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Weather and Climate Inventory
National Park Service
Klamath Network

Natural Resource Technical Report NPS/KLMN/NRTR—2007/035

ON THE COVER
Summer convection near Lassen Volcanic National Park

Weather and Climate Inventory
National Park Service
Klamath Network

Natural Resource Technical Report NPS/KLMN/NRTR—2007/035
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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
AgriMet	Pacific Northwest Cooperative Agricultural Network
BLM	Bureau of Land Management
CALTRANS	California Department of Transportation
CARB	California Air Resources Board
CASTNet	Clean Air Status and Trends Network
CDEC	California Data Exchange Center
CIMIS	California Irrigation Management Information System
COOP	Cooperative Observer Program
CRLA	Crater Lake National Park
CRN	Climate Reference Network
CWOP	Citizen Weather Observer Program
DFIR	Double-Fence Intercomparison Reference
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
I&M	NPS Inventory and Monitoring Program
LABE	Lava Beds National Monument
LAVO	Lassen Volcanic National Park
LST	local standard time
KLMN	Klamath 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
NWAC	Northwest Weather and Avalanche Center
NWAVAL	Northwest Weather and Avalanche Center network
NWS	National Weather Service
ODEQ	Oregon Department of Environmental Quality network
ODOT	Oregon Department of Transportation network

ORCA	Oregon Caves National Monument
PDO	Pacific Decadal Oscillation
PNA	Pacific-North America Oscillation
PRISM	Parameter Regression on Independent Slopes Model
RAWS	Remote Automated Weather Station network
RCC	regional climate center
REDW	Redwood National Park
SAO	Surface Airways Observation network
SCAN	Soil Climate Analysis Network
SOD	Summary Of the Day
Surfrad	Surface Radiation Budget network
SNOTEL	Snowfall Telemetry network
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
WBAN	Weather Bureau Army Navy
WHIS	Whiskeytown National Recreation Area
WMO	World Meteorological Organization
WRCC	Western Regional Climate Center
WX4U	Weather For You network

Executive Summary

Climate is a dominant factor driving the physical and ecologic processes affecting the Klamath Inventory and Monitoring Network (KLMN). In coastal park units like Redwood National and State Parks (REDW), ecological characteristics are very dependent on the frequency and length of time a given site is under the influence of maritime air, including maritime stratus and fogs, a vital moisture source for coastal park units. In interior park units, conditions are drier with much more temperature variability. Snowfall is a significant water source for interior park units like Crater Lake National Park (CRLA) and Lassen Volcanic National Park (LAVO). Summer thunderstorms can ignite fires in late summer and fall. Future climate change may have significant impacts for the KLMN such as possible decreases in winter snowpack, shifts in species distributions, and the potential loss of winter freezing temperatures. Because of its influence on the ecology of KLMN park units, climate was identified as a high-priority vital sign for KLMN 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 KLMN. In this report, we provide the following information:

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

The climate of the KLMN is generally typified by cool, wet winters and warm, dry summers. In winter, strong prevailing westerlies bring frequent storms. Extremely rugged topography and proximity to the Pacific Ocean work together to create exceptionally severe climatic gradients in KLMN park units. Mean annual precipitation in the KLMN ranges from under 500 mm at Lava Beds National Monument (LABE) to over 3000 mm at the higher elevations of LAVO. Mean annual temperatures range from under 3°C in portions of CRLA to over 15°C at lower elevations of Whiskeytown National Recreation Area (WHIS). Winter temperatures are generally mildest near the coast, where minimum temperatures rarely get below freezing. In summer, the subtropical Pacific high-pressure system strengthens and the prevailing westerlies weaken and move northward. Summer daytime temperatures struggle to get above 15°C near the coast but easily exceed 35°C in some interior park units like WHIS. Summer precipitation is usually associated with weak frontal disturbances and occasional thundershowers. The El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Pacific-North America Oscillation (PNA) all influence intra- and inter-annual climate variability in the KLMN.

Through a search of national databases and inquiries to NPS staff, we have identified 32 weather and climate stations within KLMN park units. Crater Lake National Park has the most stations

within park boundaries (10). Most of the weather and climate stations identified for KLMN park units had metadata and data records that are sufficiently complete and satisfactory in quality.

The primary source of automated weather data for these park units generally comes from RAWS (Remote Automated Weather Station) or SNOTEL (Snowfall Telemetry Network) sites. It is therefore beneficial for climate monitoring efforts in the KLMN that the NPS work closely with local agencies to continue the operation of existing RAWS and SNOTEL stations within KLMN park units, as well as to encourage the addition of new stations.

New stations would likely be beneficial in places such as the north rim of Crater Lake, where there are currently no automated weather stations. Despite the storied history of heavy snowfalls at CRLA, snowfall patterns in the park unit are severely undersampled. Only one station, a NWAVAL (Northwest Weather and Avalanche Center network) station near Rim Village, provides observations of near-real-time snowfall and snow depth. Therefore, it may be useful to partner with NRCS to convert one of the existing snowcourse sites near Rim Village into a SNOTEL station, providing additional near-real-time snowfall data for the park unit and providing another data point to compare snowfall patterns with other SNOTEL stations around CRLA.

Additional areas lacking in automated weather station coverage include northern LABE as well as southern and eastern portions of LAVO. The RAWS network already has a strong presence in these areas, so NPS may want to consider working with local agencies to install a RAWS station. SNOTEL installations could be considered as well for locations that receive substantial snowfall.

The only station we identified within Oregon Caves National Monument (ORCA) is a Citizen Weather Observer Program (CWOP) station. Although this is a real-time station, siting standards for the CWOP network are generally not well-defined and the reliability of CWOP data records is sometimes questionable. Therefore, ORCA may want to consider working with local agencies to install a RAWS site within the park unit. The RAWS network does have well-known standards for station siting and this strategy would also improve the coverage of the RAWS network, which already has a significant presence in the area surrounding ORCA.

There are no automated stations devoted to weather/climate measurements within the central portions of REDW. In addition, weather/climate station coverage is nonexistent to the east of the central portion of REDW. The park unit may want to consider adding a RAWS station at the same location as the existing GPMP and NADP stations, near the mouth of the Klamath River. A RAWS station is a natural choice for such an installation due to the RAWS network's already-significant presence in the REDW area.

Most of the KLMN park units have at least one long-term climate station either within the park or within 40 km of the park unit. Climate monitoring efforts within the KLMN 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 KLMN park units.

Acknowledgements

This work was supported and completed under Task Agreement H8R07010001, with the Great Basin Cooperative Ecosystem Studies Unit. We would like to acknowledge very helpful assistance from various National Park Service personnel associated with the Klamath Inventory and Monitoring Network. Particular thanks are extended to Dan Sarr. We also thank John Gross, Margaret Beer, Grant Kelly, Greg McCurdy, and Heather Angeloff for all their help. Portions of the work were supported by the NOAA Western Regional Climate Center.

1.0. Introduction

Weather and climate are key drivers in ecosystem structure and function. Global- and regional-scale climate variations will have a tremendous impact on natural systems (Chapin et al. 1996; Schlesinger 1997; Jacobson et al. 2000; Bonan 2002). Long-term patterns in temperature and precipitation provide first-order constraints on potential ecosystem structure and function. Secondary constraints are realized from the intensity and duration of individual weather events and, additionally, from seasonality and inter-annual climate variability. These constraints influence the fundamental properties of ecologic systems, such as soil–water relationships, plant–soil processes, and nutrient cycling, as well as disturbance rates and intensity. These properties, in turn, influence the life-history strategies supported by a climatic regime (Neilson 1987; Rodriguez-Iturbe 2000; Odion 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 Klamath Inventory and Monitoring Network (KLMN) 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 KLMN (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 KLMN park units.
- Inventory of locations for all weather stations in and near KLMN 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.

Table 1.1. Park units in the Klamath Network.

Acronym	Name
CRLA	Crater Lake National Park
LABE	Lava Beds National Monument
LAVO	Lassen Volcanic National Park
ORCA	Oregon Caves National Monument
REDW	Redwood National and State Parks
WHIS	Whiskeytown National Recreation Area

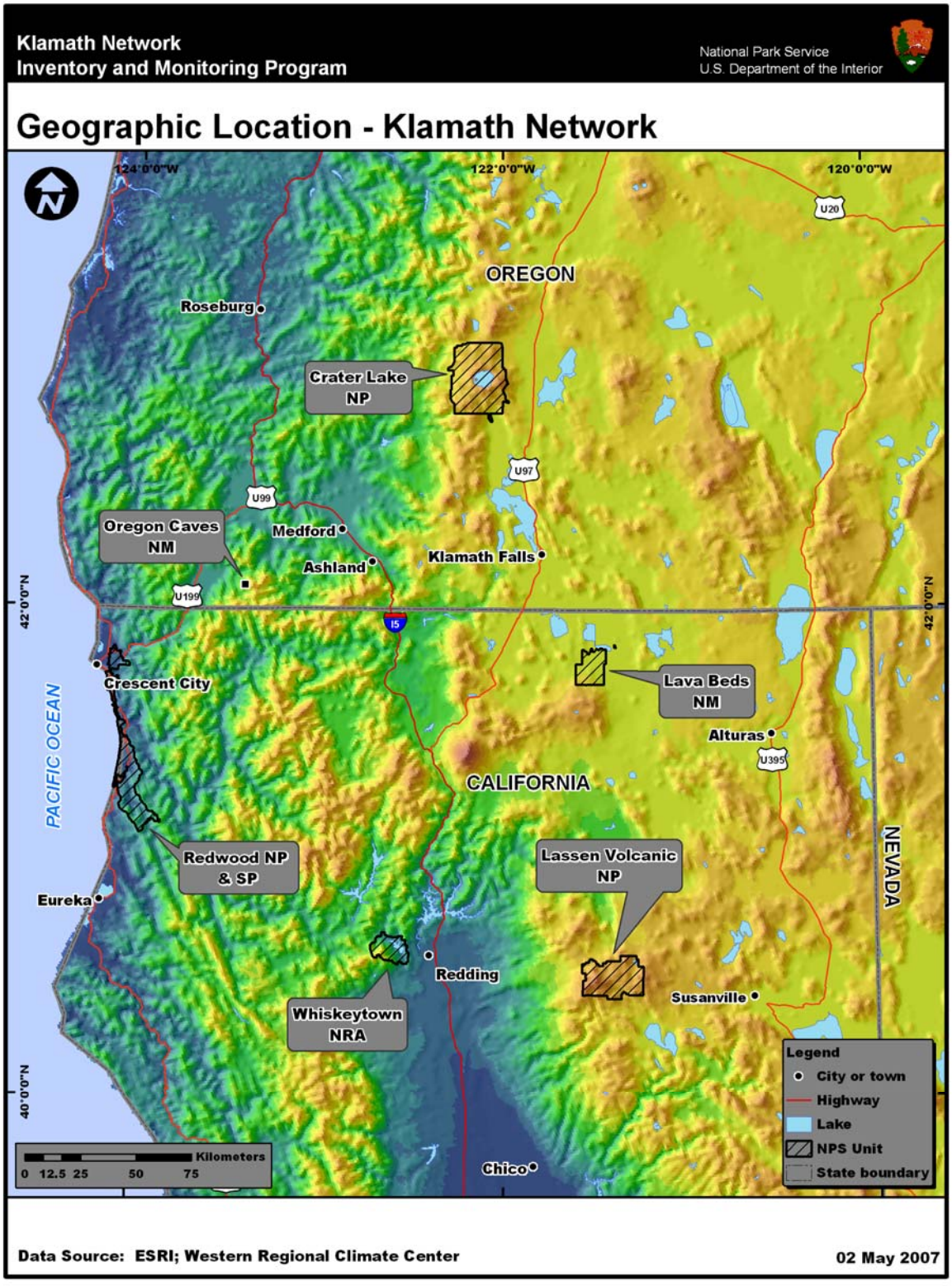


Figure 1.1. Map of the Klamath Network.

The primary questions to be addressed by climate- and weather-monitoring activities in KLMN are as follows (Odion et al. 2005):

A. What climate changes are associated with El Niño?
B. Are there changes in storm severity?
C. How is sea level changing?
D. Are ocean temperatures changing?
E. Are fog dynamics (amount, inland penetration, etc.) changing?
F. What is time and location of snowpack (melting, duration, depth)?
G. What are the trends in the frost snow free period?

1.1. Network Terminology

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

1.1.1. Weather/Climate Station Networks

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

1.1.2. NPS I&M Networks

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

1.2. Weather versus Climate Definitions

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

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

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

1.3. Purpose of Measurements

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

- What is the purpose of weather and climate measurements?

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

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

- Provide measurements for real-time operational needs and early warnings of potential hazards (landslides, mudflows, washouts, fallen trees, plowing activities, fire conditions, aircraft and watercraft conditions, road conditions, rescue conditions, fog, restoration and remediation activities, etc.).
- Provide visitor education and aid interpretation of expected and actual conditions for visitors while they are in the park and for deciding if and when to visit the park.
- Establish engineering and design criteria for structures, roads, culverts, etc., for human comfort, safety, and economic needs.
- Consistently monitor climate over the long-term to detect changes in environmental drivers affecting ecosystems, including both gradual and sudden events.
- Provide retrospective data to understand *a posteriori* changes in flora and fauna.
- Document for posterity the physical conditions in and near the park units, including mean, extreme, and variable measurements (in time and space) for all applications.

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

1.4. Design of Climate-Monitoring Programs

Determining the purposes for collecting measurements in a given weather/climate monitoring program will guide the process of identifying weather/climate stations suitable for the monitoring program. The context for making these decisions is provided in Chapter 2 where background on the KLMN 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 principles 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 at the major national networks are $1500–2500 per station per year but these costs still can vary greatly depending on the kind of automated site.

1.4.5. Communications

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

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

1.4.6. Quality Assurance and Quality Control

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

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

The quality of the data only decreases with time once the observation is made. The best and most effective quality control, therefore, consists in making high-quality measurements from the start

and then successfully transmitting the measurements to an ingest process and storage site. Once the data are received from a monitoring station, a series of checks with increasing complexity can be applied, ranging from single-element checks (self-consistency) to multiple-element checks (inter-sensor consistency) to multiple-station/single-element checks (inter-station consistency). Suitable ancillary data (battery voltages, data ranges for all measurements, etc.) can prove extremely useful in diagnosing problems.

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

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

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

1.4.7. Standards

Although there is near-universal recognition of the value in systematic weather and climate measurements, these measurements will have little value unless they conform to accepted standards. There is not a single source for standards for collecting weather and climate data nor a single standard that meets all needs. Measurement standards have been developed by the 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 KLMN. An understanding of both current climate patterns and climate history in the KLMN is important to understanding and interpreting change and patterns in ecosystem attributes (Odion et al. 2005). It is essential that the KLMN 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 KLMN, as discussed in this chapter.

2.1. Climate and the KLMN Environment

Topography and coastal influences are instrumental in defining the climate of the KLMN (Odion et al. 2005). The Klamath-Siskiyou subregion contains REDW, ORCA, and WHIS. This subregion is characterized by extremely rugged topography. Topography works along with the proximity of the subregion to the Pacific Ocean to create exceptionally severe climatic gradients. The climate of the Klamath-Siskiyou subregion is typified by cool, wet winters and warm, dry summers. In winter, a strong low pressure area generally sets up in the Gulf of Alaska, with a relatively weak subtropical Pacific high-pressure system south of that. As a result, the prevailing westerlies that are common in temperate zones strengthen and move southward during the winter months, increasing the numbers of cyclonic storms (Bryson and Hare 1974; Miller 2002). These winter storms are responsible for the majority of the subregion's annual precipitation. Topography also affects the distribution of precipitation during the winter months, with precipitation generally decreasing in the subregion from windward (west-facing) slopes and higher elevations to leeward (east facing) slopes and lower elevation areas (Miller 2002). Precipitation also tends to decrease from west to east across the Klamath-Siskiyou subregion. Despite deep, late-lying snowpacks, winters at high elevations in the Klamath-Siskiyou subregion are relatively mild and the ground rarely freezes.

