borax" is north of MOJA.

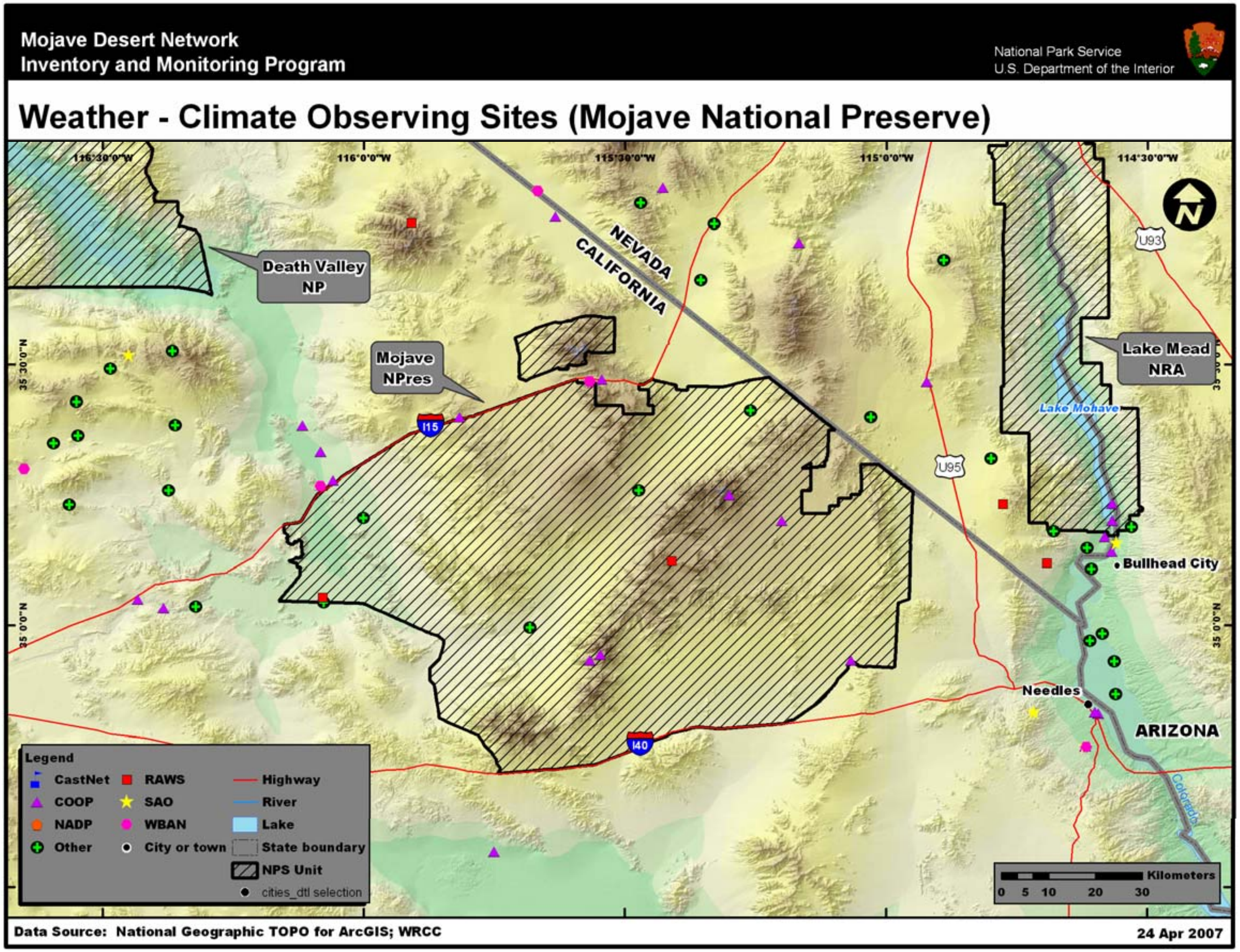


Figure 4.5. Station locations for Mojave National Preserve.

