Final Report Submitted to

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Cooperative Ecosystem Studies Unit

AN ASSESSMENT OF TEMPORAL AND SPATIAL TRENDS IN HISTORICAL CLIMATE DATA FOR THE KLAMATH NETWORK PARKS

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1. Background and Objectives

Climatic change has the potential to strongly affect park ecosystems (Parmesan 2006), and the parks of the Klamath Network (Figure 1.1) are very concerned about the potential effects of climate change on biological elements of interest within their boundaries. The Network held a climate change workshop in spring 2008 that convened the parks as well as scientists within and outside the National Park Service (NPS) to explore means of increasing their knowledge base and conveying important information to the public.

While scientists have long known that the climate is spatially diverse in the Klamath Region (Figures 1.2–1.4), there is currently a very incomplete knowledge of the temporal patterns in climate across the region. Given the geographic complexity and our knowledge that different factors vary in importance from place to place and over time, it is by no means certain that important climatic features in different areas of the Network, or even different parts of a large park, will change in concert over time. From initial discussions, the parks wished to learn whether and where historical records indicate climatic change is occurring in the Klamath Network. They are also particularly concerned about the stability of summer fogs at Redwood, about the temperature and snowpack dynamics at higher elevation parks, and about linkages between general climatic features and extreme disturbance events in all of the parks.

There are a number of climate stations within and around the parks that have been recording general climatic data for periods ranging from ten to nearly 100 years. A summary of temporal and spatial patterns in climate within the Klamath Network would provide a valuable baseline of knowledge about the Klamath parks and would provide a means for evaluating whether and to what degree climate is changing within the varied landscapes they contain.

This project was designed to analyze climatic data for parks of the Klamath Network in collaboration with park and network science staff. This work was meant to provide insight into both temporal and spatial patterns and trends in selected climatic parameters both within and around the parks. Klamath Network parks include Crater Lake NP (CRLA), Oregon Caves NM

(ORCA), Whiskeytown NRA (WHIS), Lava Beds NM (LABE), Lassen Volcanic NP (LAVO), and Redwood NP and SP (REDW).

This project had the following objectives:

Objective 1: Determine temporal trends in core climatic parameters at all suitable historical climate stations within the boundaries of and near the Klamath Network parks.

Objective 2: Determine linkages between temporal patterns of temperature and precipitation and temporal and spatial patterns of snowpack within the high elevation parks of the Klamath Network (CRLA, ORCA, LAVO, and WHIS).

Objective 3: Determine spatial and temporal patterns in marine influence at selected climate stations along the Redwood Coast.

Objective 4: Construct space-time animations to help park staff visualize and communicate the changing patterns of climate across the park landscapes.

This report is divided into seven sections. Section 2 describes methods used to obtain, process, and quality control (QC) climate data used in the analysis. Section 3 provides an overview of the climatology of the parks. Section 4 provides results for Objective 1: Temporal trends in core climatic parameters. Section 5 focuses on Objective 2: Snowpack trends and variability. Section 5 examines results for Objective 3: Spatial and temporal patterns of marine influence. Section 6 briefly describes methods used to prepare images for Objective 4: Space-time animations. Section 7 describes an online climate data viewer developed for Klamath Network Parks.

2. Climate Data

Station Data

In winter 2008-9, an intensive effort was mounted to gather and quality-check all available station climate data within and near the boundaries of each of the Klamath Network parks. The search for data extended to stations in the National Weather Service Cooperative Observer Program (COOP) and surface hourly data (e.g. ASOS; Automatic Surface Observing System) stations (http://cdo.ncdc.noaa.gov/CDO/cdo); USDA Natural Resources Conservation Service SNOTEL (Snow Telemetry) (http://www.wcc.nrcs.usda.gov/snow/); USDA Forest Service and Bureau of Land Management Remote Automatic Weather Stations (RAWS; http://www.wrcc.dri.edu/); and Bureau of Reclamation AgriMet (http://www.usbr.gov/pn/agrimet) networks. RAWS precipitation data were valid only for the months of May–September, because many of these stations are not maintained in winter, and their unheated tipping-bucket gauges do not measure snowfall well and are subject to freezing. Stations for which data were obtained are shown in Figures 2.1–2.6

Station data were obtained in two native time steps: Daily for COOP, SNOTEL and AgriMet, and hourly for ASOS and RAWS. Hourly data were aggregated to create daily values corresponding to midnight-to-midnight Local Standard Time (LST). Observations originally in Coordinated Universal Time (UTC, from French translation) were converted to LST. The offset between UTC and LST was approximated by dividing the station longitude by the factor 15 deg/hr and rounding to the nearest hour (e.g., a station at -125 degrees longitude would get an -8 hour offset from UTC). Daily maximum and minimum temperatures were the maximum and minimum of the hourly temperature observations for the 24 hour local period. Daily precipitation was the sum of the hourly incremental precipitation, calculated from hourly accumulations by subtracting the previous hour's total from the current hour's total. Negative incremental amounts (caused by evaporation, thermal expansion, resetting of accumulations, etc.) were set to missing. Daily values based upon hourly observations were subject to the requirement that at least 18 of 24 observations must be non-missing; fewer than 18 non-missing hourly observations resulted in a missing daily value. Daily observations and those based upon hourly observations were then aggregated to create monthly precipitation totals and mean maximum and minimum temperatures. A minimum of 85% of non-missing daily values were required for a monthly value to be non-missing. Our 85% data completeness criterion is not dissimilar to those used by the NCDC (NOAA-NCDC 2003) and the World Meteorological Organization (WMO 1989) in developing monthly temperature and precipitation statistics.

Initial range checking was performed for precipitation and maximum and minimum temperatures. Precipitation observations were checked for negative and extreme values while temperature observations were checked for extreme maximum and minimum values. Extreme value thresholds were selected based upon the state in which the observing station resided and, in the case of temperature, the month in which the observation was made (http://www.ncdc.noaa.gov/oa/climate/severeweather/extremes.html). The threshold for extreme precipitation was chosen to be 115% of the state record 24-hour precipitation. The threshold for extreme maximum temperature was chosen to be 3ºC above the state monthly record maximum temperature. Likewise, the threshold for extreme minimum temperature was chosen to be 3ºC below the state monthly record minimum temperature. The additional allowances were to accommodate potential new records.

Daily precipitation observations and hourly incremental amounts derived from accumulation observations were subject to both negative and extreme value checks, while monthly precipitation observations were checked for negative values only. Monthly and daily maximum and minimum temperatures, as well as hourly air temperatures, were subject to maximum and minimum temperature extreme checks. Observations that failed any of the above tests were set to missing.

Station elevations were checked for consistency against 800-m DEM elevations at the given station locations. Elevation discrepancies of more than 200 m were investigated, and either the station location or elevation corrected as a result.