In summer, the subtropical Pacific high-pressure system strengthens and the prevailing westerlies weaken and move northward. These shifts create dry conditions in the Klamath-Siskiyou subregion (Bryson and Hare 1974). When summer precipitation occurs, it usually comes in association with weak frontal disturbances and occasional thundershowers, especially at higher elevations. Lightning associated with thunderstorms commonly ignites fires in late summer and fall.

Although the Klamath-Siskiyou subregion is strongly moderated by the Pacific Ocean throughout the year, coastal influences are especially marked in summer. From June to September, warm, moist Pacific air is advected eastward by prevailing winds across the cold, upwelling coastal waters of the California current, creating a layer of moist and relatively cool air along the coast (Miller 2002). This moist, cool air is overlain by warmer, drier air, making this moist, marine layer relatively stable. The coastal mountains add to this stability by blocking the moist air from moving inland (Mitchell 1976), although occasionally a "marine push" can develop that will move cool, moist air from the Pacific Ocean over the Coast and Cascade mountain ranges into the interior (Mock 1996). The frequency and length of time a given site is under the influence of this maritime air plays a major role in the ecology of the Klamath-Siskiyou subregion. Maritime stratus and fogs decrease the amount of solar radiation that reaches

the ground, lowering maximum temperatures and increasing the humidity during the otherwise dry summers. All these factors differentiate the maritime-influenced western slopes of the Klamath-Siskiyou subregion from the drier eastern slopes (Waring 1969). Coastal slopes and valleys that are favorably oriented to northwest summer winds are bathed in summer fogs and fog drip, vital sources of moisture for redwood trees (Burgess and Dawson 2004). The marine air masses effectively delimit the landward extent of the redwood biome.

The Cascades-Modoc subregion contains CRLA, LABE, and LAVO. This subregion is more isolated from the moderating climatic influence of the Pacific Ocean. At low to moderate elevations, summers are warm and dry and winters are cooler than along the coast. The western slopes of the Cascade Mountains receive abundant precipitation from winter storms, with the majority falling as snow at higher elevations. There is a significant increase in storm frequency with latitude in this subregion, such that CRLA headquarters receives nearly 50% percent more precipitation days through the year than LAVO headquarters. This precipitation difference reflects the latitudinal transition from the Mediterranean climate regime of California to the temperate maritime climate of the Pacific Northwest (Mitchell 1976). Above 2000 m elevation, snowpacks reach great depths and often cover the ground into summer (Redmond 2007). Snowfields currently persist year-round on Lassen Peak. The eastern slopes of the Cascades and adjacent Modoc Plateau are much drier, which is reflected in the open vegetation of these areas. During winter, cold continental air frequently invades the Modoc Plateau, but these cold air masses do not often reach the higher elevations of the Cascades or spill over onto the Cascades' western slopes. Summer thunderstorms are frequent along the Cascades' crest and eastern slopes in summer.

Future climate changes will likely have significant impacts for the KLMN. Although there is uncertainty as to the exact timing and magnitude of future climate change, there is a growing scientific consensus that climate change is occurring and that human activities are contributing to this change (NAST 2001). Estimates of global temperature increases for the next century range from 1.4° to 5.8°C, depending on the assumptions that are made about future greenhouse gas emissions, population growth, etc. (Albritton et al. 2001). For the western U.S., general circulation model simulations of future climate indicate that temperatures will likely increase in both winter and summer (Giorgi et al. 2001). Precipitation is also simulated to increase in winter, with changes in summer precipitation being less certain. Thus, the KLMN may experience warmer and wetter winters, and warmer summers in the future. Some modeling studies also suggest an increase in the strength of upwelling along the coast, which would help to maintain the coastal fogs that currently ameliorate coastal summer temperatures (Snyder et al. 2003). These fogs are considered important for maintaining appropriate climate conditions for the redwoods of REDW.

The many different potential impacts of climate change have significant management implications for KLMN park units. Shifts in the distributions of species attributed to recent climate change have already been identified (e.g., Parmesan and Yohe 2003) and these shifts will continue in the future. Of particular significance to biotic communities is the potential loss of winter freezing temperatures in the KLMN. Freezing temperatures control the distributions of a variety of plant and animal species. Loss of freezing temperatures would not only allow the expansion of certain native and non-native species in the region, but would also allow some

insect pests to increase reproduction (Ayres and Lombardero 2000). Disturbance regimes, such as the frequency and magnitude of fire, will also be affected by climate change, with increased summer temperatures potentially increasing fire potential (Flannigan et al. 2000).

Climate change will also affect the hydrologic systems of the KLMN. Combined changes in temperature and precipitation will alter the amount, seasonal timing, and duration of snowpack and stream flows. These alterations affect both water quality and quantity. Mote (2003) evaluated snow data for the Pacific Northwest and found a decrease in snow water equivalent (i.e., the depth of water equivalent to the weight of the snowpack) related to increases in temperature for the period 1950-2000. A number of studies have also simulated future changes in snowpack and runoff, which indicate future decreases in snow (e.g., Leung et al. 2004) and changes in the timing of snowmelt runoff (e.g., Stewart et al. 2004) for the KLMN.

2.2. Spatial Variability

Precipitation characteristics of the KLMN are defined by the superimposed effects of topography and coast-interior gradients. Precipitation generally increases to the west and as a function of elevation in the KLMN. The wettest park unit in the KLMN is REDW, where mean annual precipitation totals exceed 2000 throughout much of the park unit (Figure 2.1; Odion et al. 2005) Park units with high-elevation settings, such as CRLA and LAVO, also have high annual precipitation totals. LAVO also has one of the most extreme precipitation gradients of any of the KLMN park units, with mean annual precipitation totals ranging from under 750 mm in eastern LAVO to near 3000 mm at the highest elevations of the park unit. In contrast to these wet locations, LABE is the driest park unit in the KLMN, with a mean annual precipitation of under 500 mm across the park unit. This park unit is located in the rainshadow of the northern California mountains. Much of the precipitation in KLMN park units occurs during the winter months (Figure 2.2), with some interior locations possibly receiving a secondary precipitation maximum during the spring months (e.g., see Figure 2.2c). Since much of the precipitation in the KLMN falls during the winter months, this precipitation falls in the form of snow for the higher-elevation park units like CRLA and LAVO, where mean annual snowfalls can exceed 15 m (Figure 2.3). Crater Lake records some of the heaviest snow in the U.S. each winter, with annual totals averaging over 13 m (Odion et al. 2005; Redmond 2007).

Mean annual temperatures across the KLMN generally follow a northeast-southwest gradient (Figure 2.4). This temperature pattern is composed of at least three components. First, temperatures generally become milder closer to the coast. Latitudinal gradients are a second contributor, with warmer conditions towards the south. Finally, mean annual temperatures in the KLMN also vary as a function of elevation, with the coolest conditions observed in the higher elevations of the Cascade Mountains. The coolest park unit in the KLMN is CRLA, where mean annual temperatures are below 3°C across much of the park unit. The warmest park unit in the KLMN is WHIS, with mean annual temperatures that can exceed 15°C at lower elevations west of Redding. Near the coast, in REDW, mean annual temperatures are around 10°C. The coast-interior climate gradients in temperature are well-defined during the winter and summer months.

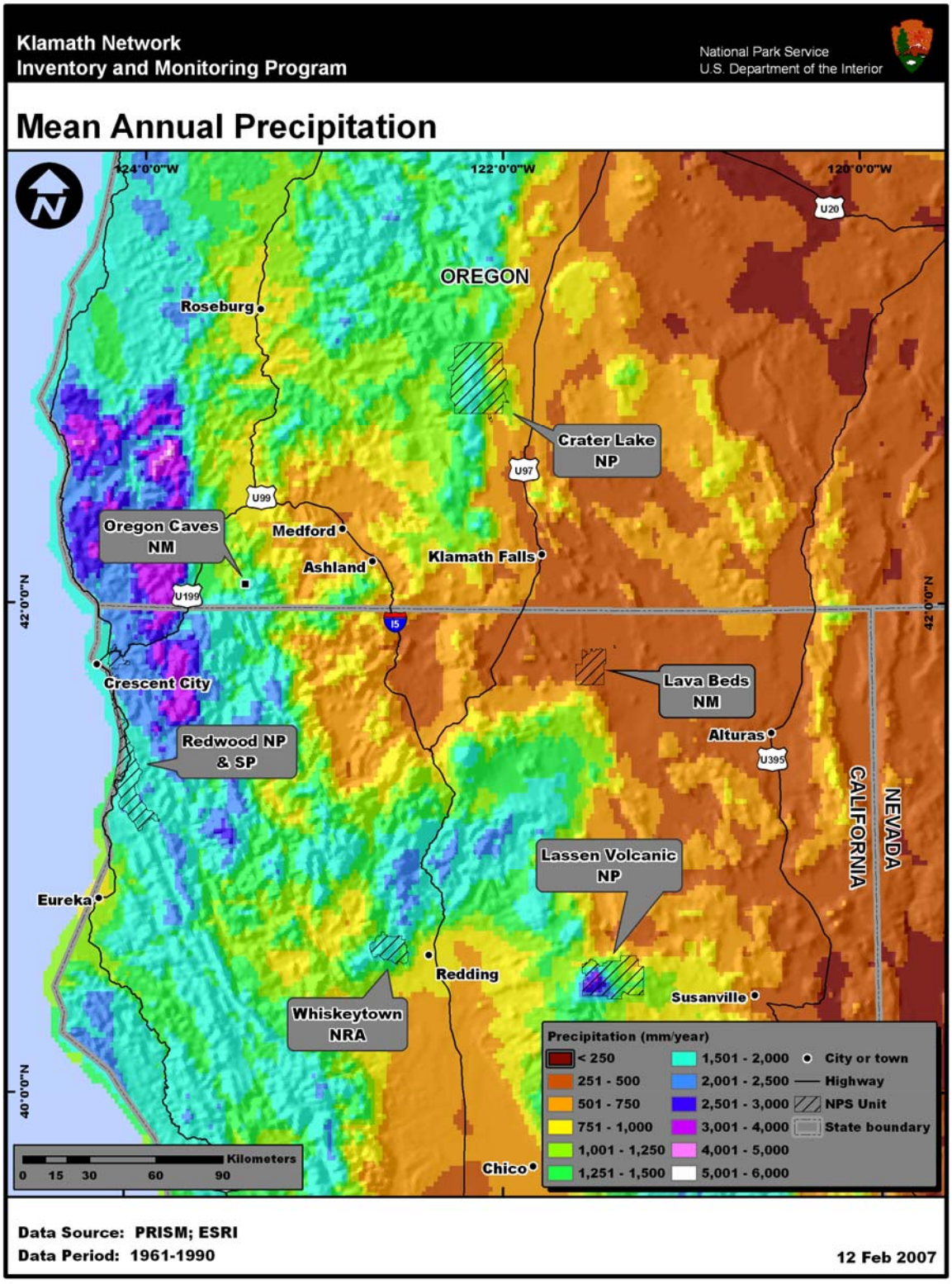
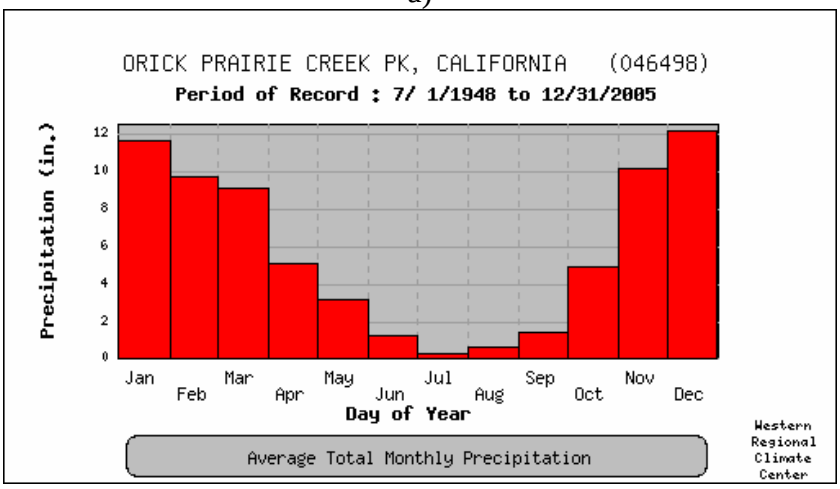
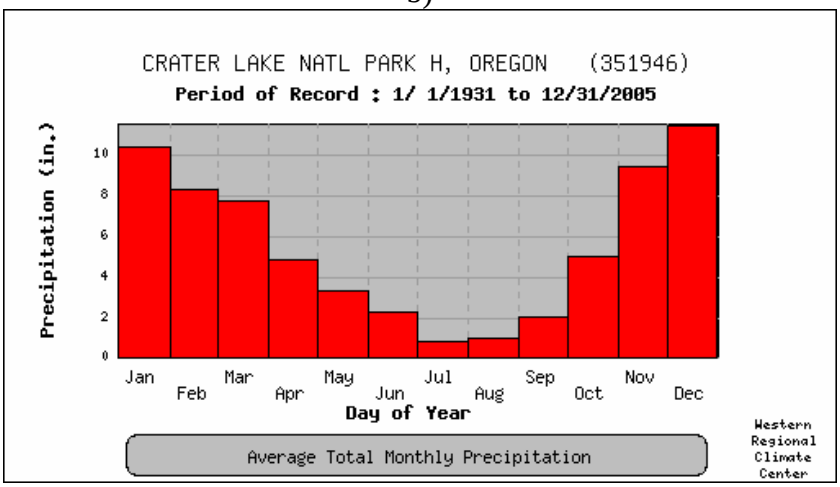


Figure 2.1. Mean annual precipitation, 1961-1990, for the KLMN.

a)



b)



c)

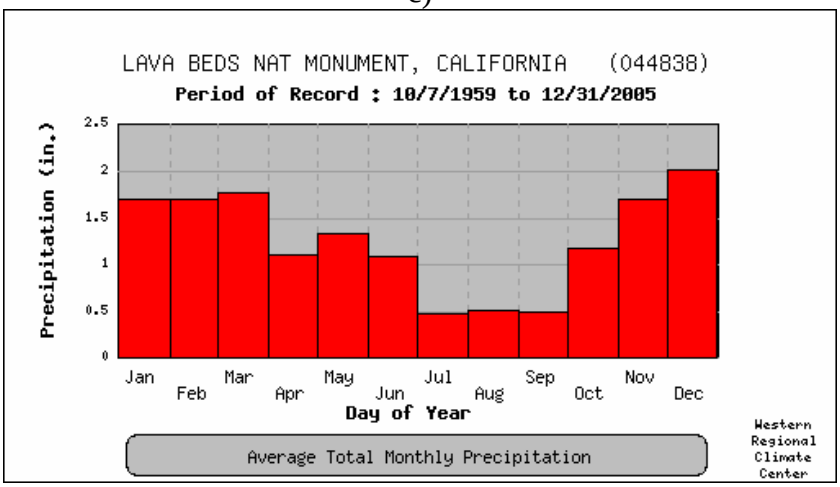


Figure 2.2. Mean monthly precipitation at selected locations in the KLMN. Locations include REDW (a), CRLA (b), and LABE (c).