5.0. Conclusions and Recommendations

We have based our findings on an examination of available climate records within MOJN 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 MOJN. Grand Canyon – Parashant National Monument (PARA) was not in MOJN at the time of this inventory so it is not discussed in this report.

5.1. Mojave Desert Inventory and Monitoring Network

Much of the desert environment within MOJN park units has little weather or climate station coverage. When they are present, most of the weather and climate stations we have identified within MOJN park units are located near visitor centers, marinas, and other areas with higher visitor concentration. DEVA (Figure 4.1) and GRBA (Figure 4.2) are great examples of this pattern. Sparse station coverage is also fairly common outside of most of the MOJN park units. However, some park units have populated areas within 40 km of park boundaries. These generally have much higher concentrations of weather and climate stations. For JOTR, Palm Springs (southwest of JOTR) and Twentynine Palms (northwest of JOTR) contain dense coverages of weather and climate stations. For LAME, Bullhead City (south) and the Las Vegas metropolitan area (northwest) provide dense station coverages. Even MANZ has a fairly dense coverage of nearby automated weather stations that are associated with the T-REX project.

The majority of stations we have identified for DEVA are concentrated along Highway 190, running roughly east-west through the center of the park unit. In turn, most of these stations along Highway 190 are concentrated near the main visitor center at Furnace Creek and include a mix of both automated stations (CARB and CASTNet stations) and long-term COOP stations. Away from Highway 190, station coverage drops off considerably. This is particularly true north of Highway 190. With the exception of the RAWS station “Oriental Wash,” just outside of DEVA, there is no station coverage in the northern half of the park unit. There are also no stations near or along Highway 178, running through the southern half of DEVA. The only stations within the southern half of DEVA are located on the west side of the Panamint Range in southwestern DEVA. One of these is the RAWS weather station “Panamint,” jointly operated by BLM and NPS. NPS has been considering removing this station. We strongly urge the NPS to reconsider this plan and keep this station operating, as it is the only near-real-time weather station within the southern half of DEVA. Weather and climate monitoring efforts in DEVA could also benefit greatly by installing one remote near-real-time station, such as RAWS, in both the northwestern and southeastern portions of the park unit. The northwestern station could be placed near Grapevine, while the southeastern station could be installed at a convenient location near Highway 178, such as Ashford Mill.

Most of the weather and climate stations within GRBA are situated along the Lehman Creek and Baker Creek drainages in northern GRBA. This area includes the visitor center for GRBA. Outside of these two drainages, there is no station coverage within the park unit. If resources allow, NPS would benefit by partnering with local agencies to install one remote near-real-time station such as a RAWS or SNOTEL station in the southern half of GRBA. A suitable location for this site would be along the Snake Creek drainage, as a well-maintained road provides fairly easy access to the area.

Lake Mead National Recreation Area (LAME) has very few active stations having records that could be considered long-term. The longest record we found among active stations within LAME goes back to 1967 (the COOP station at Willow Beach). There are even fewer automated weather stations within the park unit (i.e., one RAWS station, "Twin West," located in far eastern LAME). As a result, weather and climate monitoring efforts within LAME must rely fairly heavily on outside stations. There are numerous stations to work with outside of the park, including RAWS stations in eastern LAME and the Las Vegas metropolitan area to the west of LAME. However, these stations may not always represent accurately the weather conditions at Lake Mead and the rest of the Colorado River drainage enclosed by LAME. For instance, the RAWS stations near eastern LAME are often located on plateaus and other elevated locations well above Lake Mead. The stations in and around Las Vegas are generally separated from LAME by a few small desert mountain ranges. In light of this situation, NPS may want to consider the installation of near-real-time weather stations at popular access points such as Temple Bar Marina. Both the CEMP and RAWS networks already have a presence in the area and would provide suitable candidates for such stations. At the same time, NPS will benefit by encouraging the continued operation of those active stations having longer climate records, as these records provide valuable documentation of ongoing climate changes within LAME.