Several additional spatial quality control (QC) procedures were conducted on the monthly data. In an initial QC screening step, monthly averages for 1971–2000 were calculated for stations having data during this time period. Stations not having data during 1971–2000 had historical averages calculated from their entire period of record. These averages were tested for spatial consistency using the ASSAY QC (quality control) system, a version of PRISM that estimates data for specific station locations and compares them to the observed values (Daly et al. 2000, Gibson et al. 2002). Averages failing the ASSAY QC check were immediately omitted from further consideration if they: 1) were RAWS stations; 2) had less than three years of historical data; or 3) had three or more years of historical data but had fewer than four consecutive months of non-missing data during those years. These stations were considered to be at highest risk for poor quality.

In the second spatial QC step, all individual monthly values from the remaining stations were tested for spatial consistency using the ASSAY QC system; values failing this test were set to missing.

In the third spatial QC step, all SNOTEL temperature data and most of the surrounding non-SNOTEL temperature data were subjected to a recently-developed spatial QC system for temperature data from this network. Details on the operation of this system are available in Daly et al. (2005). Temperature data subjected to this QC process were first passed through the aforementioned range checks, as well as for maximum temperature less than minimum temperature. SNOTEL temperature data were also tested for extended periods of unchanging values (flatliners); temperatures remaining unchanged (less than 0.1ºC daily difference) for longer than ten consecutive days were set to missing. In addition, temperature values remaining at exactly 0.0 degrees Celsius for two or more consecutive days (which is a known problem in SNOTEL data) were set to missing.

The station data have not been screened or adjusted for potential inhomogeneities that can be produced by changes in equipment, location, siting and other factors. Sometimes these changes can produce non-climatic step-changes or continuous drifts in the data that can be mistaken for actual climatic variations. Therefore, the trends and variations in this analysis must be considered preliminary and subject to further scrutiny. This is especially true for the linear trend analyses, where small step changes can change a positive trend to a negative one, and vice-versa.

PRISM Gridded Time Series

This analysis makes use of a spatially interpolated data set recently produced by the PRISM Climate Group. The data set is a monthly time series of mean maximum and minimum temperature and total precipitation spanning the period January 1895 – December 2007. The gridded time series covers the conterminous United States at a grid cell resolution of 30 arc-seconds (~800 m). Because it is spatially and temporally complete, it can provide relatively stable estimates of trends and variability over the past century for the parks as a whole, or for a particular location. However, given that the station data described in the previous section were used in this interpolated product, the trends and variations in the grids must also be considered preliminary and subject to further scrutiny,

The PRISM time series data set was interpolated with the PRISM climate mapping system. PRISM (Parameter-elevation Regressions on Independent Slopes Model) is a knowledge-based system that uses point data, a digital elevation model (DEM), and many other geographic data sets to generate gridded estimates of climatic parameters (Daly et al. 2008) at monthly to daily time scales. Originally developed for precipitation estimation, PRISM has been generalized and applied successfully to temperature, among other parameters. PRISM has been used extensively to map precipitation, dew point, and minimum and maximum temperature over the United States, Canada, China, and other countries.

PRISM develops local climate-elevation regression functions for each DEM grid cell, and calculates station weights based on an extensive spatial climate knowledge base that assesses each station's physiographic similarity to the target grid cell (Daly et al., 2008). The knowledge base and resulting station weighting functions currently account for spatial variations in climate caused by elevation, terrain orientation, effectiveness of terrain as a barrier to flow, coastal proximity, moisture availability, a two-layer atmosphere (to handle inversions), and topographic position (valley, mid-slope, ridge). Details on PRISM formulation can be found in Daly et al. (2002, 2003, and 2008).

A method termed climatologically-aided interpolation (CAI) was used to generate the time series data set. CAI uses an existing spatial climate data set to improve the interpolation of another data set (Willmott and Robeson 1995). This method relies on the assumption that local spatial patterns of the element being interpolated closely resemble those of the existing climate grid (sometimes called the background or predictor grid). CAI is robust for interpolating climate variables and time periods for which station data may be relatively sparse or intermittent, as occurs in the early part of the twentieth century.

PRISM 1971–2000 mean monthly climatologies for maximum and minimum temperature and precipitation were used as the predictor grids for each monthly interpolation for each year in the time series. The PRISM 1971–2000 mean climatologies are the most sophisticated available, and are the official climatologies for the USDA (Daly et al. 2008). In each month of the time series, PRISM developed cell-by-cell regressions between the 1971–2000 predictor climatology and the data values of stations available in that month. Nationwide, the PRISM CAI procedure used 7,000–10,000 stations from 1950–present, with this number diminishing to about 2000 in 1895. As will be discussed in the coastal influence analysis for Redwood NP and SP, 2000 stations nationwide is not always a sufficient number to adequately represent the rich spatial patterns in variability that we know to occur.

Park averages of temperature and precipitation were derived from the PRISM grids, and are referred to in this analysis. These averages were calculated by averaging all PRISM 800-m grid cells within each park. Other statistics, such as park maximum, minimum, standard deviation, and lapse rate, are available through the online data viewer (see Section 8).

NCAR/NCEP Reanalysis

Near-surface wind data from the NCAR/NCEP Reanalysis data set (Kalnay et al. 1996) were used in the coastal influence analysis for REDW. The reanalysis is a combination of meteorological model output and upper-air observations, gridded at 2.5-deg resolution globally. Data were retrieved from the NOMADS (NOAA National Operational Model Archive & Distribution System) Web site. We used the Reanalysis #1 data set because it starts in 1949, whereas the Reanalysis #2 begins in 1979. The NOMADS URL is:

http://nomads.ncdc.noaa.gov/

The specific URL for the dataset is:

http://nomad3.ncep.noaa.gov:9090/dods/reanalyses/reanalysis-1/month/grb2d.gau/flx.gau

The data were retrieved using a script that requested data for given climate elements on a specific date within a specified latitude & longitude range. We retrieved 10 meter U & V winds (ugrd10m & vgrd10m) for Jan 1949 – Dec 2007 for two grid cells at latitude 40.952N and longitudes 234.375E (-125.625) & 236.25E (-123.75). The U & V winds were later converted to wind speed and direction.

Fog and Low Stratus Data

For the marine influence analysis at REDW, data for fog and low-level stratus were derived from hourly visibility and ceiling height observations made at Arcata (WBAN station 24283). Arcata was the only station with this information in the vicinity of REDW. "Fog" conditions were defined as visibility less than or equal to one mile and ceiling height less than or equal to 300 feet. "Low stratus" conditions were defined as visibility less than or equal to five miles and ceiling height less than or equal to 5000 feet. The number of hours in a month for which these conditions occurred was divided by the monthly count of hourly observations to obtain the monthly percent of hours for that condition. A combined fog/low stratus variable was calculated by summing the hours that had either condition.

Snow Course Data

Additional snow depth and snow water equivalent data were obtained from the USDA Natural Resources Conservation Service Snow Course network (http://www.wcc.nrcs.usda.gov/snowcourse/). Measurements at these high elevation stations are made manually during the winter and spring, normally around the beginning of the month. For this analysis, we assumed that all measurements were made on the first of the month.