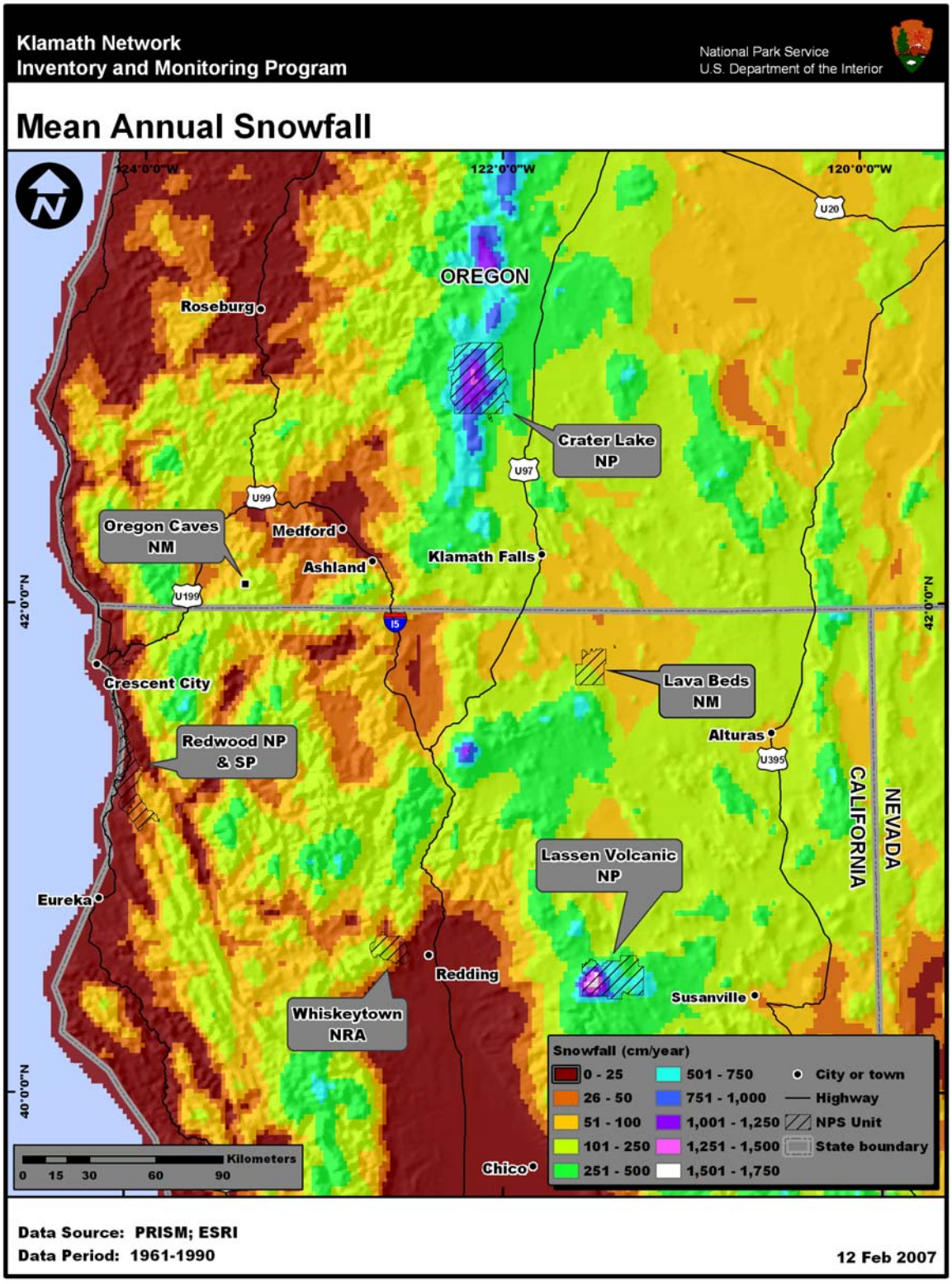


Figure 2.3. Mean annual snowfall, 1961-1990, for the KLMN.

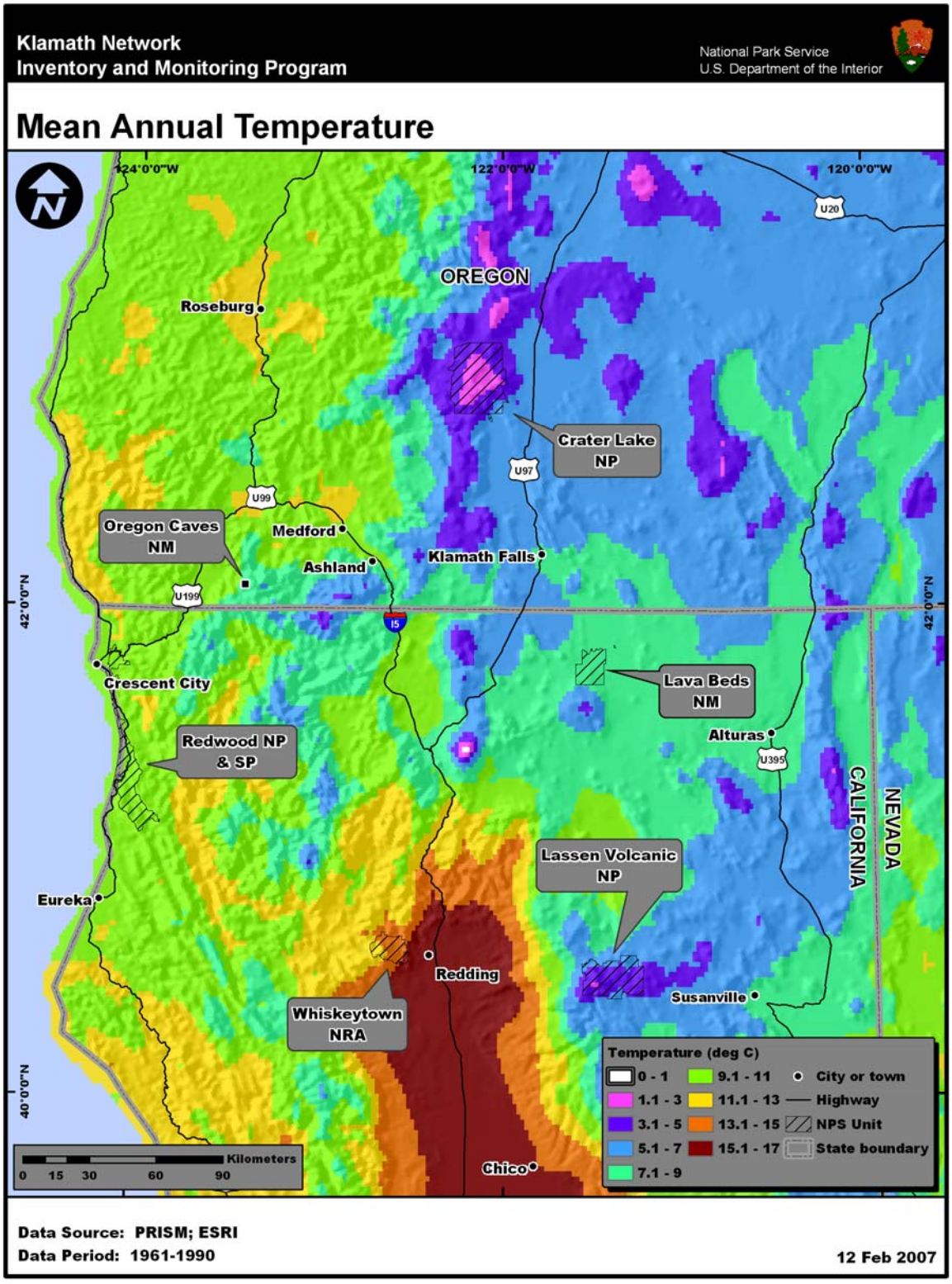


Figure 2.4. Mean annual temperature, 1961-1990, for the KLMN.

During January, portions of REDW have minimum temperatures that generally don't get below 3°C, while higher elevations of CRLA and LAVO get down below -10°C regularly (Figure 2.5). In July, however, this temperature gradient goes in the opposite direction. While portions of REDW regularly struggle to get above 16°C for daytime maximum temperatures, lower elevations of WHIS often get above 34°C (Figure 2.6) and occasionally exceed 40°C during heat waves. Topographical effects and north-south gradients are also apparent during the summer months. The higher-elevation park units (e.g., CRLA, LAVO) are still coolest.

2.3. Temporal Variability

The Pacific-North America Oscillation (PNA; Wallace and Gutzler 1981) is an important contributor to variability of storm frequencies and tracks during a given year, with variations on the order of weeks. Negative phases of the PNA generally bring cooler temperatures and increased storminess over the KLMN, especially to the park units in Oregon.

Both the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) cause interannual climate variations in the KLMN (Redmond and Koch 1991; Mock 1996; Cayan et al. 1998; Mantua 2000; Mantua and Hare 2002). El Niño conditions and/or positive phases of the PDO are associated with warmer and drier than normal conditions, particularly in northern KLMN, while La Niña conditions and/or negative phases of the PDO are associated with cooler and wetter than normal conditions.

An investigation of daily precipitation amounts around the KLMN region over the last century (Figure 2.7) reveals little in the way of an overall trend, although portions of southwestern Oregon may be showing some precipitation increases during this time period (Figure 2.7a). Throughout the KLMN, a drier period is apparent during the first part of the twentieth century. This shows up particularly well in southwestern Oregon, but is also apparent in northern California (Figures 2.7b,c).

Long-term trends in ambient temperature (Figure 2.8) indicate that temperatures have become slightly warmer over the past century, particularly in northern portions of the KLMN (Figures 2.8a,b). This finding is in line with other studies of temperature trends over the western U.S. (NAST 2001). 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

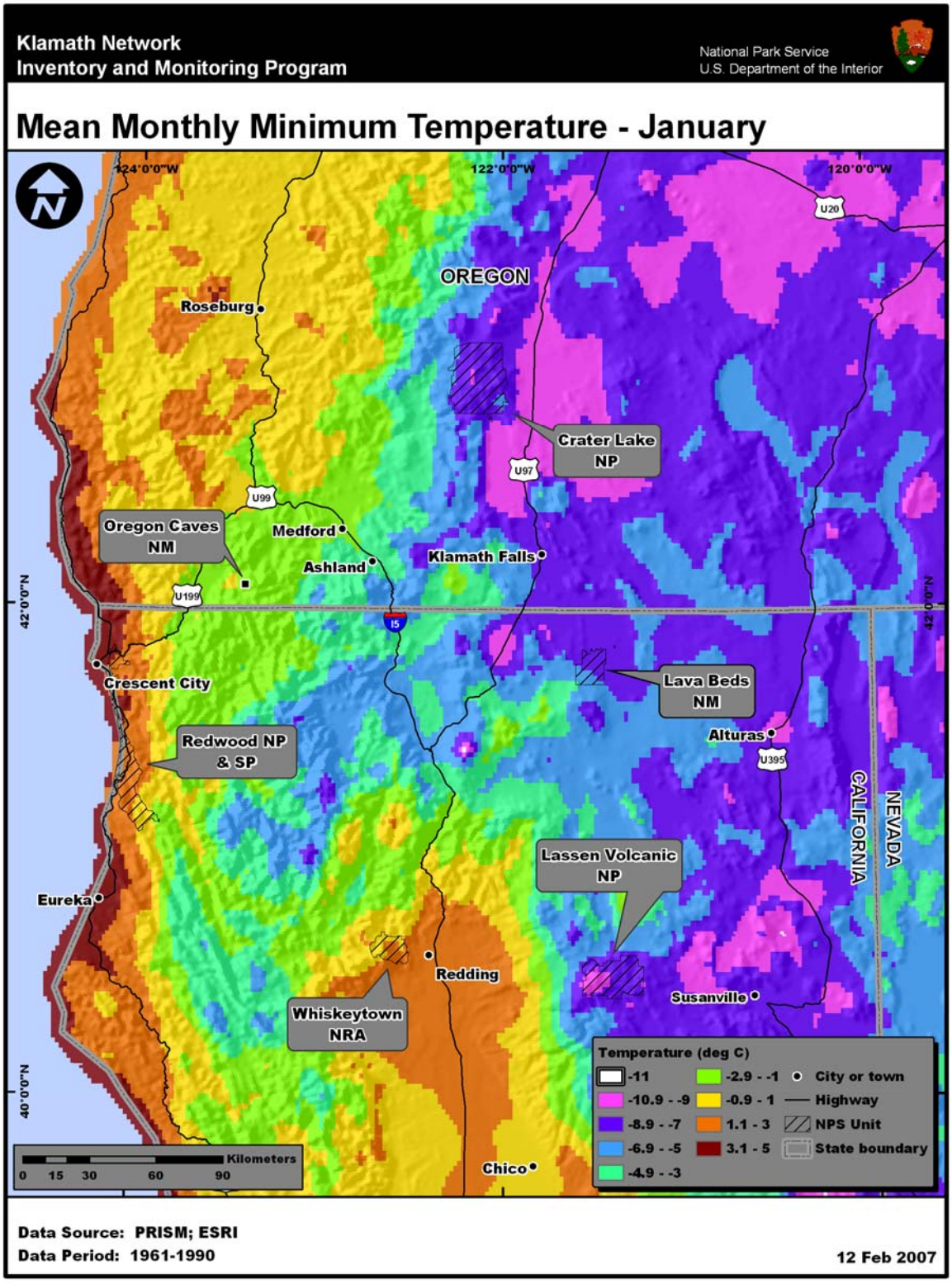


Figure 2.5. Mean January minimum temperature, 1961-1990, for the KLMN.