Joshua Tree National Park (JOTR) and MOJA both have more coverage of active weather and climate stations in the central and western portions of the park units, compared to the eastern portions. This is particularly noticeable at JOTR (Figure 4.3). In JOTR, while the far western portions of the park unit generally have satisfactory station coverage, particularly with near-real-time stations, the lower basin areas in the eastern two-thirds of the park unit are largely devoid of weather and climate stations. The only active station within this entire area is the GPMP station "Cottonwood Canyon," located in south-central JOTR. The only options for this area are COOP and SAO stations around Eagle Mountain, just outside of southeastern JOTR near Interstate 10. Areas north and east of JOTR are completely devoid of active weather and climate stations. The NPS may want to consider installing a remote near-real-time weather station (e.g., RAWS) along the main road that runs through the center of JOTR between Cottonwood and Twentynine Palms. Despite the relatively sparse station coverage in MOJA, the very nature of this park unit (national preserve) implies that minimum station coverage is likely a satisfactory objective. There is at least one active long-term climate station in the park (the COOP station "Mitchell Caverns") for which continued operation should be encouraged and would benefit climate monitoring efforts in MOJA. The near-real-time sites that are present are scattered through all but the southeast portions of MOJA. NPS could, as resources allow, consider installing a near-real-time site such as RAWS in this portion of MOJA.

5.2. Spatial Variations in Mean Climate

With local variations over short horizontal and vertical distances, topography introduces considerable fine-scale structure to mean climate (temperature and precipitation) within the MOJN park units. Issues encountered in mapping mean climate are discussed in Appendix D and in Redmond et al. (2005).

For areas where new stations will be installed, if only a few new stations will be emplaced, the primary goal should be overall characterization of the main climate elements (temperature and precipitation and their joint relative, snow). This level of characterization generally requires that

(a) stations should not be located in deep valley bottoms (cold air drainage pockets) or near excessively steep slopes and (b) stations should be distributed spatially in the major biomes of each park. If such stations already are present in the vicinity, then additional stations would be best used for two important and somewhat competing purposes: (a) add redundancy as backup for loss of data from current stations (or loss of the physical stations) or (b) provide added information on spatial heterogeneity in climate arising from topographic diversity.

5.3. Climate Change Detection

There is much interest in the adaptation of MOJN ecosystems in response to possible future climate change. In particular, there are concerns about the potential impact of global warming on species extinctions and the ability of species to adapt to future climate changes. If temperatures continue to warm and montane habitats shrink, as expected, local extinction of some species is likely.

The desire for credible, accurate, complete, and long-term climate records—from any location—cannot be overemphasized. Thus, this consideration always should have a high priority. However, because of spatial diversity in climate, monitoring that fills knowledge gaps and provides information on long-term temporal variability in short-distance relationships also will be valuable. We cannot be sure that climate variability and climate change will affect all parts of a given park unit equally. In fact, it is appropriate to speculate that this is not the case, and spatial variations in temporal variability extend to small spatial scales, a consequence of diversity within MOJN in both topography and in land use patterns.

5.4. Aesthetics

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

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

5.5. Information Access

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

Decisions about improvements in monitoring capacity are facilitated greatly by the ability to examine available climate information. Various methods are being created at WRCC to improve access to that information. Web pages providing historic and ongoing climate data, and information from MOJN 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 MOJN park units but also to climate-monitoring efforts for MOJN. 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

- Station coverage in the MOJN is generally sparse, with exception of higher station concentrations near visitor centers, marinas, and other busier locations within MOJN park units.
- Some MOJN park units have more heavily populated areas and associated dense station coverages available outside their boundaries (e.g., Palm Springs for JOTR and Las Vegas for LAME).
- The majority of stations in DEVA are along Highway 190, primarily near Furnace Creek. North and south of Highway 190, there is virtually no station coverage. Climate monitoring efforts in DEVA could benefit by installing one near-real-time station (e.g., RAWS) in both the northern and southern portions of DEVA. Suitable locations may include Grapevine (north) and Ashford Mill (south).
- NPS has been considering removing the RAWS station "Panamint," jointly operated by BLM and NPS. We strongly urge the NPS to reconsider this plan and keep this station operating, as it is currently the only near-real-time weather station within the southern half of DEVA.
- Climate monitoring efforts within GRBA could be improved by partnering with local agencies to install one remote near-real-time station (RAWS or SNOTEL) in the southern half of GRBA. A suitable location for this site would be along the Snake Creek drainage.
- LAME has very few active weather or climate stations inside its boundaries. Long-term climate stations within LAME (e.g., Willow Beach COOP station) should be preserved