3. Mean Climatological Conditions for Core Parameters

Mean conditions at and among the KLMN parks are described below, and serve as a basis for the temporal analyses that follow. Descriptions are based on the current 1971–2000 climatological period. Stations chosen to represent each park are listed in Table 3.2. Additional stations used in subsequent analyses are given in Table 3.3.

Overall Klamath Network

The KLMN parks span a range of temperature and precipitation regimes, based on their varying elevations, proximity to the coast, and exposure to Pacific Ocean Moisture (Table 3.1; Figures 3.1–3.2). WHIS is the warmest park from April to October, but the proximity of REDW to the coast provides the mildest winters of the parks. CRLS and LAVO are the coldest parks yearround due to their high elevation. All KLMN parks exhibit a Mediterranean precipitation climate, characterized by sustained summer drought. Being most highly exposed to Pacific moisture, REDW is the wettest park in the KLMN, averaging more than 300 mm/mo during the Nov–Mar wet season. LABE, located in the rain shadow of the Cascades, is by far the driest park, with no month averaging more than 50 mm total precipitation. Despite its position to the lee of the Coast Range, WHIS benefits from being on the windward exposure of moist southerly flow transported up the Sacramento Valley during many storm events. LAVO is also relatively wet, as much of the park is at high elevation, and straddles the crest of the Cascades. While CRLA also straddles the crest of the Cascades, it has a lower mean annual precipitation than LAVO, mainly due to the blocking terrain of the Coast Range and other Cascade ranges to the west.

Crater Lake NP

Three COOP stations were selected to represent CRLA: Prospect (356907), at low elevation (757 m) to the southwest of the park, Chemult (351546) at moderate elevation (1451 m) to the northeast of the park, and Crater Lake NPS HQ (351946) near the crest within the park (1974 m; Table 3.2). Plots of climatological temperature and precipitation for these three stations and the PRISM CRLA park average are shown in Figures 3.3–3.7. Comparisons of these stations illustrate the three main physiographic controls on climate at CRLA: elevation, cold air pooling, and the Cascades mountain barrier. The maximum temperature plot shows the stations to be nicely ordered by elevation, with the CRLA park average slightly warmer than Crater Lake NPS HQ. However, there is a distinct narrowing of the differences between Chemult and CRLA/Crater Lake NPS HQ in winter. This is likely a result of Chemult's relatively frequent exposure to modified arctic air masses that move east of the Cascades and persistent cold air pooling at this relatively dry and low-lying site. These cold air masses are dense and tend to hug the terrain, lessening their effect on the park, which occupies higher elevations. Prospect, on the west side of the Cascades, is largely shielded from these air masses. There is a noticeable delay in the spring warm-up at Crater Lake NPS HQ compared to the other two stations. This could be attributable to a deep snow pack that often persists into July, and the relatively slow springtime heating of the atmosphere at high elevations. The minimum temperature plot shows the effect of cold air mass persistence and pooling at Chemult more clearly; Chemult's minimum temperatures are often colder than those at Crater Lake, despite being 500 m lower in elevation. The daily temperature range reflects the dryness of the air, the amount of solar radiation, and the degree of cold air pooling at a site. The maximum temperature range occurs in late summer at all sites, when the humidity is lowest. Prospect, located in a deep valley, also has a large range, but is much warmer overall.

The high elevation of Crater Lake NPS HQ, and its position on the crest of the Cascades, makes it the wettest of the three stations. Prospect, at lower elevation but on the windward side of the mountains, is the second wettest. Chemult, well within the Cascades rain shadow, is the driest. All three exhibit a distinct summer drought and a wintertime wet season. The CRLA average is somewhat drier than Crater Lake NPS HQ, mainly because the park encompasses both windward and drier leeward precipitation regimes, chiefly north and east of the caldera.

Monthly spatial representations of CRLA temperature and precipitation climatologies are available from the 1971–2000 animations (see Section 7). The spatial patterns of maximum temperature closely follow elevation, with the coolest temperatures at high elevations and the warmest at low elevations. Minimum temperature patterns reflect cold air pooling in valleys, which often results in the highest temperatures occurring at higher elevations than the lowest temperatures. CRLA encompasses much of the Cascades rain shadow transition zone. Consequently, the west side of the park is significantly wetter than the east side in nearly all months.

Oregon Caves NM

Three stations were chosen to represent ORCA: Bigelow Camp (23G15S), a SNOTEL site (1561 m) just east of the park, Cave Junction (351448), a COOP site (390 m) about 30 km northwest of the park, and Grants Pass (353445), a COOP site (283 m) about 40 km to the north (Table 3.2). The park itself is very small, and there are no climate stations within its boundaries. Plots of climatological temperature and precipitation for these three stations and the PRISM CRLA park average are shown in Figures 3.8–3.12. Elevation plays a major role in the maximum temperature regime of the park and vicinity. The park average maximum temperature is slightly warmer than high-elevation Bigelow Camp, but much cooler than Cave Junction and Grants Pass. As discussed for CRLA, the relatively slow springtime warm-up at Bigelow Camp could be a result of a persistent snowpack, and a relatively slow springtime heating of the atmosphere at high elevations. The relative variation of minimum temperature climatology with elevation is similar to that of maximum temperature, except for summer and early fall, when Bigelow Camp and the ORCA park averages equal or exceed those of Cave Junction and Grants Pass. This is a result of cold air pooling in the valleys during the calm, clear nights characteristic of this time of year. Daily temperature range is greatest in the dry mid-summer at ORCA and Bigelow Camp, but persistent cold air pooling in late summer pushes the month of maximum temperature range in the valleys into late summer.

Although Bigelow Camp and ORCA are higher in elevation than Cave Junction, they receive only slightly more annual precipitation. All three receive more than 200 mm/month during the November–March wet period, but Cave Junction receives somewhat less in the spring and fall. Grants Pass, situated to the lee of both the Coast Ranges and Siskiyou Mountains, is comparatively dry.

Monthly spatial representations of ORCA temperature and precipitation climatologies are available from the 1971–2000 animations (see Section 7). The spatial patterns of maximum temperature closely follow elevation, with the coolest temperatures at high elevations and the warmest at low elevations. Spatial patterns of temperature in the vicinity of ORCA show it to be in a transition zone between a relatively warm valley climate and a cool mountain regime. The minimum temperature patterns reflect some cold air pooling in valleys, but the 800-m resolution of the PRISM mapped data is too coarseto resolve the numerous small valleys in and around ORCA. Precipitation is locally higher on elevated terrain near ORCA, and lower in adjacent valleys, but the gradients are not large and are inconsistent from month to month.

Whiskeytown NRA

Two COOP stations were chosen to represent WHIS: Whiskeytown Reservoir (049621) and Trinity River Hatchery (049026). Whiskeytown Reservoir is within the park near the eastern shore of the reservoir at 395 m, and Trinity River Hatchery is near the southern shore of Lewiston Lake at 567 m, about 20 km northwest of the park (Table 3.2). There were no suitable stations at high elevation to represent the mountainous areas of the park; thus, climate estimates for this part of the park are relatively uncertain. Plots of climatological temperature and precipitation for the two stations and the PRISM WHIS park average are shown in Figures 3.13–3.17. Cold air pooling is strongly evident at Trinity River Hatchery; the daily temperature range is high, and minimum temperatures are colder than those of the WHIS park average, which contains significantly higher terrain. Although the Whiskeytown Reservoir COOP site does not show strong cold air pooling, it is likely that it does occur in the park, especially in protected valleys away from the reservoir.