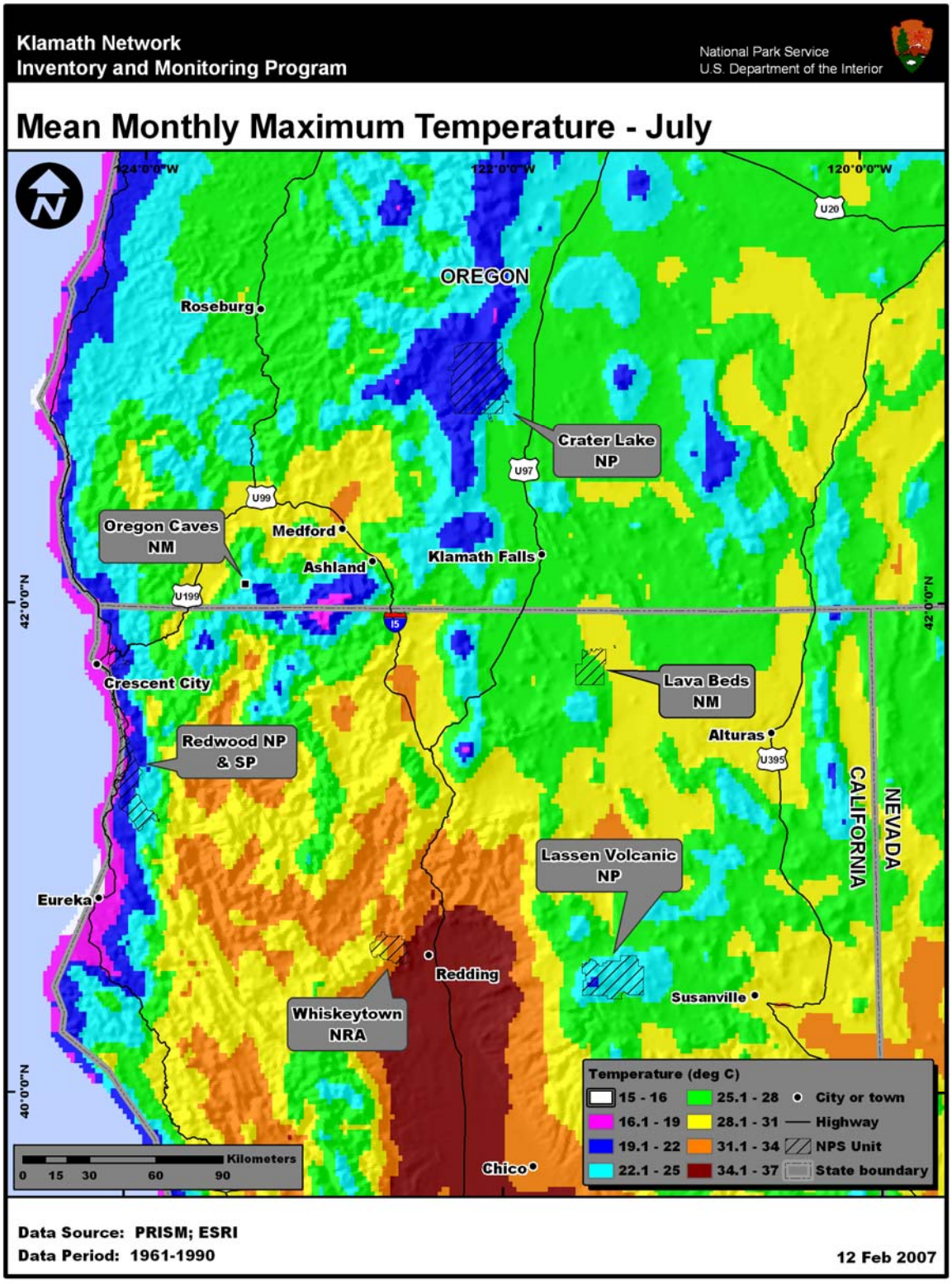
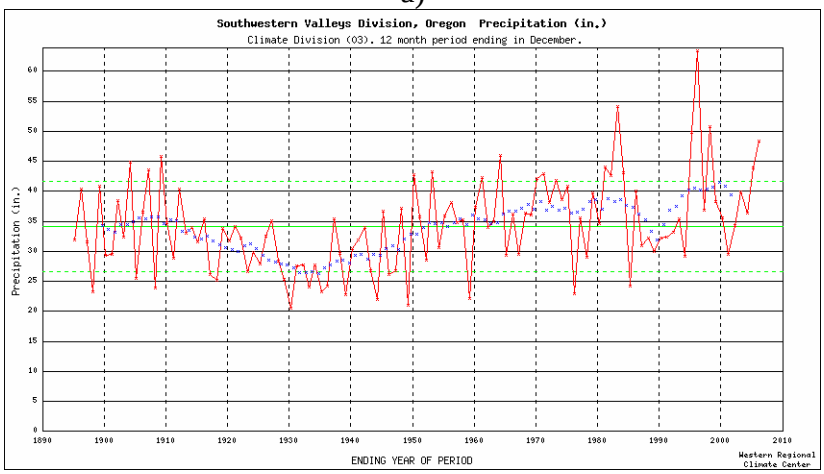
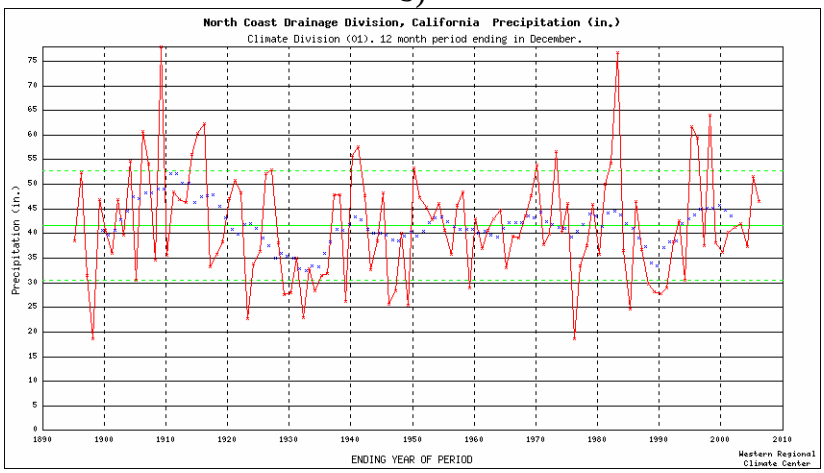


Figure 2.6. Mean July maximum temperature, 1961-1990, for the KLMN.

a)



b)



c)

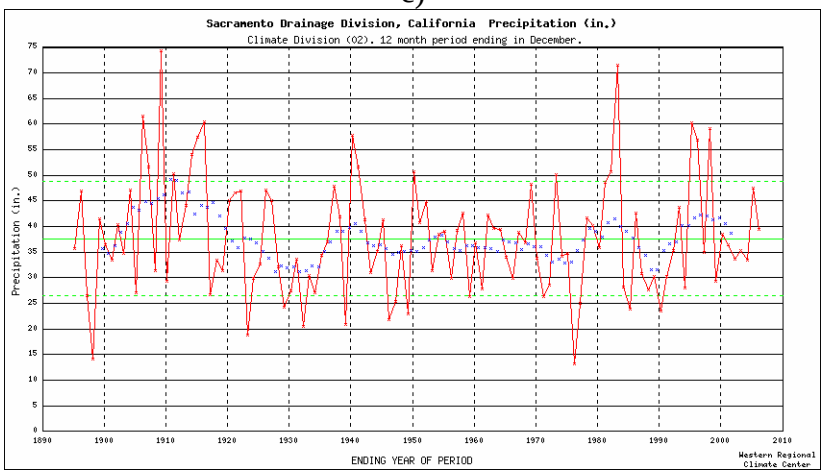
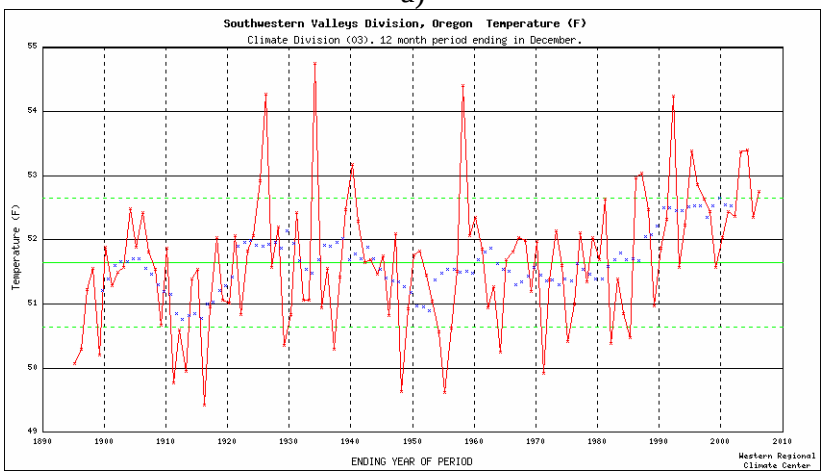
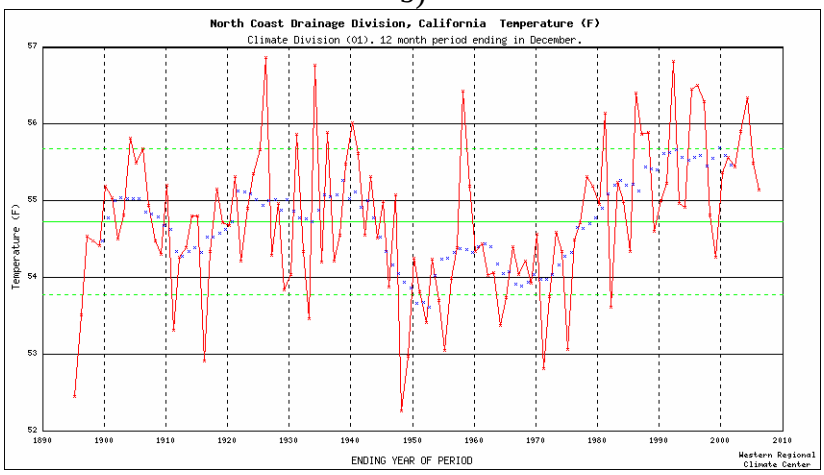


Figure 2.7. Precipitation time series, 1895-2005, for selected regions in the KLMN. These include twelve-month precipitation (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include southwestern Oregon (a), the northern California Coast (b), and the upper Sacramento River basin (c).

a)



b)



c)

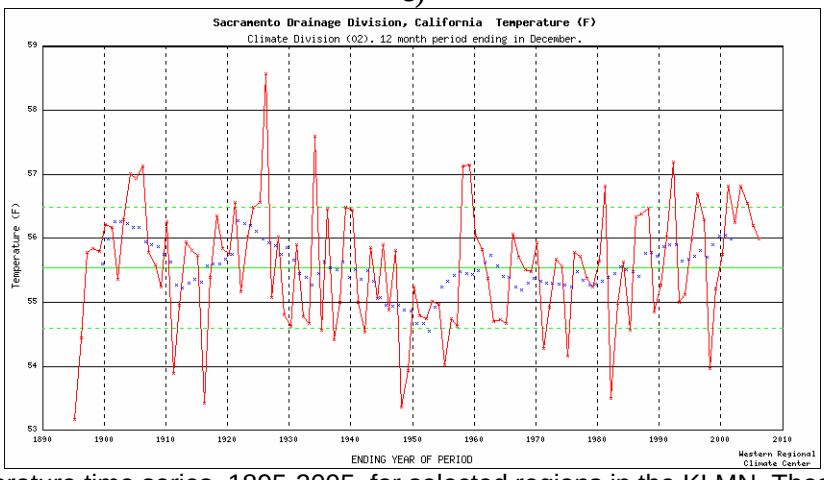


Figure 2.8. Temperature time series, 1895-2005, for selected regions in the KLMN. These include twelve-month average temperature (ending in December) (red), 10-year running mean (blue), mean (green), and plus/minus one standard deviation (green dotted). Locations include southwestern Oregon (a), the northern California Coast (b), and the upper Sacramento River basin (c).

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

3.1. Metadata Retrieval

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

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

The primary source of metadata at WRCC is the Applied Climate Information System (ACIS), a joint effort among RCCs and other NOAA entities. Metadata for KLMN weather/climate stations identified from the ACIS database are available in file “KLMN_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 KLMN 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 KLMN 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 KLMN we selected only those stations located within 40 km of the KLMN park units. This buffer distance was selected in an attempt to include automated stations from major networks such as RAWS and SNOTEL, 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 KLMN. 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 KLMN region in relation to the boundaries of the NPS park units within the KLMN. 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 KLMN region are associated with at least one of 19 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 KLMN.

Acronym	Name
AgriMet	Pacific Northwest Cooperative Agricultural Network
CALTRANS	California Department of Transportation network
CARB	California Air Resources Board network
CASTNet	Clean Air Status and Trends Network
CIMIS	California Irrigation Management Information System network
COOP	NWS Cooperative Observer Program
CWOP	Citizen Weather Observer Program
DRI	Desert Research Institute network
GPMP	NPS Gaseous Pollutant Monitoring Program
NADP	National Atmospheric Deposition Program
NRCS-SC	NRCS snowcourse network
NWAVAL	Northwest Weather and Avalanche Center network
ODEQ	Oregon Department of Environmental Quality network
ODOT	Oregon Department of Transportation network
RAWS	Remote Automated Weather Station network
SAO	NWS/FAA Surface Airways Observation network
SCAN	Soil Climate Analysis Network
SNOTEL	NRCS Snowfall Telemetry network
WX4U	Weather For You network

4.1.1. Pacific Northwest Cooperative Agricultural Network (AgriMet)

AgriMet is a network of automated weather stations operated by the U.S. Bureau of Reclamation. The stations in AgriMet are located primarily in irrigated agricultural areas throughout the Pacific Northwest.

4.1.2. California Department of Transportation (CALTRANS) Network

These weather stations are operated by the CALTRANS in support of management activities for California's transportation network. Measured meteorological elements usually include temperature, precipitation, wind, and relative humidity.

4.1.3. 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.

4.1.4. 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.

4.1.5. California Irrigation Management Information System (CIMIS) Network

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.

4.1.6. 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.

4.1.7. 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.

4.1.8. 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 environmental studies. Meteorology elements are measured every 10 minutes and include temperature, wind, humidity, barometric pressure, precipitation, and solar radiation.

4.1.9. 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.

4.1.10. 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 USDA and the U.S. Geological Survey (USGS). Precipitation is the primary climate parameter measured at NADP sites.

4.1.11. USDA/NRCS Snowcourse Network (NRCS-SC)

The USDA/NRCS maintains a 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.

4.1.12. Northwest Weather and Avalanche Center Network (NWAVAL)

The Northwest Weather and Avalanche Center (NWAC) operates a network of weather stations in the mountainous areas of the Pacific Northwest, primarily in Washington. These stations are operated in support of NWAC's primary mission of monitoring avalanche conditions in the mountains of Washington and northern Oregon. Hourly weather and climate elements that are measured include temperature, humidity, wind, and precipitation. Daily measurements are made of snowfall and snowdepth.

4.1.13. Oregon Department of Environmental Quality (ODEQ) Network

The primary mission of ODEQ is to protect and enhance Oregon's air and water quality. Weather and climate elements are measured by ODEQ stations in support of this primary mission. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

4.1.14. Oregon Department of Transportation (ODOT) Network

These weather stations are operated by ODOT in support of management activities for Oregon's transportation network. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

4.1.15. 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.

4.1.16. NWS Surface Airways Observation Network (SAO)

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

4.1.17. USDA/NRCS Soil Climate Analysis Network (SCAN)

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

4.1.18. 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.

4.1.19. Weather For You Network (WX4U)

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

4.1.20. 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.

4.1.21. 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.

4.1.22. 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 KLMN 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 KLMN (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 KLMN 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	CRLA	LABE	LAVO	ORCA	REDW	WHIS
AgriMet	**0**(0)	**3**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)
CALTRANS	**0**(0)	**0**(0)	**2**(0)	**0**(0)	**0**(0)	**4**(0)
CARB	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**1**(0)
CASTNet	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**0**(0)	**0**(0)
CIMIS	**0**(0)	**3**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
COOP	**26**(2)	**16**(1)	**11**(3)	**23**(0)	**34**(3)	**31**(4)
CWOP	**0**(0)	**0**(0)	**3**(0)	**3**(1)	**7**(0)	**6**(0)
DRI	**4**(4)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
GPMP	**0**(0)	**0**(0)	**1**(1)	**0**(0)	**1**(0)	**0**(0)
NADP	**1**(0)	**0**(0)	**1**(1)	**0**(0)	**1**(1)	**0**(0)
NRCS-SC	**9**(2)	**1**(0)	**0**(0)	**5**(0)	**0**(0)	**0**(0)
NWAVAL	**1**(1)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
ODEQ	**0**(0)	**0**(0)	**0**(0)	**1**(0)	**0**(0)	**0**(0)
ODOT	**1**(0)	**0**(0)	**0**(0)	**2**(0)	**1**(0)	**0**(0)
RAWS	**11**(1)	**9**(1)	**17**(1)	**9**(0)	**14**(2)	**13**(1)
SAO	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**9**(0)	**1**(0)
SCAN	**0**(0)	**1**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)
SNOTEL	**5**(0)	**0**(0)	**0**(0)	**2**(0)	**0**(0)	**0**(0)
WX4U	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**0**(0)	**3**(0)
Other	**0**(0)	**2**(0)	**4**(0)	**0**(0)	**0**(0)	**1**(0)
Total	**58**(10)	**36**(2)	**41**(8)	**45**(1)	**68**(6)	**60**(5)

Lists of stations have been compiled for the KLMN. As was mentioned previously, a station does not have to be within park boundaries to provide useful data and information regarding a given park unit. 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.