where possible. Numerous stations are located outside LAME but may not always represent local conditions accurately. NPS may benefit by installing one or more near-real-time stations (e.g., CEMP or RAWS stations) at popular access points such as Temple Bar Marina.

- JOTR and MOJA both have more active station coverage in the central and western portions of the park units. The NPS may want to consider installing a remote near-real-time station (e.g., RAWS) along the main road between Cottonwood and Twentynine Palms. Despite the relatively sparse station coverage in MOJA, the very nature of this park unit (national preserve) implies that minimum station coverage is likely a satisfactory objective.

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Appendix A. Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix B. Climate-monitoring principles

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

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

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

B.1.1. Effects on climate records of instrument changes, observing practices, observation locations, sampling rates, etc., must be known before such changes are implemented. This can be ascertained through a period where overlapping measurements from old and new observing systems are collected or sometimes by comparing the old and new observing systems with a reference standard. Site stability for in situ measurements, both in terms of physical location and changes in the nearby environment, also should be a key criterion in site selection. Thus, many synoptic network stations, which are primarily used in weather forecasting but also provide valuable climate data, and dedicated climate stations intended to be operational for extended periods must be subject to this policy.

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

B.1.3. Knowledge of instrument, station, and/or platform history is essential for interpreting and using the data. Changes in instrument sampling time, local environmental conditions for in situ measurements, and other factors pertinent to interpreting the observations and measurements should be recorded as a mandatory part in the observing routine and be archived with the original data.

B.1.4. In situ and other observations with a long, uninterrupted record should be maintained. Every effort should be applied to protect the data sets that have provided long-term, homogeneous observations. “Long-term” for space-based measurements is measured in decades, but for more conventional measurements, “long-term” may be a century or more. Each element in the observational system should develop a list of prioritized sites or observations based on their contribution to long-term climate monitoring.

B.1.5. Calibration, validation, and maintenance facilities are critical requirements for long-term climatic data sets. Homogeneity in the climate record must be assessed routinely, and corrective action must become part of the archived record.

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

B.1.7. Regions having insufficient data, variables and regions sensitive to change, and key measurements lacking adequate spatial and temporal resolution should be given the highest priority in designing and implementing new climate-observing systems.

B.1.8. Network designers and instrument engineers must receive long-term climate requirements at the outset of the network design process. This is particularly important because most observing systems have been designed for purposes other than long-term climate monitoring. Instruments must possess adequate accuracy with biases small enough to document climate variations and changes.

B.1.9. Much of the development of new observational capabilities and the evidence supporting the value of these observations stem from research-oriented needs or programs. A lack of stable, long-term commitment to these observations and lack of a clear transition plan from research to operations are two frequent limitations in the development of adequate, long-term monitoring capabilities. Difficulties in securing a long-term commitment must be overcome in order to improve the climate-observing system in a timely manner with minimal interruptions.

B.1.10. Data management systems that facilitate access, use, and interpretation are essential. Freedom of access, low cost, mechanisms that facilitate use (directories, catalogs, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.) and quality control should guide data management. International cooperation is critical for successful management of data used to monitor long-term climate change and variability.

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

B.2.1. Assess the impact of new climate-observing systems or changes to existing systems before they are implemented.

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

B.2.2. Require a suitable period where measurement from new and old climate-observing systems will overlap.

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

B.2.3. Treat calibration, validation, algorithm-change, and data-homogeneity assessments with the same care as the data.

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

B.2.4. Verify capability for routinely assessing the quality and homogeneity of the data including high-resolution data for extreme events.