WHIS park average precipitation is very similar to that of Whiskeytown Reservoir, and is significantly wetter than Trinity River Hatchery. The park receives much of its precipitation from southerly moisture streaming up the Sacramento Valley during winter storms. Trinity River Hatchery is sheltered from this southerly moisture flow by mountains located in and around WHIS. Precipitation increases during the fall to a January–March maximum, dropping steeply in spring to a low in summer.

Monthly spatial representations of WHIS temperature and precipitation climatologies are available from the 1971–2000 animations (see Section 7). WHIS spans a transition between the climates of the Central Valley and those of the adjacent mountains. The spatial patterns of maximum temperature closely follow elevation, with the coolest temperatures at high elevations in the western and southern parts of the park, and the warmest at low elevations in the north and east. The minimum temperature patterns reflect some cold air pooling in valleys, mostly confined to the western portion of the park. Although there are little data to support the analysis, precipitation is generally greatest in the mountains in the southern half of the part, and least in the relatively sheltered areas to the north.

Lava Beds NM

Two COOP stations were chosen to represent LABE: Lava Beds NM (044838) and Tulelake (049053). Lava Beds NM is located at 1454 m in the center of the park, and Tulelake is at 1230 m, about 20 km north of the park (Table 3.2). Plots of climatological temperature and precipitation for these two stations and the PRISM LABE park average are shown in Figures 3.18–3.22. Temperatures at Lava Beds are indicative of its elevated location near the edge of the Tulelake basin; it is slightly cooler during the day but warmer at night than Tulelake, which is near the center of the basin and its cold air pool. LABE park average minimum temperatures are slightly lower than those of the Lava Beds NM station, because the park has more area below the headquarters (and thus closer to the cold air pool) than above it.

Positioned in the desert interior, LABE receives far less precipitation than the other KLMN parks. A summer precipitation minimum still occurs, but is higher relative to the winter maximum than in the other parks. Both Lava Beds NM and Tulelake exhibit two precipitation maxima, the largest in winter, and a second in late spring.

Monthly spatial representations of LABE temperature and precipitation climatologies are available from the 1971–2000 animations (see Section 7). LABE is situated on gently sloping terrain, and the climatic gradients are equally subtle. The spatial patterns of maximum temperature closely follow elevation, with the coolest temperatures at high elevations, and the warmest at low elevations. As discussed above, the Tule Lake Basin acts as a cold air pool, and LABE is situated on the edge of this pool. As a result, minimum temperatures in most months are generally lower at the lower elevations in the northern part of the park than those at the higher elevations to the south. LABE is also situated on the leeward (northern) edge of a precipitation maximum produced by the Medicine Lake Volcano to the south. The southern part of the park receives spill-over precipitation from this area, and is slightly wetter than rest of the park.

Mount Lassen NP

Three COOP stations were chosen to represent LAVO: Manzanita Lake (045311), just inside the northwest boundary at 1753 m, Mineral (045679), at 1486 m about 15 km southwest of the park, and Chester (041700), at 1381 m about 20 km southeast of the park (Table 3.2). Plots of climatological temperature and precipitation for these three stations and the PRISM LAVO park average are shown in Figures 3.23–3.27. Despite Manzanita Lake's relatively high elevation, most of LAVO is still higher, and this is reflected in park average temperatures that are cooler than those of Manzanita Lake. Mineral and Chester are representative of well-protected basins in the area that are subject to cold air pooling; minimum temperatures are relatively low compared to those of Manzanita Lake, especially during the relatively clear months of summer and fall.

Precipitation is greatest at the highest elevations and in the southwestern park of the park, where access to moisture from the southwest is greatest. Mineral, representative of the southwestern area, receives significantly more precipitation than Manzanita Lake or Chester. Chester, representative of the lower, rain-shadowed parts of eastern LAVO, receives the least moisture. The LAVO park average is the wettest of the four, as it contains much high elevation area. Precipitation seasonality is similar to that of WHIS, with the wettest period being January–March. In contrast, CRLA and ORCA are wettest early in the winter, and become drier as March approaches.

Monthly spatial representations of LAVO temperature and precipitation climatologies are available from the 1971–2000 animations (see Section 7). LAVO spans a transition between the climates of the western and eastern exposures of the California Cascades. Mount Lassen and surrounding peaks dominate the spatial patterns of both temperature and precipitation. The spatial patterns of maximum temperature closely follow elevation, with the coolest temperatures centered over high elevations, and the warmest at low elevations. The minimum temperature patterns reflect some cold air pooling in valleys, although a lack of data compromise the spatial detail. The lowest minimum temperatures generally occur in the eastern part of the park, which is more exposed to arctic air masses than the western side. Precipitation is generally greatest in the vicinity of Mount Lassen and on the windward exposure to the south and southwest of the mountain. Precipitation is lowest in low-lying valleys with northern exposures, mainly in the northwestern and northeastern corners of the part.

Redwood NP and SP

Three COOP stations were chosen to represent REDW: Klamath (044577), 9 m, about 3 km from the coast and just outside the park boundary, Orick Prairie (046498), 49 m, inside the park and partially sheltered from coastal influence by intervening hills, and Orleans (046508), 122 m, outside the park and situated well inland (Table 3.2). Plots of climatological temperature and precipitation for these three stations and the PRISM REDW park average are shown in Figures 3.28–3.32. Maximum temperatures show a strong coastal/inland gradient among the stations. Orleans, sheltered from marine influence, exhibits a continental climate with the coldest winters and the warmest summers of the three stations. Orick Prairie is somewhat less continental and Klamath the least, with the coolest summers and the warmest winters. The REDW park average falls between Orleans and Orick Prairie. Minimum temperatures also show this gradient in continentality; except for the core summer months, Klamath is warmer than Orleans. Orick Prairie, moderately continental and located in a sheltered valley subject to cold air pooling, is substantially cooler than the other sites, except in mid-winter. The park average minimum temperature is cooler than Klamath but warmer than Orick Prairie. Except for Orleans, the daily temperature range behaves very differently than the other KLMN parks. The temperature range at Klamath reaches a minimum in summer, rather than winter, and peaks in October. This mirrors the frequency of days with marine stratus, which reaches a maximum in mid-summer and a minimum in autumn. The park average temperature range is consistent with that of Orick Prairie, the transitional site, with a minimum in winter and a maximum in late summer.

Precipitation is relatively high at Klamath, which has direct access to Pacific moisture, and decreases inland to a minimum at Orleans, located in the rain shadow of the Coast Range. Orick Prairie is again in the coastal/inland transition zone, with moderate precipitation. The REDW park average is wetter than Klamath, because the average reflects orographically enhanced precipitation on the windward side of the Coast Range within the park boundaries. Precipitation seasonality has similarities to both Oregon parks and WHIS and LAVO; early winter is the wettest period, but precipitation remains high through March.