Ten weather/climate stations were identified within the boundaries of CRLA (Table 4.3; Figure 4.1). Only one of these is inactive; this was a COOP station that operated on Crater Lake's north rim from 1963 until 1976. The COOP station "Crater Lake" is located at Rim Village on the lake's southern rim and provides the longest climate record in the park. This station has operated since 1919. With the exception of numerous gaps from 1943 through September 1946, this station has a very complete data record. Desert Research Institute (DRI) operates a few stations throughout the park unit; most of these stations started operating in 1999 or 2000. "Crater Lake Buoy" is located on Crater Lake itself. "Crater Lake USGS Gage" (1987-present) is situated at Cleetwood Cove along the north shore of the lake. The other two DRI stations are located in south CRLA. "Crater Lake Rim" is located at Rim Village, while "Crater Lake Lagoon" is near park headquarters. Two NRCS-SC sites are within CRLA; "Park H.Q. Rev." is just southeast of Rim Village, while "Annie Spring Rev." is 5 km south of Rim Village. The NWAVAL station "Crater Lake" is near Rim Village. The only RAWS station we identified within CRLA (Panhandle) is in the extreme southern portion of the park.

Table 4.3. Weather/climate stations for the KLMN 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?
Crater Lake National Park (CRLA)							
Crater Lake	42.897	-122.133	1974	COOP	10/1/1919	Present	Yes
Crater Lake N Rim	42.983	-122.067	2074	COOP	10/1/1963	9/30/1976	Yes
Crater Lake Buoy	42.954	-122.090	1885	DRI	9/1/2000	Present	Yes
Crater Lake Lagoon	42.888	-122.137	1942	DRI	9/1/1999	Present	Yes
Crater Lake Rim	42.912	-122.149	2149	DRI	2/1/2000	Present	Yes
Crater Lake USGS Gage	42.976	-122.088	1859	DRI	10/1/1987	Present	Yes
Annie Spring Rev.	42.883	-122.167	1835	NRCS-SC	1/1/1929	Present	Yes
Park H.Q. Rev.	42.900	-122.133	1996	NRCS-SC	1/1/1943	Present	Yes
Crater Lake	42.910	-122.140	1951	NWAVAL	M	Present	Yes
Panhandle	42.769	-122.064	1341	RAWS	9/1/1991	Present	Yes
Big Camas R.S.	43.233	-122.467	942	COOP	11/13/1937	5/31/1960	No
Chemult	43.229	-121.789	1451	COOP	2/1/1937	Present	No
Chiloquin 12 NW	42.702	-121.996	1274	COOP	6/1/1980	Present	No
Diamond Lake	43.183	-122.133	1629	COOP	9/1/1965	10/31/1976	No
Diamond Lake Lodge	43.183	-122.133	1586	COOP	4/21/1927	9/30/1953	No
Fort Klamath 7 SW	42.617	-122.083	1269	COOP	3/1/1953	10/18/1966	No
Klamath Agency	42.633	-121.933	1272	COOP	5/1/1953	Present	No
Lemolo Lake 3 NNW	43.360	-122.221	1243	COOP	9/1/1966	Present	No
Lookout Butte	42.983	-121.933	1870	COOP	7/1/1953	Present	No
Persist	42.767	-122.600	863	COOP	4/1/1950	3/3/1965	No
Persist 2 NW	42.783	-122.617	763	COOP	4/1/1950	5/31/1950	No
Persist 4 NW	42.800	-122.633	595	COOP	7/1/1948	4/30/1950	No
Prospect 2 SW	42.734	-122.516	757	COOP	10/1/1905	Present	No
Prospect 5 SE	42.717	-122.400	1025	COOP	10/1/1967	5/1/1981	No
Prospect 6 SW	42.700	-122.600	522	COOP	12/1/1950	9/30/1951	No
Rustler Peak	42.617	-122.350	1894	COOP	6/1/1953	Present	No
Sand Creek	42.850	-121.900	1427	COOP	4/1/1929	5/31/1950	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Seven Lakes	42.650	-122.133	1903	COOP	9/1/1965	10/31/1976	No
Stump Lake	43.250	-122.283	1190	COOP	10/1/1967	5/1/1981	No
Tiller 15 ENE	43.007	-122.696	762	COOP	8/1/1955	Present	No
Toketee Falls	43.275	-122.450	628	COOP	2/1/1953	Present	No
Toketee R.S.	43.267	-122.417	808	COOP	5/1/1960	Present	No
Trail 12 NE	42.783	-122.667	564	COOP	9/12/1951	4/30/1970	No
Union Creek R.S.	42.900	-122.467	1007	COOP	11/1/1965	10/31/1969	No
Lost Creek Dam	42.668	-122.683	475	NADP	10/21/1980	12/6/1983	No
Chiloquin (PP&L)	42.583	-121.850	1277	NRCS-SC	1/1/1927	Present	No
Crystal (PP&L)	42.667	-122.067	1265	NRCS-SC	1/1/1930	Present	No
Fort Klamath (PP&L)	42.717	-122.000	1280	NRCS-SC	1/1/1939	Present	No
Harriman Lodge (PP&L)	42.450	-122.100	1265	NRCS-SC	1/1/1939	Present	No
North Umpqua	43.283	-122.150	1286	NRCS-SC	1/1/1937	Present	No
South Fork Canal	42.717	-122.400	1067	NRCS-SC	1/1/1937	Present	No
Trap Creek	43.250	-122.250	1158	NRCS-SC	1/1/1937	Present	No
Diamond Lake (Ore 138 MP 83)	43.127	-122.132	1603	ODOT	M	Present	No
Big Butte	42.689	-122.385	860	RAWS	5/7/1987	Present	No
Buckeye	43.036	-122.655	998	RAWS	1/1/1985	Present	No
Chemult	43.226	-121.789	1411	RAWS	6/1/1992	1/31/2002	No
Chiloquin	42.577	-121.894	1347	RAWS	6/1/1986	Present	No
Cinnamon	43.250	-122.150	1413	RAWS	5/1/1985	Present	No
Klamath NWR	42.953	-121.582	1381	RAWS	6/1/2002	Present	No
Mount Stella	42.937	-122.435	1437	RAWS	5/1/1985	Present	No
Rover	43.019	-122.000	1600	RAWS	6/1/1995	Present	No
Toketee	43.240	-122.400	1024	RAWS	1/1/1985	Present	No
Zim	42.689	-122.468	860	RAWS	5/1/1987	Present	No
Chemult Altenate	43.217	-121.800	1451	SNOTEL	M	Present	No
Cold Springs Camp	42.533	-122.183	1859	SNOTEL	10/1/1981	Present	No
Diamond Lake	43.183	-122.133	1620	SNOTEL	10/1/1980	Present	No
Sevenmile Marsh	42.683	-122.133	1890	SNOTEL	10/1/1980	Present	No
Sheep Canyon	43.183	-122.250	1228	SNOTEL	10/1/1980	Present	No
Lava Beds National Monument (LABE)							
Lava Beds N M	41.740	-121.507	1454	COOP	7/1/1948	Present	Yes
Indian Well	41.742	-121.538	1454	RAWS	5/1/1997	Present	Yes
Klamath Falls	42.165	-121.755	1250	AgriMet	6/1/2001	1/31/2004	No
Lorella	42.078	-121.224	1268	AgriMet	6/1/2001	12/31/2001	No
Worden	42.017	-121.787	1244	AgriMet	6/1/2001	12/31/2001	No
Medicine Lake	41.592	-121.610	2042	CDEC	10/1/1985	Present	No
MacDoel	41.792	-122.064	1297	CIMIS	1/1/1986	6/30/1986	No
Tulelake	42.003	-121.427	1232	CIMIS	M	Present	No
Tulelake F.S.	41.959	-121.471	1230	CIMIS	3/1/1989	Present	No
Bryant Mountain	42.083	-121.250	1745	COOP	9/1/1967	10/31/1976	No
Clear Lake Dam	41.933	-121.067	1394	COOP	5/1/1907	10/31/1955	No
Klamath Falls	42.164	-121.755	1247	COOP	12/29/1941	1/23/2004	No
Long Bell Stn.	41.467	-121.417	1336	COOP	10/1/1958	9/30/1976	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Malin	42.017	-121.417	1235	COOP	1/1/1911	5/31/1949	No
Malin 5 E	42.008	-121.319	1410	COOP	10/1/1968	Present	No
Medicine Lake	41.583	-121.617	2053	COOP	7/1/1948	9/30/1976	No
Merrill 2 NW	42.050	-121.633	1244	COOP	6/1/1949	10/16/1968	No
Mount Hebron 11 ESE	41.733	-121.800	1336	COOP	5/1/1952	2/28/1961	No
Mount Hebron R.S.	41.784	-122.045	1295	COOP	1/1/1907	Present	No
Steele Swamp	41.867	-120.950	1388	COOP	7/1/1948	5/31/1950	No
Tennant	41.583	-121.917	1449	COOP	5/1/1952	9/30/1957	No
Tulelake	41.960	-121.474	1230	COOP	1/1/1932	Present	No
Tulelake 5 WSW	41.917	-121.567	1229	COOP	1/1/1932	10/31/1957	No
Tulelake Inspection	41.600	-121.200	1345	COOP	5/1/1959	8/31/1959	No
Dog Hollow AM	42.117	-121.117	1494	NRCS-SC	1/1/1958	Present	No
Adin – Portable	41.628	-121.298	1524	RAWS	M	Present	No
Doublehead	41.625	-121.068	1219	RAWS	3/1/1997	5/31/1999	No
Juanita Lake	41.786	-122.006	1646	RAWS	12/1/1988	Present	No
Klamath Basin NWR California	41.944	-121.565	1231	RAWS	8/1/2006	Present	No
Lower Klamath	41.999	-121.700	1249	RAWS	6/1/2002	Present	No
Round Mountain	41.427	-121.464	1603	RAWS	3/1/1991	Present	No
Timber Mountain	41.629	-121.298	1512	RAWS	8/1/2002	Present	No
Van Bremmer	41.643	-121.794	1502	RAWS	6/1/1993	Present	No
Klamath Falls	42.147	-121.724	1245	SAO	12/29/1941	Present	No
Lynhart Ranch	42.020	-121.390	1247	SCAN	M	Present	No
Klamath Falls	42.133	-121.750	1248	WBAN	3/1/1944	9/30/1945	No
Lassen Volcanic National Park (LAVO)							
Lassen Volcanic NP-Manzanita	40.535	-121.576	1791	CARB	M	Present	Yes
Manzanita Lake F.S.	40.540	-121.576	1756	CASTNet	10/1/1987	Present	Yes
Butte Lake	40.567	-121.300	1848	COOP	7/1/1961	9/30/1976	Yes
Manzanita Lake	40.542	-121.576	1753	COOP	1/1/1949	Present	Yes
Mount Harkness	40.433	-121.300	2452	COOP	7/1/1953	Present	Yes
Manzanita Lake F.S.	40.540	-121.576	1756	GPMP	11/1/1987	6/30/1995	Yes
Lassen Volcanic NP-Manzanita	40.537	-121.539	1756	NADP	6/13/2000	Present	Yes
Hat Mountain	40.502	-121.423	2438	RAWS	9/1/1995	3/31/1999	Yes
Fredonyer Pass East	40.390	-120.790	1431	CALTRANS	M	Present	No
Fredonyer Pass Summit	40.360	-120.865	1738	CALTRANS	M	Present	No
Blacks Mountain	40.770	-121.168	2149	CDEC	M	Present	No
Humbug	40.115	-121.368	1981	CDEC	1/1/1984	Present	No
Rattlesnake (CDWR)	40.125	-121.043	1859	CDEC	1/1/1984	Present	No
Snow Mountain	40.778	-121.782	1814	CDEC	9/1/1998	Present	No
Blacks Mountain Ranch	40.733	-121.250	1708	COOP	7/1/1948	10/31/1960	No
Chester	40.303	-121.242	1381	COOP	10/1/1909	Present	No
Chester R.S.	40.283	-121.250	1382	COOP	6/1/1955	Present	No
Forward Mill	40.433	-121.733	1007	COOP	1/1/1952	10/31/1958	No
Hat Creek R.S.	40.800	-121.500	1022	COOP	7/1/1948	10/9/1978	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Mineral	40.346	-121.609	1486	COOP	11/1/1909	Present	No
Shingletown 2 E	40.500	-121.850	1084	COOP	11/1/1958	4/2/1984	No
Swain Mountain	40.450	-121.100	1879	COOP	7/1/1957	6/30/1976	No
CW1579 Chester	40.304	-121.232	1381	CWOP	M	Present	No
CW4663 Cassel	40.918	-121.550	971	CWOP	M	Present	No
KG6QHS Shingletown	40.477	-121.989	637	CWOP	M	Present	No
Blacks Mtn. - PSW	40.731	-121.118	1844	RAWS	12/1/1996	2/28/1998	No
Bogard R.S.	40.598	-121.083	1722	RAWS	7/1/1992	Present	No
Butte Meadows	40.079	-121.504	1512	RAWS	5/1/1990	6/30/2000	No
Carpenter Ridge	40.069	-121.583	1467	RAWS	6/1/2000	Present	No
Chester	40.290	-121.085	1379	RAWS	10/1/1989	Present	No
Gordon	40.759	-120.896	1890	RAWS	9/1/2002	Present	No
Hatcreek Micro #1	40.703	-121.367	1219	RAWS	6/1/1995	10/31/1995	No
Ladder Butte	40.807	-121.297	1753	RAWS	4/1/1988	Present	No
Lassen Lodge	40.344	-121.714	1219	RAWS	5/1/1990	Present	No
LN2 –Portable	40.283	-121.200	1829	RAWS	2/20/1987	Present	No
LN3 – Portable	40.283	-121.200	1829	RAWS	2/20/1987	Present	No
LN5 - Portable	40.759	-120.896	457	RAWS	3/11/1992	Present	No
Manzanita Lake	40.540	-121.580	1725	RAWS	6/1/1990	Present	No
Soldier Mountain	40.926	-121.586	1131	RAWS	5/1/1990	Present	No
Westwood	40.307	-120.900	1768	RAWS	5/1/1990	Present	No
Whitmore	40.620	-121.904	748	RAWS	5/1/1990	Present	No
Oregon Caves National Monument (ORCA)							
CW2072 Oregon Caves	42.100	-123.410	1219	CWOP	M	Present	Yes
Althouse	42.017	-123.567	1382	COOP	5/1/1965	10/31/1976	No
Applegate	42.246	-123.176	391	COOP	11/1/1967	Present	No
Applegate 2 SE	42.250	-123.133	393	COOP	10/1/1958	1/31/1961	No
Bolan Peak	42.033	-123.467	1909	COOP	7/1/1953	Present	No
Buncom 1 NNE	42.180	-122.985	594	COOP	7/1/1948	Present	No
Cave Junction 1 WNW	42.177	-123.675	390	COOP	3/1/1962	Present	No
Copper	42.033	-123.133	580	COOP	7/1/1948	10/9/1975	No
Copper 4 NE	42.081	-123.104	555	COOP	9/23/1950	Present	No
Elk Valley	41.988	-123.718	520	COOP	1/1/1938	Present	No
Grants Pass	42.424	-123.324	283	COOP	1/1/1893	Present	No
Happy Camp R.S.	41.804	-123.376	341	COOP	3/1/1914	Present	No
Idlewild Hwy. Mntnc. S.	41.900	-123.767	381	COOP	5/1/1959	6/30/1977	No
Illinois Valley R.S.	42.167	-123.650	406	COOP	7/1/1953	Present	No
Kerby	42.217	-123.650	387	COOP	9/1/1898	6/5/1967	No
Kerby 3 NNW	42.232	-123.664	369	COOP	11/1/1966	Present	No
Low Divide	42.133	-123.367	1098	COOP	9/1/1967	10/31/1976	No
Ruch	42.223	-123.047	472	COOP	4/1/1963	Present	No
Selma	42.275	-123.528	445	COOP	11/18/1997	6/22/2005	No
Selma 4 W	42.283	-123.700	458	COOP	11/1/1960	6/30/1961	No
Star R.S.	42.150	-123.067	482	COOP	7/1/1948	Present	No
Swede Basin	42.383	-123.667	1122	COOP	9/1/1967	10/31/1976	No
Whiskey Peak	42.017	-123.250	1830	COOP	9/1/1967	10/31/1976	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Williams 1 NW	42.228	-123.286	442	COOP	5/16/1892	Present	No
CW5474 Grants Pass	42.429	-123.386	279	CWOP	M	Present	No
CW5579 O'Brien	42.044	-123.714	472	CWOP	M	Present	No
Althouse #2	42.033	-123.483	1381	NRCS-SC	1/1/1937	Present	No
Althouse #3	42.000	-123.550	1524	NRCS-SC	1/1/1982	Present	No
Grayback Peak	42.117	-123.300	1829	NRCS-SC	1/1/1936	Present	No
King Mountain 2	42.050	-123.200	1219	NRCS-SC	1/1/1961	Present	No
Page Mountain	42.033	-123.550	1234	NRCS-SC	1/1/1955	Present	No
Grants Pass/Parkside School	42.434	-123.348	277	ODEQ	M	Present	No
Hayes Hill (US 199 MP 16.4)	42.330	-123.591	500	ODOT	M	Present	No
O'Brien (US 199 MP 41)	42.001	-123.723	518	ODOT	M	Present	No
Buck Peak	42.070	-123.233	1598	RAWS	1/1/1985	10/31/1995	No
Crazy Peak	41.992	-123.604	1210	RAWS	1/1/1985	Present	No
Happy Camp Micro	41.793	-123.377	447	RAWS	6/1/1995	11/30/1995	No
Illinois Valley Airport	42.117	-123.667	423	RAWS	1/1/1985	Present	No
Onion Mountain Lookout	42.300	-123.400	1353	RAWS	1/1/1985	Present	No
Provolt Seed Orchard	42.290	-123.230	360	RAWS	1/1/1985	Present	No
Slater Butte	41.859	-123.353	1423	RAWS	12/1/1988	Present	No
Squaw Peak	42.067	-123.017	1513	RAWS	1/1/1985	Present	No
Star	42.150	-123.067	511	RAWS	5/1/1987	7/31/2005	No
Bigelow Camp	42.083	-123.350	1561	SNOTEL	10/1/1980	Present	No
King Mountain	42.050	-123.200	1219	SNOTEL	M	Present	No
Redwood National & State Parks (REDW)							
Crescent City 7 ENE	41.794	-124.085	37	COOP	12/4/1951	9/12/2003	Yes
Orick Prairie	41.362	-124.019	49	COOP	5/1/1937	Present	Yes
Schoolhouse Peak	41.150	-123.883	933	COOP	6/1/1953	Present	Yes
Yurok Tribe-Requa	41.559	-124.092	110	NADP	8/17/2006	Present	Yes
School House	41.138	-123.906	805	RAWS	1/1/2001	Present	Yes
Westside	41.223	-124.053	393	RAWS	12/1/2004	Present	Yes
Brookings	42.030	-124.241	24	AgriMet	6/1/2001	12/31/2001	No
Arcata Mad River	40.917	-124.067	3	COOP	12/1/1965	8/21/1990	No
Blue Creek Mtn. L.O.	41.400	-123.767	1467	COOP	7/1/1960	10/31/1972	No
Blue Lake Redwood Cr.	40.917	-123.817	299	COOP	1/1/1956	10/16/1965	No
Brookings	42.077	-124.318	53	COOP	5/1/2002	Present	No
Butler Valley Ranch	40.767	-123.900	128	COOP	5/1/1970	6/1/1975	No
Buzzard Roost	42.200	-124.167	759	COOP	9/1/1965	10/31/1976	No
Camp Six Lookout	41.833	-123.867	1129	COOP	9/1/1963	9/30/1976	No
China Flat	40.867	-123.583	183	COOP	7/1/1908	9/30/1955	No
Crescent City	41.796	-124.215	12	COOP	1/1/1893	Present	No
Crescent City Mntnc. S.	41.767	-124.200	15	COOP	7/1/1948	3/3/1983	No
Elk Valley	41.988	-123.718	520	COOP	1/1/1938	Present	No
Fort Dick	41.867	-124.150	14	COOP	11/1/1951	6/1/1989	No
Fort Dick River	41.881	-124.135	0	COOP	6/1/1965	9/19/2004	No
Gasquet R.S.	41.845	-123.965	117	COOP	7/1/1948	Present	No
Hoopa	41.048	-123.678	101	COOP	12/1/1965	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Hoopa	41.050	-123.667	110	COOP	7/1/1948	8/1/1983	No
Hoopa 2 SE	41.033	-123.650	98	COOP	11/1/1954	11/1/1967	No
Idlewild Hwy Mntnc. S.	41.900	-123.767	381	COOP	5/1/1959	6/30/1977	No
Klamath	41.579	-124.075	9	COOP	7/1/1948	Present	No
Klamath 2	41.533	-124.050	17	COOP	7/1/1948	3/31/1973	No
Klamath Glen	41.517	-124.000	2	COOP	12/1/1957	10/26/1990	No
Korbel	40.867	-123.950	46	COOP	11/1/1959	5/31/1975	No
Orick	41.283	-124.067	2	COOP	11/1/1959	8/7/1995	No
Orick 10 SE	41.183	-123.917	756	COOP	11/1/1959	6/30/1963	No
Orleans	41.304	-123.536	131	COOP	6/1/1953	Present	No
Orleans	41.309	-123.532	122	COOP	4/1/1903	Present	No
Redwood Creek O'kane	40.907	-123.815	268	COOP	9/1/1964	Present	No
Salyer R.S.	40.883	-123.583	189	COOP	1/1/1931	9/27/1968	No
Smith River 3 WNW	41.950	-124.200	9	COOP	8/1/1956	11/30/1958	No
Smith River Hiouchi	41.789	-124.054	34	COOP	10/1/1989	9/19/2004	No
Willow Creek 1 NW	40.947	-123.637	141	COOP	9/1/1968	Present	No
CW0570 Blue Lake	41.042	-123.876	183	CWOP	M	Present	No
CW1528 Gasquet	41.846	-123.962	356	CWOP	M	Present	No
CW2108 Brookings	42.053	-124.279	44	CWOP	M	Present	No
CW3303 Gasquet	41.847	-123.977	122	CWOP	M	Present	No
CW3885 Brookings	42.073	-124.313	58	CWOP	M	Present	No
CW5510 Brookings	42.052	-124.232	317	CWOP	M	Present	No
CW5579 O'Brien	42.044	-123.714	472	CWOP	M	Present	No
Redwood	41.561	-124.083	235	GPMP	11/1/1987	5/31/1995	No
O’Brien (US 199 MP 41)	42.001	-123.723	518	ODOT	M	Present	No
Big Hill	41.098	-123.636	1088	RAWS	3/1/1997	Present	No
Camp Six	41.831	-123.876	1152	RAWS	7/1/2003	Present	No
Gasquet	41.846	-123.979	152	RAWS	11/1/1993	Present	No
Hoopa	41.048	-123.671	114	RAWS	4/1/1997	Present	No
Kneeland	40.720	-123.927	834	RAWS	12/1/2004	Present	No
Maple Creek	40.796	-123.937	512	RAWS	1/1/1995	Present	No
Oak Knoll	41.839	-123.849	591	RAWS	12/1/1988	Present	No
Red Mound	42.123	-124.301	534	RAWS	8/1/1994	Present	No
Ship Mtn.	41.736	-123.792	1615	RAWS	6/1/2001	Present	No
Ship Mtn. 1	41.850	-123.967	122	RAWS	M	Present	No
Wheeler Creek	42.067	-124.117	439	RAWS	12/1/1986	8/31/1992	No
Yurok	41.290	-123.858	151	RAWS	10/1/2002	Present	No
Arcata	40.978	-124.109	61	SAO	7/1/1943	Present	No
Brookings	42.030	-124.245	15	SAO	5/1/1912	Present	No
Brookings Cg. M.	42.050	-124.267	0	SAO	6/1/1962	3/11/1970	No
Brookings State Arpt.	42.074	-124.290	140	SAO	M	Present	No
Crescent City	41.780	-124.237	17	SAO	12/1/1948	Present	No
Eureka	40.811	-124.160	6	SAO	12/1/1886	Present	No
Eureka	40.800	-124.117	2	SAO	7/1/1990	6/1/1992	No
Saint George Reef Li.	41.833	-124.383	45	SAO	10/1/1972	Present	No
Trinidad Marine Lab.	41.067	-124.150	30	SAO	10/1/1972	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Whiskeytown National Recreation Area (WHIS)							
Brandy Creel	40.617	-122.567	375	COOP	7/1/1972	9/30/1981	Yes
Redding 12 WNW	40.651	-122.607	432	COOP	3/25/2003	Present	Yes
Whiskeytown	40.633	-122.550	332	COOP	7/1/1959	4/30/1960	Yes
Whiskeytown Reservoir	40.612	-122.528	395	COOP	4/1/1960	Present	Yes
Oak Bottom	40.651	-122.606	404	RAWS	8/1/2001	Present	Yes
BAMI5	40.520	-122.300	154	BAMI	M	Present	No
Antlers	40.885	-122.383	329	CALTRANS	M	Present	No
Buckhorn Sandhouse	40.654	-122.754	825	CALTRANS	M	Present	No
Oregon Mountain Summit	40.739	-122.980	870	CALTRANS	M	Present	No
Vollmers	40.942	-122.427	405	CALTRANS	M	Present	No
Redding-Health Dept Roof	40.551	-122.381	149	CARB	M	Present	No
Beegum	40.350	-122.867	393	COOP	10/1/1919	6/30/1955	No
Churn Creek	40.467	-122.300	137	COOP	7/1/1912	5/31/1927	No
Cottonwood A D R	40.383	-122.283	119	COOP	10/1/1964	6/11/1982	No
Cow Creek Millville	40.500	-122.233	122	COOP	2/1/1969	Present	No
Delta	40.950	-122.417	357	COOP	11/1/1975	3/31/1978	No
Ferguson Ranch	40.350	-122.450	244	COOP	1/1/1952	9/30/1981	No
French Gulch	40.700	-122.633	336	COOP	1/1/1952	1/1/1983	No
Harrison Gulch R.S.	40.364	-122.965	838	COOP	10/1/1943	Present	No
Lakehead	40.899	-122.391	426	COOP	1/1/1998	Present	No
Lakeshore 2	40.867	-122.383	329	COOP	6/1/1946	9/30/1981	No
Ono	40.483	-122.617	298	COOP	1/1/1952	4/2/1984	No
Oregon Mountain	40.717	-122.967	1168	COOP	10/1/1969	5/31/1974	No
Platina	40.367	-122.883	689	COOP	3/1/1962	5/9/1974	No
Redding	40.583	-122.400	220	COOP	1/1/1893	2/28/1949	No
Redding	40.519	-122.299	153	COOP	9/1/1997	Present	No
Redding	40.518	-122.299	151	COOP	9/1/1944	Present	No
Redding 5 SSE	40.500	-122.367	130	COOP	1/1/1958	1/27/1992	No
Redding Fire Stn. 2	40.583	-122.400	177	COOP	8/1/1944	4/19/1979	No
Redding Fire Stn. 4	40.550	-122.383	143	COOP	4/19/1979	10/1/1987	No
Redding R.S.	40.583	-122.383	153	COOP	4/1/1953	5/31/1956	No
Shasta Dam	40.714	-122.416	328	COOP	1/1/1943	Present	No
Trinity Center Range	41.000	-122.683	702	COOP	5/15/1914	11/30/1960	No
Trinity Dam Vista Point	40.800	-122.767	763	COOP	7/1/1959	12/1/1973	No
Trinity River Hatchery	40.726	-122.795	567	COOP	12/1/1973	Present	No
Turntable Creek	40.767	-122.300	326	COOP	6/1/1947	10/31/1969	No
Vollmers	40.950	-122.450	409	COOP	12/1/1937	10/31/1975	No
Weaverville	40.735	-122.939	622	COOP	1/1/1894	Present	No
CW2838 Bella Vista	40.629	-122.241	750	CWOP	M	Present	No
CW4626 Bella Vista	40.629	-122.241	207	CWOP	M	Present	No
CW5599 Redding	40.605	-122.332	204	CWOP	M	Present	No
KG6QHS-1 Redding	40.584	-122.406	198	CWOP	M	Present	No
N6RZR-2 Anderson	40.439	-122.240	126	CWOP	M	Present	No
N6RZR-2 Anderson	40.439	-122.240	131	CWOP	M	Present	No
Arbuckle Basin	40.398	-122.833	579	RAWS	1/1/1995	Present	No