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

B.2.5. Integrate assessments like those conducted by the International Panel on Climate Change into global climate-observing priorities.

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

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

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

B.2.7. Place high priority on increasing observations in regions lacking sufficient data and in regions sensitive to change and variability.

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

B.2.8. Provide network operators, designers, and instrument engineers with long-term requirements at the outset of the design and implementation phases for new systems.

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

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

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

B.2.10. Focus on data-management systems that facilitate access, use, and interpretation of weather data and metadata.

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

B.3. Literature Cited

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Appendix C. Factors in operating a weather/ 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 a 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. 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.) 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 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 oceans, 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 MOJN: http://www.wrcc.dri.edu/nps/pub/MOJN/metadata/MOJN_from_ACIS.tar.gz.

Appendix G. Descriptions of weather/climate monitoring networks

G.1. The Arizona Meteorological Network (AZMET)

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

The Arizona Meteorological Network (AZMET) provides near-real-time weather data that is used primarily for agricultural applications in southern and central Arizona. This network began operating stations in January, 1987.

G.2. California Air Resources Board (CARB) Network

- Purpose of network: provide meteorological data in support of air resource monitoring efforts in California.
- Data websites: http://www.met.utah.edu/jhorel/html/mesonet and http://www.arb.ca.gov.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Data are in near-real-time.
  - Extensive coverage in California.
- Network weaknesses:
  - Limited number of meteorological elements.

Meteorological measurements are taken at CARB sites in support of their overall mission of promoting and protecting public health, welfare and ecological resources in California through the reduction of air pollutants, while accounting for economical effects of such measures.

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

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

The CASTNet network is 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.4. Clark County (Nevada) Regional Flood Control District (CCRFCD) Network

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

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

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

G.5. Community Environmental Monitoring Program (CEMP)

- Purpose of network: monitor airborne levels of manmade radioactivity from activities at the Nevada Test Site.
- Primary management agencies: WRCC and Desert Research Institute.
- Data website: http://www.wrcc.dri.edu.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity and dewpoint temperature.
  - Wind speed and direction.
  - Barometric pressure.
  - Solar radiation.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: $50000 for installation ($20000 in equipment; $30000 in construction of station). Maintenance costs are site-dependent and vary widely.
- Network strengths:
  - High-quality data and metadata.
  - Sites are well-maintained.
- Network weaknesses:
  - Density of station coverage is low.
  - Network has relatively small geographical extent (Nevada and its immediate surroundings).
  - Sites are expensive to operate.

The CEMP network has 26 monitoring stations in areas surrounding the Nevada Test Site. CEMP is a joint effort of the Nevada Operations office of the Department of Energy and the Desert Research Institute.

G.6. California Irrigation Management Information System (CIMIS)

- Purpose of network: provide meteorological data to assist in irrigation activities and other water resource management issues for California agricultural interests.
- Primary management agencies: California Department of Water Resources.
- Data website: http://www.cimis.water.ca.gov/cimis/data.jsp.
- Measured weather/climate elements:

- Air temperature.
- Precipitation.
- Relative humidity.
- Wind speed and direction.
- Solar radiation.
- Soil temperature and moisture (some sites).

- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Near-real-time.
  - Sites are generally well-maintained.
  - Data access.
- Network weaknesses:
  - Somewhat limited number of meteorological elements.
  - Coverage limited to California.

The California Irrigation Management Information System (CIMIS), operated through the California Department of Water Resources, is a network of over 120 automated weather stations in the state of California. CIMIS stations are used to assist irrigators in managing their water resources efficiently.