Monthly spatial representations of REDW temperature and precipitation climatologies are available from the 1971–2000 animations (see Section 7). REDW spans a transition between the climates of the coast and the interior. The spatial patterns of maximum temperature are influenced by a combination of marine influences and elevation. In spring, summer, and fall, the cool, marine influence is greatest along the immediate coastline, and spreads inland at low elevations across coastal plains and through gaps in the terrain. In the transition between coastal and inland regimes, terrain that rises above the marine inversion is typically warmer than lower terrain within the marine layer. Inland, beyond the reach of marine influence, temperatures are very warm, and higher terrain is cooler than lower terrain. In winter, maximum temperatures are milder along the coast than inland. Minimum temperatures are also mildest along the coast in winter. Overall, however, minimum temperatures respond less strongly to coastal influence, and instead respond to local cold air pooling and elevation. REDW lies on the windward exposure of the Coast Range, and precipitation is greatest at the higher elevations of the park. The coastal strip and low-lying valleys generally receive less precipitation.

4. Objective 1: Temporal trends in core climatic parameters

Temporal trends and variations in temperature and precipitation were analyzed for each park from available data. Data included both actual stations and PRISM park averages. Two time periods were chosen for trend analysis: 1895–2007 and 1971–2007. The first period was chosen to provide a long-term context. Given that very few climate stations had unbroken observational records over the entire 20th century, 1895–2007 trends were calculated only for PRISM-derived park averages, which were interpolated from data observed at numerous stations. The second period was chosen to describe relatively recent trends that may better correspond to the observational period of park research. In addition, many more climate stations had an unbroken observational record for this period. A straightforward statistical approach was used to calculate trends. A least-squares linear regression function was applied to each time series, and a p-value calculated. An alpha value of 0.10 (90% level) was chosen as the threshold for significance. No special criteria were used in choosing this value, and readers are free to select alternative alpha values. The linear regression lines apply only to the time periods over which they were calculated, and are not valid outside this period; therefore, they offer no information for years before or after the period. Given the sparseness of the climate data and uncertainties in their representativeness of park conditions, a more sophisticated statistical analysis was not warranted.

Crater Lake NP

Plots of century-long trends and variations for CRLA annual precipitation and mean, minimum, and maximum temperature are shown in Figures 4.1–4.4. A summary of the trends in these variables for two periods, 1895–2007 and 1971–2007, is given in Table 4.1. Park average trends are broken out by month in Tables 4.2 and 4.3 Tables 4.4–4.6 summarize 1971–2007 monthly and annual trends for Prospect, Crater Lake NPS HQ and Chemult. There has been little trend in annual precipitation during either time period. The five-year moving average highlights a precipitation minimum around 1930, a maximum in about 1950, then a series of variations with a wavelength of about 10 years. There has been a significant drying trend in September precipitation, however, that appears in both periods in the CRLA average, and also for the three stations. A sharp precipitation decrease in the late 1980s is largely responsible for the overall trend (Figure 4.5). This is consistent with an unpublished analysis done by Daly for the HJ Andrews Experimental Forest east of Eugene in the Oregon Cascades, and suggests that the summer drought has been extending into late summer and early fall more often than before.

Temperature trends are significantly positive for several months and for the annual average. While trends in maximum temperature are weak, minimum temperature has seen significant increases over both the short and long time periods. Trends are not the same among stations and the park average, and it is important not to conclude too much from trend statistics at one location. However, it is clear that annual minimum temperatures have been increasing since the 1970s. This trend is relatively weak at Chemult, however. All locations show upward trends significant at the 90% level for the period 1971–2007 in January, April, May, and July.

Oregon Caves NM

Plots of century-long trends and variations for ORCA annual precipitation and mean, minimum, and maximum temperature are shown in Figures 4.6–4.9. A summary of the trends in these variables for two periods, 1895–2007 and 1971–2007, is given in Table 4.7. Park average trends are broken out by month in Tables 4.8 and 4.9 Tables 4.10–4.11 summarize 1971–2007 monthly and annual trends for Cave Junction and Grants Pass COOP stations. There has been little trend in annual precipitation during either time period. The five-year moving average highlights a precipitation minimum in the 1920s and 30s, a maximum in about 1950, then a series of cyclical variations with a wavelength of 10–20 years. The significant (90% level) September drying seen at CRLA is also present at ORCA, but is offset by a significant precipitation increase in August.

Annual maximum, minimum, and mean temperatures have increased substantially across the board in both the long and short time periods at ORCA. Unlike CRLA, both minimum and maximum temperatures have been increasing rapidly, at a rate of 0.5–0.6°C/decade over the past century. However, a look at the individual station trends shows a high level of disagreement. At Cave Junction, daily maximum temperatures have been warming significantly in nearly all months since 1971, while this warming is not evident at Grants Pass. In fact, Grants Pass shows no significant warming in any month for any temperature variable. Insufficient data are available from Bigelow Camp to develop sufficiently long trends. A time series plot of August maximum temperature at Cave Junction, Grants Pass, and Bigelow Camp is shown in Figure 4.10. Cave Junction is cooler than Grants Pass early in the record, which makes physical sense given its higher elevation. However, their places reverse in 1991, when Cave Junction becomes warmer than Grants Pass; this warm bias appears to increase in the early 2000s. Bigelow Camp, with observations beginning in 1990, mimics the variations in Cave Junction fairly closely, but does not seem to share its strong warming signal. Comparisons with the few other stations in the vicinity were inconclusive. A search of station metadata at NOAA did not turn up any changes to the sites that would have caused such temperature discrepancies. Therefore, the long-term temperature trends at ORCA remain unclear, pending a more intensive study of the station records.

Whiskeytown NRA

Plots of century-long trends and variations for WHIS annual precipitation and mean, minimum, and maximum temperature are shown in Figures 4.11–4.14. A summary of the trends in these variables for two periods, 1895–2007 and 1971–2007, is given in Table 4.12. Park average trends are broken out by month in Tables 4.13 and 4.14 Tables 4.15–4.16 summarize 1971–2007 monthly and annual trends for Trinity River Hatchery and Whiskeytown Reservoir. Precipitation over WHIS has been increasing slightly over the past century, but the increase is not significant at the 90% level. Precipitation was relatively high in the early part of the century, and reached a minimum in the 1920s and 30s. Unlike CRLA and ORCA, however, precipitation was relatively constant until the 1970s, when maxima occurred in the mid-1980s and late1990s. As seen at ORCA, August precipitation increased significantly (90% level). A decrease in September precipitation is significant in the 1971–2007 period but not 1895–2007. December precipitation exhibited a broadly based increase, significant for both trend periods and occurring in the WHIS average, Trinity Fish Hatchery, and Whiskeytown Reservoir. As is evident from Figure 4.15, extremely wet Decembers have been on the rise at WHIS in recent years.