Name	Lat.	Lon.	Elev. (m)	Network	Start	End	In Park?
Baker	40.279	-122.487	213	RAWS	5/1/1990	12/31/1997	No
Five Cent	40.751	-122.918	796	RAWS	6/1/2004	Present	No
Hayfork	40.550	-123.165	708	RAWS	4/1/1997	Present	No
Lowden	40.689	-122.831	951	RAWS	11/1/1999	7/31/2004	No
Patty Mocus	40.295	-122.867	1067	RAWS	10/1/1990	Present	No
Rattle Brush	40.892	-122.552	1280	RAWS	10/1/1995	12/31/1996	No
Redding Airport	40.516	-122.291	152	RAWS	6/1/2001	Present	No
Redding Airport Prtble.	40.850	-122.500	152	RAWS	4/1/2000	8/31/2001	No
Sugarloaf (SHF)	40.917	-122.438	1280	RAWS	11/1/1999	Present	No
Trinity Camp	40.679	-122.833	640	RAWS	4/1/1996	Present	No
Weaverville	40.735	-122.943	640	RAWS	7/1/1998	8/31/2005	No
Redding	40.518	-122.299	151	SAO	9/1/1944	Present	No
Delta	40.950	-122.433	366	WBAN	5/1/1933	9/30/1944	No
Anderson	40.450	-122.300	152	WX4U	M	Present	No
Palo Cedro	40.560	-122.240	184	WX4U	M	Present	No
Redding	40.590	-122.390	169	WX4U	M	Present	No

Of the 24 COOP stations we identified within 40 km of CRLA (Table 4.3), 10 are active. The COOP station “Prospect 2 SW” is located 22 km southwest of CRLA and provides the longest climate record in the area (1905-present).The data record at “Prospect 2 SW” is very complete. Another long-term record is available at the COOP station “Chemult,” 24 km northeast of CRLA. This station’s data record, which goes back to 1937, was very complete until 1980 but has had scattered data gaps since then. Several other active COOP stations within 40 km of CRLA have data records that go back to the 1950s.

Despite only identifying one RAWS station within CRLA (Panhandle), there are numerous RAWS stations within 40 km of the park unit (Table 4.3). The RAWS stations “Big Butte” and “Rover” have data records that are unreliable. Other than these two stations, the remaining stations have fairly complete data records. The longest data records come from the RAWS stations “Buckeye” (29 km west of CRLA) and “Toketee” (22 km northwest of CRLA), both starting in January 1985. The only RAWS stations for which we didn’t note significant data gaps are “Chiloquin” (1986-present), located 26 km southeast of CRLA, and “Klamath NWR” (2002-present), located 26 km southeast of CRLA.