G.7. China Lake/Fort Irwin Network (CLR)

- Purpose of network: provide weather data in support of operations at the China Lake Naval Air Weapons Station and the Fort Irwin National Training Center.
- Primary management agencies: U.S. Army and Navy.
- Data websites: http://www.nawcwpns.navy.mil/~weather/chinalake/clweather.html and http://www.irwin.army.mil/weather/weather/weather.html.
- Measured weather/climate elements:
  - Air temperature.
  - Barometric pressure.
  - Relative humidity.
  - Wind speed and direction.
  - Precipitation (some sites).
  - Solar radiation (some sites).
- Sampling frequency: unknown.
- Reporting frequency: varies; usually 5-minute, 10-minute, or hourly.
- Estimated station cost: unknown.
- Network strengths:
  - High-quality data.
  - Sites are well-maintained.
- Network weaknesses:
  - Data access.
  - Limited geographical extent.

This network of 29 weather stations is located around the China Lake Naval Air Weapons Station and the Fort Irwin National Training Center, providing weather data in support of operations at these bases. This network is located between Death Valley and the Mojave Desert, at the south end of the Owens Valley in east-central California.

G.8. 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.9. 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.10. 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.11. U.S. Department of Energy Nevada Test Site (DOENTS) Network

- Purpose of network: provide weather data in support of activities at the Nevada Test Site.
- Primary management agencies: NOAA/Air Resources Laboratory/Special Operations and Research Division.
- Data websites: http://www.met.utah.edu/jhorel/html/mesonet and http://www.sord.nv.doe.gov/arlsord-1.htm.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed and direction.
  - Barometric pressure.
- Sampling frequency: unknown.
- Reporting frequency: every 15 minutes.
- Estimated station cost: unknown.
- Network strengths:
  - High-quality data.
  - Sites are well-maintained.
- Network weaknesses:
  - Limited geographical coverage (southwestern Nevada).

The NOAA/Air Resources Laboratory/Special Operations and Research Division operates this network that provides weather data in support of activities at the Nevada Test Site in southwestern Nevada.

G.12. U.S. Department of Energy Office of Repository Development (DOERD) Network

- Purpose of network: provide weather data in support of activities at the Yucca Mountain Site.

- Primary management agencies: U.S. Department of Energy and the University of Nevada – Reno.
- Data website: http://hrcweb.nevada.edu.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed and direction.
  - Barometric pressure.
  - Solar radiation.
- Sampling frequency: unknown.
- Reporting frequency: every 15 minutes.
- Estimated station cost: unknown.
- Network strengths:
  - High-quality data.
  - Sites are well-maintained.
- Network weaknesses:
  - Data access.
  - Limited geographical extent (near Yucca Mountain).

This network provides weather data in support of activities at the Yucca Mountain Site in southwestern Nevada.

G.13. Desert Research Institute (DRI) Network

- Purpose of network: sample weather and climate in various desert and mountain locations in support of ongoing research activities at WRCC and Desert Research Institute.
- Primary management agencies: WRCC and Desert Research Institute.
- Data website: http://www.wrcc.dri.edu.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity and dewpoint temperature.
  - Wind speed and direction.
  - Barometric pressure.
  - Solar radiation.
- Sampling frequency: every 3 seconds.
- Reporting frequency: every 10 minutes.
- Estimated station cost: $10000, with maintenance costs of about $2000 per year.
- Network strengths:
  - High-quality data and metadata.
  - Sites are well-maintained.
  - Data are in near-real-time.
- Network weaknesses:
  - Network has relatively small geographical extent (Nevada and its immediate surroundings).

The Desert Research Institute (DRI) operates this network of automated weather stations, located primarily in California and Western Nevada. Many of these stations are located in remote mountain and desert locations and provide data that are often used in support of various mountain- and desert-based environmental studies in the region.

G.14. 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.
  - 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.15. NOAA Ground-Based GPS Meteorology (GPS-MET) Network

- Purpose of network:
  - Measure atmospheric water vapor using ground-based GPS receivers.
  - Facilitate use of these data operational and in other research and applications.