WHIS annual temperatures have been increasing significantly over the century, especially minimum temperatures. Minimum temperatures have been increasing in a rising, cyclical pattern that has peaks around 1900, 1940, 1970, and at present. Increases were significant for every month during 1895–2007. The significant annual maximum temperature increase stemmed from a strong warming in September. Monthly trends during 1971–2007 were greater in terms of degrees per decade, but reached the 90% significance level only in March, July, and August.

Lava Beds NM

Plots of century-long trends and variations for LABE annual precipitation and mean, minimum, and maximum temperature are shown in Figures 4.16–4.19. A summary of the trends in these variables for two periods, 1895–2007 and 1971–2007, is given in Table 4.17. Park average trends are broken out by month in Tables 4.18 and 4.19 Tables 4.20–4.21 summarize 1971–2007 monthly and annual trends for Lava Beds National Monument and Tulelake COOP stations. There has been very little overall trend in annual precipitation over the century. Precipitation was relatively high in the early part of the century, and fell to a minimum in the 1920s and 30s. Precipitation varied relatively closely about the mean until the 1970s, when a cyclical pattern began, with maxima in the mid-1980s and late1990s, similar to WHIS. Neither the park average nor the stations exhibit significant trends over either of the two trend periods.

Temperatures have been rising more strongly in the last thirty years than in the past century, owing to a recent period of relatively consistent warmth. LABE park average maximum temperatures show significant increases in January and September and decreases in November over the 1895–2007 period. Over the 1971–2007 period, maximum temperatures increased significantly in March, July, and annually. Significance levels do not match well among stations. The Lava Beds NM COOP shows significant increases in January, March, July, and October, while Tulelake shows no significant increases. The story is the same with minimum temperatures; little spatial coherence is seen in trends. This suggests that the either data are noisy, or that local effects, such as changes in the frequency and intensity of cold air pooling, are causing temperatures to vary differently.

Mount Lassen NP

Plots of century-long trends and variations for LAVO annual precipitation and mean, minimum, and maximum temperature are shown in Figures 4.20–4.23. A summary of the trends in these variables for two periods, 1895–2007 and 1971–2007, is given in Table 4.22. Park average trends are broken out by month in Tables 4.23 and 4.24. Tables 4.25–4.27 summarize 1971–2007 monthly and annual trends at Chester, Manzanita Lake, and Mineral COOP stations. The century-long LAVO park average precipitation time series looks similar to that of LABE and WHIS, with no overall trends. A significant decrease in precipitation is seen in September over the 1971–2007 period, but unlike the other parks, August also shows a significant decrease. These trends are repeated at the Chester, Manzanita Lake, and Mineral COOP stations. As seen in WHIS, LAVO December precipitation shows a significant increase, but it is not significant at the COOP stations.

Maximum temperatures have not varied overall during the last century. The time series is dominated by a warm period during the 1920s and 1930s, after a cold period in the late 1800s and early 1900s. Recent variations have been more cyclical in nature, with the occasional very cold year, such as 1982–83 and 1998. The minimum temperature time series is dominated by a striking cold period from the mid-1970s to the mid-1990s, punctuated by several very cold years. This cold period is best seen at Mineral, where minimum temperatures fall rapidly between 1972 and 1975 (shown for August in Figure 4.24). Comparisons of the LAVO minimum temperatures with NCAR/NCEP reanalysis temperature data at 700 hPa (~ 3000 m) indicate that this was a relatively cool period in the upper atmosphere. One contributor appears to be the lapse rate, which was relatively steep during this period, and would have cooled high-elevation temperatures further than those at lower elevations. Despite this corroborating information, the PRISM LAVO park average temperatures are obviously uncertain and deserve further scrutiny, given the lack of data at high elevations in the park.

There were very few significant maximum temperature trends common to LAVO, Chester, Manzanita Lake, and Mineral. LAVO park average had no significant trends during 1895–2007, and a significant warming during 1971–2000 only in March. This was matched only at Mineral. Chester showed significant cooling in January and February that was not repeated at other sites. In addition, only Chester exhibited many months with significant warming trends in minimum temperature, nearly 1°C/decade in summer. Overall, the minimum temperature time series at the three COOP sites were quite different. Temporal variations in minimum temperature can operate at very fine spatial scales, responding to factors such as elevation, local topographic position, and frequency of synoptic conditions conducive to cold air pooling (Daly et al. in press).

Redwood NP and SP

Plots of century-long trends and variations for REDW annual precipitation and mean, minimum, and maximum temperature are shown in Figures 4.25–4.28. A summary of the trends in these variables for two periods, 1895–2007 and 1971–2007, is given in Table 4.28. Park average trends are broken out by month in Tables 4.29 and 4.30. Tables 4.31–4.33 summarize 1971–2007 monthly and annual trends at Klamath, Orick Prairie, and Orleans COOP stations. The century-long REDW park average annual precipitation time series looks similar to that of ORCA, with no overall trends. The five-year moving average highlights a precipitation minimum in the 1920s and 30s, and a maximum in about 1950, followed by a series of cyclical variations with a wavelength of 10–20 years. A significant decrease in precipitation occurred in September over both trend periods, and like LAVO, August also decreased significantly during the 1971–2007 period.

Somewhat surprisingly, 1971–2007 minimum temperature trends at Klamath (coastal) and Orleans (inland) were similar, but had little in common with trends at Orick Prairie (transition; Tables 4.31–4.33). Overall, minimum temperatures are not as affected by the coastal proximity gradient as maximum temperatures. Klamath and Orleans warmed significantly in January, April, May, and July, while Orick Prairie cooled in August and September. There were no significant trends in maximum temperature, except for September cooling at Orick Prairie and January cooling at Orleans. Further information on the spatial and temporal variations in coastal influence at REDW is presented in Section 6.

5. Objective 2: Snowpack trends and variability

Mean climatologies and temporal trends and variations in snowfall, snow depth, and snow water equivalent (SWE) on the ground were analyzed for CRLA, ORCA, WHIS and LAVO from available data. Snow variables are not included in the PRISM data sets, so only station data were used. Statistical methods are the same as those described in Section 4. Time periods over which trends were analyzed vary, depending on the periods of record of the stations used, but the 1971–2007 period is typically included in all parks. Snow course stations used in the analyses are given in Table 3.3.

Crater Lake NP

The snow climatology at CRLA is illustrated in Figures 5.1 and 5.2. On average, snow falls at Crater Lake NPS HQ in all months but July and August, and reaches a maximum during the December–February core winter period. Snow depth reaches a maximum in April, when 3000 mm can be expected on the ground. Chemult, at lower elevation and on the dry side of the Cascades, receives much lower snowfall, and a snow pack that reaches only about 500 mm in March. While Prospect is on the wet, windward side of the Cascades, its low elevation results in little snow fall or accumulation.

