



Annual Climate Report for Grant-Kohrs Ranch National Historic Site, 2007

Natural Resource Report NPS/ROMN/NRR—2009/101



ON THE COVER

Grant-Kohrs Ranch National Historic Site.

Photography by: Donna Shorrock, Rocky Mountain Inventory and Monitoring Network.

Annual Climate Report for Grant-Kohrs Ranch National Historic Site, 2007

Natural Resource Report NPS/ROMN/NRR—2009/101

Isabel Ashton, Brent Frakes, David Pillmore, and Jennifer Burke

National Park Service
Rocky Mountain Network
1201 Oakridge Drive
Fort Collins, Colorado 80525

April 2009

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

Natural Resource Reports are the designated medium for disseminating high priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability. Examples of the diverse array of reports published in this series include vital signs monitoring plans; monitoring protocols; "how to" resource management papers; proceedings of resource management workshops or conferences; annual reports of resource programs or divisions of the Natural Resource Program Center; resource action plans; fact sheets; and regularly-published newsletters.

Views, statements, findings, conclusions, recommendations and data in this report are solely those of the author(s) and do not necessarily reflect views and policies of the U.S. Department of the Interior, NPS. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

This report is available from Rocky Mountain Network and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/NRPM>).

Please cite this publication as:

Ashton, I., B. Frakes, D. Pillmore, and J. Burke. 2009. Annual climate report for Grant-Kohrs Ranch National Historic Site, 2007. Natural Resource Report NPS/ROMN/NRR—2009/101. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	v
Tables.....	vii
Appendices.....	ix
Executive Summary	xi
Introduction.....	1
Data and Methods	2
Local Station Data	2
Park and Catchment Climate Indices.....	3
Regional Datasets	3
Global Datasets	4
Reporting Framework.....	4
Results and Discussion	5
Temperature.....	5
Precipitation.....	9
Snow Water Equivalent	11
Drought	13
River Flow	15
Correlation among Atmospheric Indices and Climate Parameters.....	17
Conclusions.....	18
Literature Cited	19

Figures

	Pages
Figure 1. Locations of weather and climate stations within and around Grant-Kohrs Ranch National Historic Site.....	2
Figure 2. Monthly temperature anomalies for the water year 2007 from Grant-Kohrs Ranch National Historic Site.....	6
Figure 3. Annual temperature anomalies from Grant-Kohrs Ranch National Historic Site for the water years 1978 -2007.....	7
Figure 4. Monthly maximum temperatures for Grant-Kohrs Ranch National Historic Site and surrounding region, 2007 water year.	8
Figure 5. Monthly precipitation anomalies for the water year 2007 from Grant-Kohrs Ranch National Historic Site.....	9
Figure 6. Annual precipitation anomalies from Grant-Kohrs Ranch National Historic Site for the water years 1978 -2007.....	10
Figure 7. Monthly accumulated precipitation for Grant-Kohrs Ranch National Historic Site and surrounding region for the 2007 water year.....	11
Figure 8. Monthly snow-water equivalent anomalies for the water year 2007 in the region of Grant-Kohrs Ranch National Historic Site.	12
Figure 9. Snow-water equivalent anomalies in the region of Grant-Kohrs Ranch National Historic Site for 1978 -2007.	13
Figure 10. Monthly Palmer Drought Severity Index (PDSI) for Montana Climate Division 1, water year 2007.....	14
Figure 11. Annual average Palmer Drought Severity Index (PDSI) for Montana Climate Division 1 from 1978-2007.....	15
Figure 12. The 2007, daily mean hydrograph is measured in cubic feet per second (cfs), for the USGS Clark Fork River gage, directly upstream of Grant-Kohrs Ranch National Historic Site.	16
Figure 13. Annual peak flow (in cubic feet per second) departure from the 30-yr mean for the USGS Clark Fork River gage, directly downstream of Grant-Kohrs Ranch National Historic Site.	17