  - Provides data for weather forecasting, atmospheric modeling and prediction, climate monitoring, calibrating and validation other observing systems including radiosondes and satellites, and research.
- Primary management agency: NOAA Earth System Research Laboratory.
- Data website: http://gpsmet.noaa.gov/jsp/index.jsp.
- Measurements:
  - Dual frequency carrier phase measurements every 30 seconds.
- Ancillary weather/climate observations:
  - Air temperature.
  - Relative humidity.
  - Barometric pressure.
- Reporting frequency: currently 30 min.
- Estimated station cost: $0-$10000, depending on approach. Data from dual frequency GPS receivers installed for conventional applications (e.g. high accuracy surveying) can be used without modification.
- Network strengths:
  - Frequent, high-quality measurements.
  - High reliability.
  - All-weather operability.
  - Many uses.
  - Highly leveraged.
  - Requires no calibration.
  - Measurement accuracy improves with time.
- Network weakness:
  - Point measurement.
  - Provides no direct information about the vertical distribution of water vapor.

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

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

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

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

G.16. National Atmospheric Deposition Program (NADP)

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

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

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

- Purpose of network: collect snowpack and related climate data to assist in forecasting water supply in the western U.S.
- Primary management agency: NRCS.
- Data website: http://www.wcc.nrcs.usda.gov/snowcourse/.

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

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

G.18. Portable Ozone Monitoring System (POMS)

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

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

G.19. 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.20. NWS/FAA Surface Airways Observation Network (SAO)

- Purpose of network: provide near-real-time (hourly or near hourly) measurements of meteorological variables and are used both for airport operations and weather forecasting.

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

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

G.21. USDA/NRCS Snowfall Telemetry (SNOTEL) Network

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

- Snow depth.
  - Relative humidity (enhanced sites only).
  - Wind speed (enhanced sites only).
  - Wind direction (enhanced sites only).
  - Solar radiation (enhanced sites only).
  - Soil moisture and temperature (enhanced sites only).
- Sampling frequency: 1-minute temperature; 1-hour precipitation, snow water content, and snow depth. Less than one minute for relative humidity, wind speed and direction, solar radiation, and soil moisture and temperature (all at enhanced site configurations only).
- Reporting frequency: reporting intervals are user-selectable. Commonly used intervals are every one, two, three, or six hours.
- Estimated station cost: $20000 with maintenance costs approximately $2000/year.
- Network strengths:
  - Sites are located in high-altitude areas that typically do not have other weather or climate stations.
  - Data are of high quality and are largely complete.
  - Very reliable automated system.
- Network weaknesses:
  - Historically limited number of elements.
  - Remote so data gaps can be long.
  - Metadata sparse and not high quality; site histories are lacking.
  - Measurement and reporting frequencies vary.
  - Many hundreds of mountain ranges still not sampled.
  - Earliest stations were installed in the late 1970s; temperatures have only been recorded since the 1980s.

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

G.22. Union Pacific Railroad Network (UPR)

- Purpose of network: provide near-real-time meteorological data to support the shipping and transport activities of the Union Pacific Railroad.
- Primary management agency: Union Pacific Railroad.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
  - Wind gust and direction.
- Sampling frequency: unknown.

- Reporting frequency: unknown.
- Estimated station cost: unknown.
- Network strengths:
  - Real-time data.
  - Fairly extensive network (covers much of central and western U.S.).
- Network weaknesses:
  - Uncertain data quality and station maintenance.
  - Access to archived data is difficult.

This is a network of weather stations managed by UPR to support their shipping and transport activities, primarily in the central and western U.S. These stations are generally located along the UPR's main railroad lines. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

G.23. U.S. Geological Survey (USGS)

- Purpose of network: investigating the connection between climate properties and geologic processes in the southwestern U.S.
- Primary management agency: USGS.
- Data website: http://esp.cr.usgs.gov/info/sw/clim-met.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
- Sampling frequency: 4 seconds.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Near-real-time data.
  - High-quality data.
- Network weaknesses:
  - Sparse coverage.

Stations with the USGS Southwest Climate Impact Meteorological Stations network (CLIM-MET) are operated under the American Drylands Project. This project investigates the connection between climate properties and geologic processes in the southwestern U.S. Climate data from this project are being input into regional climate models that simulate future climatic conditions for the region.

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

NPS/MOJN/NRTR—2007/007, April 2007

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