Snow depth and snow water equivalent (SWE) time series and trends are given in Figures 5.3–5.8, and Table 5.1. Snow depth records for the Crater Lake COOP are the longest available, and extend back to 1930. The trend line for the 1930–2007 period is negative, but not significant. Snow data are also available from the Crater Lake NPS HQ and Annie Spring snow courses. The common period of record among the three sites is 1947–2007, and is adopted here. The snow depth time series at the Crater Lake NPS HQ snow course looks similar to that of the COOP site in their general temporal fluctuations, but the COOP time series has a significant negative slope and that of the snow course does not. The Annie Spring snow course site shows significant negative trends in both snow depth and SWE over the 1947–2007 period. Given that the sites are very close together, this serves as a reminder of the danger of concluding too much from trends at one station. No sites had significant trends during 1971–2007.

All stations exhibit recent cyclical patterns of about 20 years in length, coincident with those of precipitation, indicating that precipitation is the main driver of the snowfall and snow pack dynamics in the CRLA. Elevations at CRLA are generally high enough to prevent recent temperature increases from negatively affecting the snowpack. However, the effects of warming temperatures on snowfall can be seen at lower elevations outside the park. There is a noticeable relationship between increasing temperatures and diminishing snowfall in January at Prospect, for example (Figure 5.9).

Oregon Caves NM

The snow climatology in the vicinity of ORCA is illustrated in Figures 5.10–5.12. Cave Junction, about 300 m lower than the lowest elevation in ORCA, receives very little snow on average; Grants Pass receives even less. The Bigelow Camp SNOTEL site, well within the elevation range of ORCA, receives a moderate snowpack that reaches a maximum in March of about 330 mm SWE.

Snow depth and SWE time series are given in Figures 5.13 and 5.14, and Table 5.2. The nearest snow course site with a lengthy period of record is Grayback Peak snow course, about 10 km northeast of ORCA, It elevation, at 1829 m, matches the highest elevations of the park. Both snow depth and SWE have decreased over 1936–2007, but only the SWE decrease was significant at the 90% level. No significant trends have occurred since 1971. There is insufficient information to draw conclusions about potential relationships between temperature or precipitation and snow depth, snow fall, or SWE at ORCA. Data that are available do not show any obvious relationships.

Whiskeytown NRA

The snow climatology of WHIS and vicinity is illustrated in Figures 5.15 and 5.16. Little snow falls at either Whiskeytown Reservoir or Trinity River Hatchery; the elevations of these sites are well below the local winter snow level. Although Shasta Bally, the highest point and one of the most unique features in the park, does accumulate a winter snowpack, we were unfortunately unable to identify any snow data for high elevation sites in the area; the snow course network does not cover this region.

Mount Lassen NP

The snow climatology at LAVO is illustrated in Figures 5.17 and 5.18. Despite receiving less overall precipitation than Mineral, snowfall is greatest at Manzanita Lake, due to its high elevation. Given that elevations within LAVO range as high as 3000 m, snowfall is very substantial in many parts of the park. Snow depth typically reaches a maximum in March at Manzanita (650 mm) and Mineral (500 mm), and in February (400 mm) at Chester. The snow is normally gone by June at all COOP stations, but persists well into summer and beyond on the higher peaks within LAVO.

A snow depth time series for Manzanita Lake is given in Figure 5.19 and Table 5.3. April 1 snow depth at Manzanita Lake has been decreasing significantly since 1949, owing largely to a period of relatively low snow packs in the 1980s and 1990s. However, March 1 snow depth shows little trend, as do January 1 and February 1 snow depth time series (not shown). This suggests a temperature effect late in the snow season. A time series of mean temperature for March, the month preceding the April 1 snow depth measurements, indeed indicates that March mean temperature has been increasing significantly (Figure 5.20). January mean temperature has also warmed significantly since 1949, but not the other winter months (not shown). Major effects on snowpack of a warmer March are likely confined to the lowest elevations of the park, where temperatures are relatively high. As illustrated in Figure 5.21, Manzanita Lake represents the warmest March mean temperatures that can be expected in the park. The coldest mean March temperatures in LAVO, as estimated by PRISM, are well below freezing, but rising.

6. Objective 3: Spatial and temporal patterns of marine influence at Redwood National and State Parks

To develop a picture of the spatial and temporal patterns of marine influence at REDW, mean climatologies and temporal trends and variations in wind speed and direction and fog and low stratus were analyzed from available data in the area. These variables are not included in the PRISM data sets, so only station and reanalysis data were used. Statistical methods for trend analysis are the same as those described in Section 4. Stations used in the analyses are given in Table 3.3.

Mean spatial patterns of summer marine influences at REDW can be approximated by viewing the patterns of 1971–2000 mean monthly maximum temperatures for the months of June–October (see animation and Section 7). Marine influence is greatest along the immediate coastline, and spreads inland at low elevations across coastal plains and through gaps in the terrain. In the transition between coastal and inland regimes, terrain that rises above the marine inversion is typically warmer than lower terrain within the marine layer. Inland, beyond the reach of marine influence, low elevation temperatures increase markedly, so that the general decline in temperature with elevation occurs. The penetration of marine air into inland areas is generally least effective during summer, because high pressure limits the ability of the marine layer move over terrain barriers, and onshore wind patterns are weak. During winter, low pressure and stronger onshore flow allow a generally greater marine influence throughout the park.

Wind and fog data were collected as described in Section 2 to assist in a temporal analysis of marine influences at REDW. Wind data were obtained from the NCAR/NCEP reanalysis as described in Section 2. Monthly mean maximum temperatures at Orick Prairie were used as an indicator of the penetration of marine influence, due to its location in the coastal/inland transition zone, long period of record, and relatively close proximity to the wind and fog locations.

Wind climatology at REDW is illustrated in Figures 6.1 and 6.2. The first station shown is the WBAN station at Arcata (24283). The other "stations" are NCEP/NCAR Reanalysis data set grid points: NCEP West (NCEP00) positioned approximately 130 km west of Arcata, and NCEP East (NCEP01) at approximately 30 km east of Arcata. These two grid locations were chosen because they were closest to REDW. There were few observational data for wind available in this area of the coast, necessitating the use of modeled data for the analysis. Arcata, the only coastal COOP/WBAN station with wind data, had observations for about 10 years during 1992–2001. Wind speed is lowest in October through March, with a slight winter maximum. Wind speeds increase in the spring to reach a maximum in summer before decreasing steadily to autumn. Winds are out of the south to southeast during the winter, and consistently from the northwest from April to September; spring and fall are transition periods.

Trends and variations in wind speed at NCEP West for the months of June through October during 1949–2007 are shown in Figures 6.3–6.7. A summary of the trends and significance levels for these two variables is given in Table 6.1 for 1949–2007 and in Table 6.2 for 1971–2007. An increase in wind speed in September was significant at the 90% level for both periods; the same was true for October, but only during 1971–2007. Wind speed decreased significantly in May during 1971–2007. June wind speed varied in a cyclical manner from 1949 to 2007, with a period of about 15 years. July had a slightly more regular ten year variation, while the other months showed little decadal periodicity. Of particular interest was a general increase in wind speeds for all summer months from the mid-1980s to about 2004. Wind direction (not shown) followed the climatological average closely (see Figure 6.2), and was very consistent from year to year.