We identified five SNOTEL sites (all active) within 40 km of CRLA (Table 4.3). Along with RAWS sites, SNOTEL sites are the primary sources of automated weather data for the region surrounding CRLA. The closest SNOTEL site to CRLA is “Sevenmile Marsh,” located 11 km south of the park unit. “Cold Springs Camp” is another SNOTEL station located south of CRLA (28 km from park unit). The remaining SNOTEL stations we identified were located north and northeast of the park unit (Figure 4.1).

We identified two stations (both active) within LABE (Table 4.3; Figure 4.1). The COOP station “Lava Beds N M” is located in south-central LABE and provides a data record going back to 1948.This data record is fairly complete but had numerous data gaps during the 1970s and 1980s. The RAWS station “Indian Well” is also located in south-central LABE and has been providing

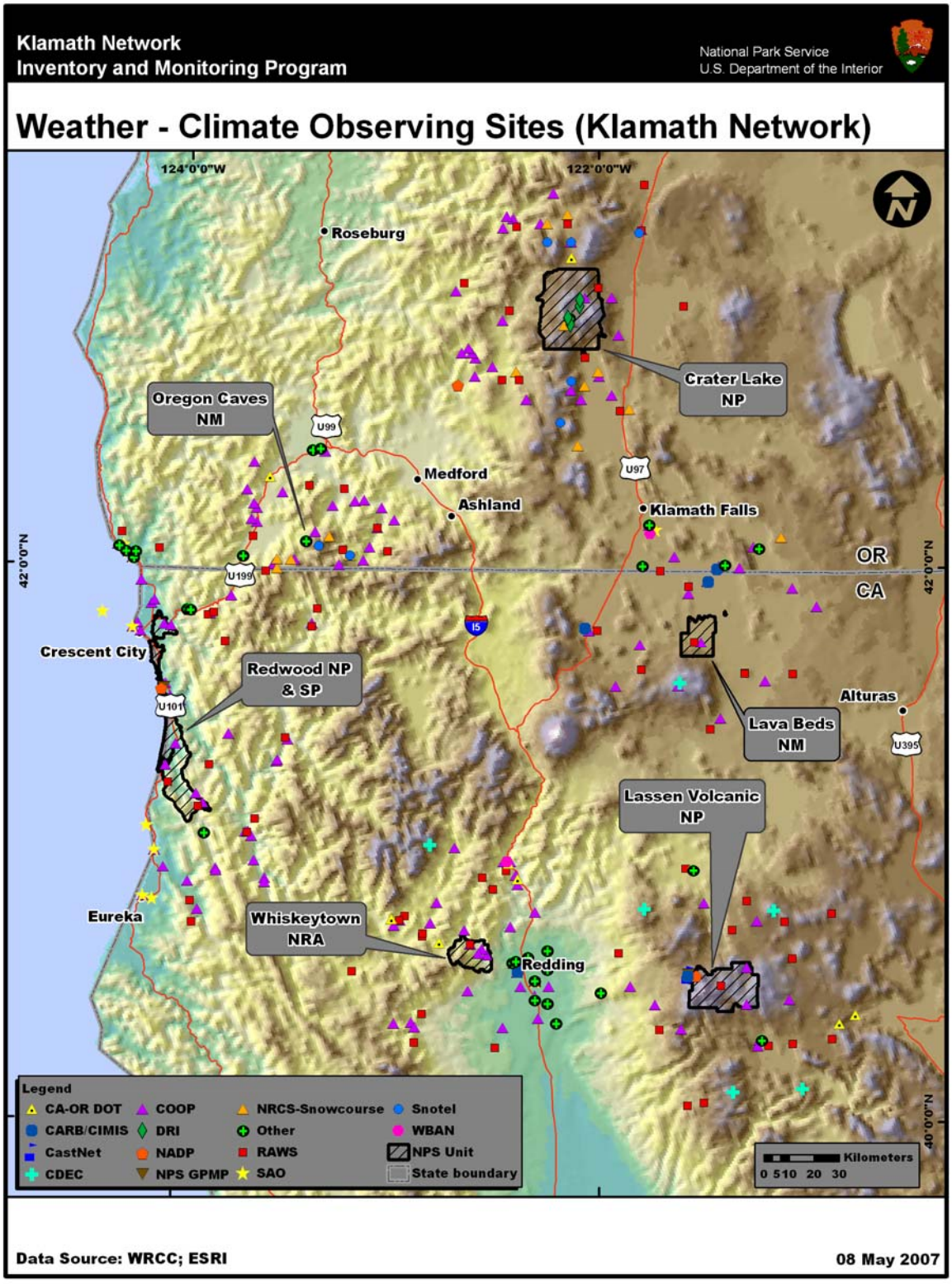


Figure 4.1. Station locations for the KLMN park units.

near-real-time weather data since 1997. There were numerous data gaps at this RAWS site from 1997 to 1999, but the data record has been very complete since 1999.

Several weather/climate networks have been identified that currently provide near-real-time data for the region surrounding LABE. A CDEC station (Medicine Lake) and two CIMIS stations ("Tulelake" and "Tulelake F.S.") have been identified within 40 km of LABE (Table 4.3). A SAO station is located at Klamath Falls, 37 km northwest of LABE (Figure 4.1). This SAO station has operated since 1941. A SCAN station (Lynhart Ranch) was identified 19 km northeast of LABE. Eight RAWS stations (seven active) were identified within 40 km of LABE. One of the active stations (Adin – Portable) has a questionable data record. Of the remaining RAWS stations, the longest record comes from "Juanita Lake," which is 33 km west of LABE and has operated since 1986. This station, however, recently had a large data gap for the first half of 2006. Three of the RAWS stations have very complete data records. These include "Lower Klamath" (2002-present), 21 km northwest of LABE; "Round Mountain" (1991-present), 29 km south of LABE; and "Van Bremmer" (1993-present), 17 km southwest of LABE.

Eight weather/climate stations were identified within the boundaries of LAVO (Table 4.3). Five of these stations are still active. The majority of the stations within LAVO are located at or near the visitor center at the northwest corner of the park unit (Figure 4.1), including a CARB station (Lassen Volcanic NP - Manzanita), a CASTNet station (Manzanita Lake F.S.), one of the two COOP stations in the park unit (Manzanita Lake), and a NADP station (Lassen Volcanic NP - Manzanita). The CARB and CASTNet sites are the main source for automated data within LAVO. The longest climate record is from the COOP station "Manzanita Lake," which has been active since 1949. The COOP station "Mount Harkness," located in southeastern LAVO, also provides a longer data record, having been active since 1953.

Out of the eight COOP stations identified within 40 km of the boundaries of LAVO, three are active (Table 4.3). The longest record we identified was from the COOP station "Chester," which is 13 km southeast of LAVO and has been active since October 1909. The record at this station is very complete. Another reliable long-term record was identified at the COOP station "Mineral," which is located 9 km southwest of LAVO and has been active since November 1909. The COOP station "Chester R.S." is 16 km southeast of LAVO and has been active since 1955.

RAWS stations are the primary source of near-real-time data within 40 km of LAVO. Sixteen RAWS stations were identified; 13 of these are active (Table 4.3). The only RAWS stations with unreliable data records are "LN2-Portable" and "LN3-Portable," both located 16 km east of LAVO (Figure 4.1). Most of the 16 RAWS stations have occasional, small data gaps. The most complete data records come from the stations "Carpenter Ridge" (2000-present), 40 km south of LAVO, and "Whitmore" (1990-present), 29 km northwest of LAVO.

One weather station was identified within the boundaries of ORCA (Table 4.3; Figure 4.1). This is a CWOP station (CW2072 Oregon Caves) that provides near-real-time data.

Out of the 23 COOP stations identified within 40 km of the boundaries of ORCA, 13 are active (Table 4.3). The closest COOP station to ORCA is "Bolan Peak," which is 8 km southwest of

ORCA and has been active since 1953. The longest record we identified was from the COOP station "Williams 1 NW," which is 17 km northeast of ORCA and has been active since 1892. This is a precipitation-only site whose data record is very complete. Another reliable long-term record was identified at the COOP station "Grants Pass," which is 37 km north of ORCA and has been active since 1893. The COOP station "Happy Camp R.S." (1914-present) is 32 km south of ORCA. The data record at this site is fairly complete but there are scattered, small data gaps and there are generally no weekend observations. Three other active COOP stations have data records going back to the 1930s and 1940s. "Elk Valley" is 28 km southwest of ORCA and has been active since 1938. This station's data record has not been reliable since the 1970s. "Buncom 1 NNE" is 35 km northeast of ORCA and has been active since 1948. This station's data record is mostly complete except for data gaps in August-October of 1984 and in January-October of 1985. "Star R.S." is 28 km northeast of ORCA and has been active since 1948. Several other active COOP stations we identified have data records beginning in the 1950s and 1960s.

Five active NRCS-SC sites were identified within 40 km of ORCA (Table 4.3). Most of these are located south and east of the park unit (Figure 4.1). The closest sites to ORCA are "Althouse #2" (8 km south) and "Grayback Peak" (8 km east).

RAWS and SNOTEL stations are the primary source of near-real-time data within 40 km of ORCA (Table 4.3; Figure 4.1). Nine RAWS stations were identified; six of these are active (Table 4.3). The most complete data records come from the stations "Illinois Valley Airport" (1985-present), 21 km west of ORCA, and "Provolt Seed Orchard" (1985-present), 25 km northeast of ORCA. Two SNOTEL stations are located within 40 km of ORCA. "Bigelow Camp" is 4 km southeast of ORCA and "King Mountain" is 17 km southeast of ORCA.

Six weather/climate stations were identified within REDW (Table 4.3). Five of these stations are still active. The longest climate record is at the COOP station "Orick Prairie," which is in the south-central portion of REDW (Figure 4.1) and has been active since 1937. This climate record is fairly complete, with occasional, small data gaps. The COOP station "Schoolhouse Peak," located in the southeastern part of REDW, also provides a longer data record, having been active since 1953. The NADP station "Yurok Tribe-Requa" is located just north of the mouth of the Klamath River. Two RAWS stations are currently operating within REDW. "Schoolhouse" is in the southeastern part of REDW and has a very complete data record going back to 2001. "Westside" is in the south-central REDW and has been active since 2004. "Westside" has a data gap from January through March in 2005.

Out of the 31 COOP stations identified within 40 km of the boundaries of REDW, 10 are active (Table 4.3). The COOP station "Eureka," 34 km south of REDW, has the longest record among these active COOP stations, having been active since 1886. The data record at "Eureka" is very complete. The COOP station "Crescent City," 6 km west of the north end of REDW, has been active since 1893. The record at this station is largely complete but there were no weekend observations during the 1960s and 1970s. A very reliable long-term record was identified at the COOP station "Orleans," which is located 33 km east of REDW and has been active since 1903. The COOP station "Elk Valley," discussed previously, is 36 km northeast of the northern end of REDW. "Gasquet R.S." is a precipitation-only COOP station that is 10 km east of the northern

end of REDW and has a very complete data record (1948-present). The COOP station “Klamath” is just outside of central REDW and has a very reliable data record (1948-present).

Stations with the RAWS and SAO networks are the primary source of near-real-time data within 40 km of REDW units (Table 4.3; Figure 4.1). Twelve RAWS stations (11 active) and nine SAO stations (eight active) were identified. Three of the RAWS stations we identified (Kneeland, Ship Mtn., Ship Mtn. 1) have unreliable data records. “Kneeland” is located 40 km south of REDW. “Ship Mtn.” and “Ship Mtn. 1” are both located east of the north end of REDW. The RAWS station “Gasquet” (1993-present), 9 km east of the northern part of REDW, was unreliable until 1999. The RAWS station “Camp Six” (2003-present), 14 km east of the northern part of REDW, had a large data gap from February 2004 until June 2004. Six of the RAWS stations have very complete data records. Four of these (Big Mill, Hoopa, Maple Creek, and Yurok) are located within 40 km of southern REDW. The other two (“Oak Knoll” and “Red Mound”) are located within 40 km of the northern part of REDW. The remaining RAWS stations we identified have occasional, small data gaps.

The longest record among the SAO stations we identified for REDW comes from “Eureka,” 34 km south of REDW. This dataset goes back to 1886. Another long data record comes from the SAO station “Brookings” (1912-present), 24 km north of REDW. Two other active SAO stations (“Arcata” and “Crescent City”) have data records going back to the 1940s. The SAO station “Crescent City”, 8 km west of the northern part of REDW, is the closest SAO station to REDW.

Five weather/climate stations were identified within WHIS (Table 4.3; Figure 4.1). Three of these stations are active, including two COOP stations and one RAWS stations. The COOP station “Whiskeytown Reservoir” has a very complete data record which starts in 1960. The other active COOP station, “Redding 12 WNW,” is located in the northwestern part of WHIS and has been active since 2003. The RAWS station “Oak Bottom” has a very complete data record which starts in 2001.

Out of the 27 COOP stations identified within 40 km of the boundaries of WHIS, eight are active (Table 4.3). The COOP station “Weaverville,” 22 km west of the Trinity Unit, has the longest record among these active COOP stations, having been active since 1894. The data record at “Eureka” is fairly complete, with occasional, small data gaps. The COOP station “Shasta Dam” is just south of the Shasta Lake Unit of WHIS and has been active since 1943. The record at this station is very complete. Another data record starting in 1943 comes from the COOP station “Harrison Gulch R.S.,” which is located 33 km southwest of the Whiskeytown Unit. This station has no weekend observations and is generally quite unreliable. The COOP station “Redding” is 18 km from WHIS and has a reliable data record.

With the exception of the SAO station “Redding” and a few stations with other networks (CALTRANS, CARB, CWOP and WX4U), RAWS stations are the primary source of automated weather data within 40 km of WHIS units. Seven active RAWS stations were identified (Table 4.3). The longest RAWS record is from the station “Patty Mocus,” 35 km southwest of the Whiskeytown Unit of WHIS. This station has been active since1990; however, its data record has only been reliable since March 1999. The other active sites have fairly reliable data records, with occasional small data gaps.

5.0. Conclusions and Recommendations

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

5.1. Klamath Inventory and Monitoring Network

Most of the KLMN park units are at least 40 km from any SAO or similar airport stations. Therefore, the primary source of automated weather data for these park units generally comes from RAWS or SNOTEL stations. RAWS stations are particularly common throughout KLMN park units. It is therefore beneficial for climate monitoring efforts in the KLMN that the NPS work closely with local agencies to continue the operation of existing RAWS stations within KLMN park units, as well as encourage the addition of new RAWS stations.

One place where the addition of such a station would be useful is along the north rim of Crater Lake in CRLA. There are currently no weather or climate stations in this area. The only active stations identified in this report for northern CRLA are down along the shore of Crater Lake, including manual and automated stations at Cleetwood Cove.

Crater Lake National Park is well known for its heavy snowfalls (Redmond 2007). However, it appears that the snowfall patterns in the park are severely undersampled. There are only two NRCS-SC sites and one NWAVAL station in the park unit, all near Rim Village. The NWAVAL station provides the only near-real-time observations of snowfall and snow depth in the park unit. Due to the interest in snowfall within CRLA, a useful strategy might be to partner with NRCS to convert one of the NRCS-SC sites near Rim Village (“Annie Spring Rev.” or “Park H.Q. Rev.”) into a SNOTEL station, providing additional near-real-time snowfall data for the park unit and providing another data point to compare snowfall patterns with other SNOTEL stations around CRLA. Additional SNOTEL stations in the park unit could be considered as funds become available.

All the stations we identified within LABE are near the main visitor center at Indian Wells, in the south-central portion of the park unit. With variations of several hundred meters across the park unit, topography is enough of a factor in LABE climate that monitoring efforts could likely benefit from installing additional automated stations. Locations in northern LABE would provide excellent candidates for one such station. The RAWS network already has a strong presence in the area, so NPS may want to consider working with local agencies to install a RAWS station.