Tables

	Pages
Table 1. Global atmospheric indices (NWS-CPC 2008) examined in the GRKO annual report and periods of record collected for each index.....	4
Table 2. The number of frost free days, first and last frost dates for active stations within and around Grant-Kohrs Ranch National Historic Site during 2007.....	5
Table 3. Correlation coefficients between the six atmospheric indices (NWS-CPC 2008) and the climate at Grant-Kohrs National Historic Site from 1978-2007.....	18
Table 4. Common acronyms used in this report.	21
Table 5. Inventory of all climate data collected for the 2007 Annual Climate Report of Grant-Kohrs Ranch National Historic Site.	23
Table 6. The maximum (red), average (black) and minimum (blue) temperatures (Fahrenheit) for three weather stations near Grant-Kohrs Ranch National Historic Site during the 2007 water year.	23
Table 7. The 2007 maximum 24-hour (blue), total accumulated (black), and number of precipitation days (green) by month for stations near Grant-Kohrs Ranch National Historic Site.	24

Appendices

	Pages
Appendix A. Common Climate Acronyms.....	21
Appendix B. Supplementary Tables	23

Executive Summary

Weather and climate are the primary drivers of almost all physical and ecological processes that determine the distribution, structure, and function of ecosystems. Here, the Rocky Mountain Inventory and Monitoring Network (ROMN) provides a summary and analysis of climate within and around Grant–Kohrs Ranch National Historic Site (GRKO) for the 2007 water year (WY2007; October 2006 – September 2007). We found the following:

- Maximum temperatures for GRKO were above normal in 2007. Locally and regionally, maximum temperatures were unusually high during the summer months, especially in July. Over the past 30 years, 2007 was one of the warmest years on record, especially at the park scale.
- Compared to the last 30 years, precipitation, snow-water equivalents (SWE), and river flow during 2007 were normal. August was a dry month, resulting in a moderate drought in August and September. Overall, however, 2007 was not a drought year.
- The Atlantic Multi-decadal Oscillation may be a useful predictor of annual temperature and precipitation at GRKO.

In general, there has been an increase in temperature, decrease in SWE, and trend toward earlier peak flows throughout the Western United States (US) during the last 50 or so years associated with human impacts on the atmosphere (Barnett et al. 2008). These trends are expected to continue in the absence of drastic policy changes (Barnett et al. 2008). Since the trends in the local climate at GRKO have been consistent with models of the Western US, predictive models of climate and hydrology in the West should provide meaningful insights into future GRKO climate. In other words, it is reasonable to expect that GRKO will continue to experience hotter years in the future.

Introduction

Weather and climate are the primary drivers of almost all physical and ecological processes that determine the distribution, structure, and function of ecosystems. Weather refers to the state of the atmosphere at a given time and location, while climate refers to the average conditions over a longer period and can be used to describe local, regional, or global scales (AMS 2008). To understand and manage resources within a national park, it is critical to have access to weather and climate information that accurately describes the region in and around a park. Here, the Rocky Mountain Inventory and Monitoring Network (ROMN) provides a summary and analysis of climate within and around Grant–Kohrs Ranch National Historic Site (GRKO) for the 2007 water year (WY2007; October 2006 – September 2007).

The GRKO annual report presents summaries of datasets of varying spatial and temporal scales including: 1) weather stations within and around the park, 2) a park-level climate index, 3) the Snow Data Assimilation System (SNODAS; see Appendix 1 for a list of acronyms used throughout this report), 4) the Parameter-elevation Regressions on Independent Slopes Model (PRISM), (5) regional drought indices, (6) hydrologic data, and (7) the relationship between local climate and global atmospheric indices. Weather stations within and around the park can provide detailed daily or hourly observations of weather at one location. These can provide useful data when investigators are interested in that specific location, but it is difficult to extrapolate local station data to larger areas. Therefore, a park-level climate index that aggregates station data will more accurately describe the entire park. Regional-scale information provides insight into spatial variability in climate within the park and the region. Hydrological data provide a watershed-scale assessment of water availability and precipitation. Finally, because trends in global indices are more predictable than local climate, understanding the relationship between them increases our ability to produce meaningful climate forecasts and provide a better understanding of how regional climate is affected by continental to global scale changes in climate.