Combined fog and low stratus plots and trends for Arcata are shown in Figures 6.8–6.12. A summary of trends for fog, low stratus, and combined are given in Table 6.3 for 1949–2007 and Table 6.4 for 1971–2007. The percent of hours of combined fog and low stratus declined significantly at the 90% level in July and August during 1949–2007 and in May and June during 1971–2007. June followed a similar saw-toothed pattern to that of June wind speed, although the patterns are out of phase. July, August, and October all had a period of relatively low variability from about 1971 to 1981. Of note was a general decrease in the frequency of fog and low stratus for all summer months from the mid-1980s to about 2004. As mentioned above, wind speeds generally increased over the same period. While there is no consistent relationship between NCAR/NCEP wind speed and Arcata percentage of fog and low stratus over the 1949–2007 period, there does appear to have been a generally inverse relationship over the last twenty years.

Analysis of potential relationships between monthly mean maximum temperature at Orick Prairie and either NCAR/NCEP wind speed or Arcata percentage of fog and low stratus did not show any consistent patterns. There were instances during the record of higher winds and/or fog and lower maximum temperatures, and vice versa, but not enough to definitively show that wind and fog conditions were closely tied to Orick Prairie maximum temperatures. This is not surprising, given the complex marine air penetration patterns that characterize REDW.

There is insufficient data to support an analysis of how temporal trends in marine influence are varying spatially. The inter-annual variations of temperature between coastal and inland sites often have low correlations, making it difficult to infer conditions at one location from another. This lack of correlation occurs up and down the US West Coast, and is most pronounced in summer. It is the result of limited onshore flow penetration, which segregates mechanisms controlling immediate coastal zone temperatures from those inland.

To explore this effect at REDW and vicinity, we defined a domain that includes much of the coastline and adjacent inland areas from just north of the San Francisco Bay Area to the Oregon border. We used the PRISM coastal proximity grid (Figure 6.13; Daly et al. 2008) to define coastal influence. For each month, mean temperature observations from all stations with a coastal proximity index of 100 or less (coastal) were averaged for each year during the period 1971–2000. The same was done for stations with coastal proximity indexes of 300–600 (inland). These average mean temperatures were correlated and an r-value calculated for each month. The coastal strip is remarkably different from the interior in its behavior, resulting in a correlation coefficient as low as 0.1 when compared to adjacent inland areas in July (blue line in Figure 6.14).

To assess the ability of the PRISM data set to simulate this coastal/inland discrepancy, mean temperature values for all PRISM grid cells with coastal proximities of < 100 (coastal) and 300–600 (inland) were each averaged together and correlated. PRISM coastal correlations nicely approximated those of the station data, indicating that the integrity of the coastal strip was largely maintained (red bars in Figure 6.14). This is possible because PRISM uses coastal proximity as one of its station weighting functions.

The next question to consider is: How far back in time did PRISM maintain this integrity, given a reduction in stations during the early years? Coastal-inland correlation coefficients were calculated for successive 30-year periods back to 1901 and plotted in Figure 6.15. The PRISM data set maintains high coastal/inland integrity until the 1911–1940 period (specifically about 1920), when the correlation coefficient rises markedly. A plot of the mean number of stations for each 30-year period (green line in Figure 4.31) shows that there is only one coastal station remaining in the data set before 1940. Further, this station (Crescent City) had questionable data quality during these years. This indicates that there is a limit to the ability of PRISM to maintain the integrity of physiographically distinct climatic regions; without sufficient station data to represent these regions, integrity breaks down.

7. Objective 4: Space-time animations

Two sets of animations were created for each park to provide time-lapse illustrations of precipitation and temperature variations across the park. The first set of animations was created from the PRISM gridded time series of annual precipitation and mean annual temperature. They highlight the interannual variability of these parameters for the years 1895–2007. A second set of animations was created from the PRISM 1971–2000 gridded climatological averages of total monthly precipitation, and average monthly maximum, minimum, and mean temperature. They illustrate month-to-month variability of these parameters within an average year.

The animations were made by first creating PNG images of the PRISM grids for each of the parks using the Geographic Resources Analysis Support System (GRASS). The PNG files were then combined together using Windows Movie Maker to create Windows Media Video (WMV) files. The time series images are displayed for about one second each and the normals images are displayed for about two seconds. A one-quarter second fade was inserted between each frame to provide a smooth transition between frames.

8. Online Data Viewer

A database was created to hold the time series of monthly raw and QC'ed station data, and corresponding modeled values extracted from the 1895–2007 PRISM time series grids. Stations were chosen for their proximity to the parks and for their historical period of record; only stations that had data in at least 10 calendar years included in the database. Time series statistics for each park, generated from the portion of the PRISM grids encompassed by the park, were also added. An online, web-based data viewer was designed to interface with the database, providing access to the data and tools for visualization. The data viewer is accessible at http://gisdev.nacse.org/prism/klamath.

The viewer allows the user to select any one of the parks and view monthly climate data for that particular park and its associated stations. A navigable map of the selected park and surrounding area appears next to the list of parks. The associated stations are marked on the map to illustrate their positions relative to the park and each other. Selection of a station results in the map re-centering and zooming to the location of the station.

Once a park is selected, a variety of statistics related to the park grid may be viewed. These PRISM-derived grid statistics include average, maximum, minimum, range, standard deviation, and lapse rate. Available climate parameters for PRISM grid statistics are precipitation, maximum, minimum, and mean temperature, and temperature range. Multiple statistics may be viewed for a single park or a single statistic may be viewed for multiple parks. Likewise, multiple statistics may be viewed for a single parameter or a single statistic may be viewed for multiple parameters. Data from one or more stations may be viewed along with the park statistics, or no park statistic can be selected leaving only the station data for display.

Station climate parameters available are maximum, minimum, and mean temperature, temperature range, precipitation, snow-water equivalent (SWE), snowfall, snow depth, and wind speed and direction. Stations having data for a particular climate parameter are available for selection, though a specific park may not have station data for all parameters. If no data exists for a selected parameter, the station list will be empty. Stations are initially listed in descending order by total number of non-missing raw observations, but the list may be resorted based on station ID, name, or elevation. Raw observations are displayed by default, but the user can instead choose to display the QC'ed observations if they exist. A station's PRISM grid values can also be overlaid if they are available. Multiple parameters for a single station or multiple stations for a single parameter may be chosen for display. The user can also choose between the station name or ID as the label for the time series plot.

There are additional conditions available to restrict the temporal behavior of the resulting plot. The user can choose to display the time series for a particular month, the annual value, or all monthly values available between a starting and ending year. If a start or end year is not selected, the earliest or latest year with non-missing data for all selected stations will be used. Annual values are based on the calendar year, but an option to display annuals based upon water year is also available. Values can also be grouped together by station ID, year, and/or month for aggregate operations on the entire time series. In particular, by selecting all months between a start and end year, grouping by station ID and month, and averaging, long-term climatologies can be generated for specific periods. Lastly, a moving average, and a linear least-squares regression line and associated statistics can be added to the plot before displaying. An option for downloading the data as a file is also available.

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