With the exception of the COOP station at Mt. Harkness, almost all of the active stations identified within LAVO are located near the visitor center at the northwestern corner of the park unit. Much of southwestern and northeastern LAVO remains unsampled by weather/climate stations. This park unit contains significant, large topographical variations, containing a wide variety of local climate conditions that remain unsampled at the present time. Highway 89 in southwestern LAVO and an access road in southeastern LAVO both provide ready access to suitable locations for new automated station installations. Both RAWS and SNOTEL stations

could be considered for such installations, due to substantial snowfall during the winter months and wildfire issues during the summer months.

The only station we identified within ORCA is a CWOP station. Although this is a real-time station, siting standards for the CWOP network are generally not well-defined and the reliability of CWOP data records is sometimes questionable. Therefore, ORCA may want to consider working with local agencies to install a RAWS site within the park unit. The RAWS network does have well-known standards for station siting (BLM 1997) and this strategy would also improve the coverage of the RAWS network, which already has a significant presence in the area surrounding ORCA.

There are no automated stations devoted to weather/climate measurements within the central portions of REDW. In addition, weather/climate station coverage is nonexistent to the east of the central portion of REDW. The park unit could consider adding a RAWS station at the same location as the existing GPMP and NADP stations, near the mouth of the Klamath River. A RAWS station is a natural choice for such an installation due to the RAWS network's already significant presence in the REDW area.

Most of the KLMN park units have at least one long-term climate station either within the park (e.g., the COOP station "Crater Lake" at CRLA) or within 40 km of the park unit. Climate monitoring efforts within the KLMN 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 KLMN park units.

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 KLMN park units. Nearer to the coast, severe coast-interior gradients in temperature over short distances are also common. 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 KLMN ecosystems in response to possible future climate change. In particular, for interior park units, there are concerns about snowpack trends in response to climate changes, while at REDW, there are concerns about changes in ocean levels and temperatures, along with changes in fog patterns (Odion et al. 2005). The KLMN region is

strongly affected by ENSO cycles. Future climate changes could affect the frequency, intensity, and duration of ENSO events in the area, which would in turn impact KLMN ecosystems.

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

- Automated stations in KLMN park units are associated primarily with the RAWS and SNOTEL networks. Expanded coverage of these networks could be considered in locations including the north rim of Crater Lake in CRLA, northern LABE, and central REDW.
- CRLA is well known for heavy winter snowfall, yet has little automated station coverage to monitor snowfall. The park unit could consider converting one of the existing NRCS-SC sites into an automated SNOTEL station.
- Northeastern and southwestern LAVO are currently lacking automated weather stations. Suitable sites for new automated stations in LAVO include locations along Highway 89 and the access road from Chester, California.
- Uncertainties related to siting and data record reliability at the CWOP site in ORCA underscore the need for an automated station such as RAWS within ORCA. The RAWS network has well-identified siting standards and already has a substantial presence in the ORCA area.
- Climate monitoring efforts in KLMN will benefit by continuing the operation of those long-term climate stations identified in and near KLMN park units.

6.0 Literature Cited

Albritton, D. L., L. G. Meira Filho, U. Cubasch, X. Dai, Y. Ding, D. J. Griggs, B. Hewitson, J. T. Houghton, I. Isaksen, T. Karl, and others, editors. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

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

Ayres, M. P., and M. J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment **262**:263-286.

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

Bryson, R. A., and F. K. Hare, editors. 1974. Climates of North America. Amsterdam, Elsevier.

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

Burgess, S. S. O., and T. E. Dawson. 2004. The contribution of fog to the water relations of Sequoia sempervirens (D. Don): foliar uptake and prevention of dehydration. Plant, Cell & Environment **27**:1023-1034.

Cayan, D. R., M. D. Dettinger, H. F Diaz, and N. E. Graham. 1998. Decadal variability of precipitation over western North America. Journal of Climate **11**:3148-3166.

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

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

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

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

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

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

Flannigan, M. D., B. J. Stocks, and B. M. Wotton. 2000. Climate change and forest fires. The Science of the Total Environment **262**:221-229.

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

Giorgi, F., B. Hewitson, J. Christensen, M. Hulme, H. Von Storch, P. Whetton, R. Jones, L. Mearns, and C. Fu. 2001. Regional climate information—evaluation and projections. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton, J.T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, editors. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

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

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

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

Leung, L. R., Y. Qian, X. Bian, W. M. Washington, J. Han, and J. O. Roads. 2004. Mid-century ensemble regional climate change scenarios for the western United States. Climatic Change **62**:75-113.

Mantua, N. J. 2000. The Pacific Decadal Oscillation and climate forecasting for North America. Online. (http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_cs.htm) Accessed 27 April 2004.

Mantua, N. J. and S. R. Hare. 2002. The Pacific decadal oscillation. Journal of Oceanography **58**:35-44.

Miller, G. R. 2002. Pacific Northwest Weather. Frank Amato Publications, Portland, Oregon.

Mitchell, V. L. 1976. The regionalization of climate in the western United States. Journal of Applied Meteorology **15**:920-926.

Mock, C. J. 1996. Climatic controls and spatial variations of precipitation in the Western United States. Journal of Climate **9**:1111-1125.

Mote, P. W. 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes. Geophysical Research Letters **30**:1601-1604.

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

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

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

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

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

Odion, D., D. Sarr, B. Truitt, A. Duff, S. Smith, W. Bunn, E. Beever, S. Shafer, S. Smith, J. Rocchio, and others. 2005. Vital Signs Monitoring Plan for the Klamath Network: Phase II Report. Klamath Network, National Park Service, Ashland, Oregon.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421**:37-42.

Redmond, K. T., and R. W. Koch. 1991. Surface climate and streamflow variability in the western United States and their relationship to large-scale circulation indices. Water Resources Research **27**:2381-2399.

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

Redmond, K. T. 2007. Evaporation and the hydrologic budget of Crater Lake, Oregon. Hydrobiologia **574**:29-46.

Rodriguez-Iturbe, I. 2000. Ecohydrology: A hydrologic perspective of climate-soil-vegetation dynamics. Water Resources Research **36**:3-9.

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

Snyder, M. A., L. C. Sloan, N. S. Diffenbaugh, and J. L. Bell. 2003. Future climate change and upwelling in the California Current. Geophysical Research Letters **30**:1823-1826.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a 'business as usual' climate change scenario. Climatic Change **62**:217-232.

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

Wallace, J. M., and D. S. Gutzler. 1981. Teleconnections in the geopotential height field during the Northern Hemisphere winter. Monthly Weather Review **109**:784-812.

Waring, R. H. 1969. Forest plants of the eastern Siskiyous: their environmental and vegetational distribution. Northwest Science **43**:1-17.

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

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

Appendix A. Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix B. Climate-monitoring principles

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

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

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

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

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

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

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

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

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

B.1.7. Regions having insufficient data, variables and regions sensitive to change, and key

measurements lacking adequate spatial and temporal resolution should be given the highest priority in designing and implementing new climate-observing systems.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

B.3. Literature Cited

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

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

Appendix C. Factors in operating a 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 (Global Positioning System), 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).

D.4. Literature Cited

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Yang, D., B. E. Goodison, J. R. Metcalfe, V. S. Golubev, R. Bates, T. Pangburn, and C. Hanson. 1998. Accuracy of NWS 8" standard nonrecording precipitation gauge: results and

application of WMO intercomparison. Journal of Atmospheric and Oceanic Technology **15**:54-68.

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

Appendix E. Master metadata field list

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

Field Name	Field Type	Field Description
updated_by	char(8)	Person who last updated a record.
var_major_id	int2	Defines major climate variable.
var_minor_id	int2	Defines data source within a var_major_id.
zipcode	char(5)	Zipcode where a latitude/longitude point resides.
nps_netcode	char(4)	Network four-character identifier.
nps_netname	varchar(128)	Displayed English name for a network.
parkcode	char(4)	Park four-character identifier.
parkname	varchar(128)	Displayed English name for a park/
im_network	char(4)	NPS I&M network where park belongs (a net code)/
station_id	varchar(16)	Station identifier.
station_id_type	varchar(16)	Type of station identifier.
network.subnetwork.id	varchar(16)	Identifier of a sub-network in associated network.
subnetwork_key	int2	Foreign key defining sub-network for a station.
subnetwork_name	varchar(30)	English name for a sub-network.
slope	integer	Terrain slope at the location.
aspect	integer	Terrain aspect at the station.
gps	char(1)	Indicator of latitude/longitude recorded via GPS.
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 KLMN: http://www.wrcc.dri.edu/nps/pub/KLMN/metadata/KLMN_from_ACIS.tar.gz.

Appendix G. Descriptions of weather/climate monitoring networks

G.1. Pacific Northwest Cooperative Agricultural Network (AgriMet)

- Purpose of network: provide weather/climate data for regional crop water use modeling, frost monitoring, and various agricultural research projects in the Pacific Northwest.
- Primary management agency: BLM.
- Data website: http://www.usbr.gov/pn/agrimet/wxdata.html.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity and dewpoint temperature.
  - Precipitation.
  - Wind speed.
  - Solar radiation.
- Sampling frequency: hourly.
- Reporting frequency: hourly; some stations report every 10 minutes if real-time communications are available.
- Estimated station cost: $12000 with maintenance costs around $2000/year.
- Network strengths:
  - AgriMet has near-real-time data.
  - Period of record is relatively long.
  - Sites are well maintained.
- Network weaknesses:
  - Only agricultural sites are sampled.
  - AgriMet has a limited geographic extent (Pacific Northwest).

AgriMet is a satellite-based network of automated weather stations operated by the BLM. Stations in AgriMet are located primarily in irrigated agricultural areas throughout the Pacific Northwest.

G.2. California Department of Transportation (CALTRANS) Network

- Purpose of network: provide weather data to support management of California's transportation network.
- Primary management agency: CALTRANS.
- Data website: http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Pressure.
  - Wind speed and direction.
  - Wind gust and direction.
- Sampling frequency: unknown.
- Reporting frequency: unknown.
- Estimated station cost: unknown.

- Network strengths:
  - Real-time data.
  - Routine station maintenance.
- Network weaknesses:
  - Coverage is limited to the state of California.
  - Access to archived data can be difficult.

These weather stations are operated by CALTRANS in support of management activities for California's transportation network. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

G.3. 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.4. Clean Air Status and Trends Network (CASTNet)

- Purpose of network: provide information for evaluating the effectiveness of national emission-control strategies.
- Primary management agency: EPA.
- Data website: http://epa.gov/castnet/.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed.
  - Wind direction.
  - Wind gust.

    - Gust direction.
    - Solar radiation.
    - Soil moisture and temperature.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: $13000.
- Network strengths:
    - High-quality data.
    - Sites are well maintained.
- Network weaknesses:
    - Density of station coverage is low.
    - Shorter periods of record for western United States.

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.5. California Irrigation Management Information System (CIMIS) Network

- 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.6. 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.7. 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.8. 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 environmental studies in the region.

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

- Purpose of network: measurement of ozone and related meteorological elements.
- Primary management agency: NPS.
- Data website: http://www2.nature.nps.gov/air/monitoring.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
  - Solar radiation.
  - Surface wetness.
- Sampling frequency: continuous.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Stations are located within NPS park units.
  - Data quality is excellent, with high data standards.
  - Provides unique measurements that are not available elsewhere.
  - Records are up to 2 decades in length.
  - Site maintenance is excellent.
  - Thermometers are aspirated.
- Network weaknesses:
  - Not easy to download the entire data set or to ingest live data.
  - Period of record is short compared to other automated networks. Earliest sites date from 2004.
  - Station spacing and coverage: station installation is episodic, driven by opportunistic situations.

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

G.10. National Atmospheric Deposition Program (NADP)

- Purpose of network: measurement of precipitation chemistry and atmospheric deposition.

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

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

G.11. 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.12. Northwest Weather and Avalanche Center Network (NWAVAL)

- Purpose of network: support snow- and avalanche-monitoring efforts at NWAC.
- Primary management agency: NWAC.
- Data website: http://www.nwac.noaa.gov.

- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Precipitation.
  - Wind speed and direction.
  - Wind gust and direction.
- Sampling frequency: hourly.
- Reporting frequency: hourly.
- Estimated station cost: unknown.
- Network strengths:
  - Strategic location in montane and alpine environments, locations that traditionally have sparse weather/climate observations.
  - Data are readily available.
- Network weaknesses:
  - Geographic coverage – limited to mountain areas.
  - Data quality is sometimes questionable.

The Northwest Weather and Avalanche Center (NWAC) operates a network of weather stations in the mountainous areas of the Pacific Northwest, primarily in Washington. These stations are operated in support of NWAC's primary mission of monitoring avalanche conditions in the mountains of Washington and northern Oregon. Hourly weather and climate elements that are measured include temperature, humidity, wind, and precipitation. Daily measurements are made of snowfall and snowdepth.

G.13. Oregon Department of Environmental Quality Network (ODEQ)

- Purpose of network: support ODEQ's mission to protect air and water quality in Oregon.
- Primary management agency: ODEQ.
- Data websites: http://www.deq.state.or.us and http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Pressure.
  - Wind speed and direction.
  - Wind gust and direction.
- Sampling frequency: unknown.
- Reporting frequency: unknown.
- Estimated station cost: unknown.
- Network strengths:
  - Real-time data.
- Network weaknesses:
  - Network coverage is limited to the state of Oregon.

The primary mission of ODEQ is to protect and enhance Oregon's air and water quality. Weather and climate elements are measured by ODEQ stations in support of this primary mission. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

G.14. Oregon Department of Transportation Network (ODOT)

- Purpose of network: provide weather data to support management of Oregon's transportation network.
- Primary management agency: ODOT.
- Data websites: http://www.oregon.gov/ODOT and http://www.met.utah.edu/jhorel/html/mesonet.
- Measured weather/climate elements:
  - Air temperature.
  - Relative humidity.
  - Pressure.
  - Wind speed and direction.
  - Wind gust and direction.
- Sampling frequency: unknown.
- Reporting frequency: unknown.
- Estimated station cost: unknown.
- Network strengths:
  - Real-time data.
  - Routine station maintenance.
- Network weaknesses:
  - Coverage is limited to the state of Oregon.
  - Access to archived data can be difficult.

These weather stations are operated by ODOT in support of management activities for Oregon's transportation network. Measured meteorological elements include temperature, precipitation, wind, and relative humidity.

G.15. 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.16. 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.17. USDA/NRCS Soil Climate Analysis Network (SCAN)

- Purpose of network: comprehensive soil-climate network used in natural resource assessments and other conservation activities in the U.S.
- Primary management agency: USDA/NRCS.
- Data website: http://www.wcc.nrcs.usda.gov/scan/.
- Measured weather/climate elements:
  - Air temperature.
  - Precipitation.
  - Relative humidity.
  - Wind speed.
  - Wind direction.
  - Barometric pressure.
  - Solar radiation.
  - Snow water content.
  - Snow depth.
  - Soil moisture and temperature (enhanced sites only).
- Sampling frequency: 1-minute temperature; 1-hour precipitation, snow water content, and snow depth. Less than one minute for relative humidity, wind speed and direction, solar radiation, and soil moisture and temperature (all at enhanced site configurations only).
- Reporting frequency: reporting intervals are user-selectable. Commonly used intervals are every one, two, three, or six hours.

- Estimated station cost: $25000, with maintenance costs approximately $1000/year.
- Network strengths:
  - Sites are well-maintained.
  - Data are of high quality and are largely complete.
  - Very reliable automated system.
- Network weaknesses:
  - Short data records.
  - Network is still in development.

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

G.18. 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.19. Weather For You Network (WX4U)

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

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

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