This WY2007 report summarizes these datasets of varying spatial and temporal scales to meet the following objectives:

- Provide a general summary of GRKO's climate for WY2007 by describing climate parameters relevant to ecological processes and management decisions – temperature, precipitation, snow cover, and drought;
- Provide an inventory of climate related datasets available for further analysis;
- Quantify the strength of climatic relationships at different spatial and temporal scales;
- Provide a prototype report for GRKO managers and other users to comment on and refine for future annual summary reports and summaries.

This report is not intended to provide a comprehensive analysis of climate, a physical understanding of why changes occur, or to determine long-term trends in climate. Based on the findings of the annual reports, the Network plans to provide a more detailed trend analysis once every 5-7 years which will investigate these trends and relationships in more detail at the park scale. In the future, we expect annual reports to be available approximately 9 months after the end of the water year (June). The lag time is due to the time required for the cooperating stations to quality control and publishes the datasets.

Data and Methods

Local Station Data

In 2008, ROMN acquired the long-term data from 8 different COOP weather stations and 2 different SNOTEL sites within a 40 km of GRKO, Montana Climate Division 1, and hydrographic data for the Clark Fork River in Deer Lodge, Montana (Figure 1). The 40 km buffer distance was selected as a standard by the National Park Service climate inventory program (Davies et al. 2007) to include at least a few automated stations from major networks, but also to keep the size of the stations lists to a reasonable number. Station-level data were collected from three National Weather Service Daily COOP monitoring networks stations (NWS-COOP 2007); Snowpack Telemetry (SNOTEL) (NRCS 2007a); and Snow Course (NRCS 2007b) (See Appendix 2 for a summary of the stations in each network, the period of record and their current status). These data were collected via the websites of each agency and since data are only posted after passing some quality assurances, we assumed that the acquired information had passed the appropriate quality control and had limited or no errors. This section briefly outlines the data and methods used to produce the 2007 annual report of climate in Grant-Kohrs Ranch National Historic Site. Full descriptions of the data and methods will be described in the Weather and Climate Protocol (Frakes et al., *in preparation*).

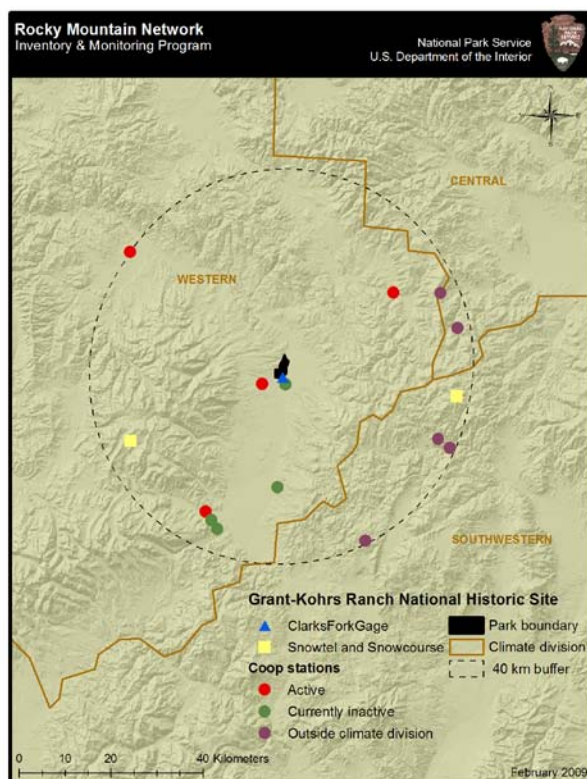


Figure 1. Locations of weather and climate stations within and around Grant-Kohrs Ranch National Historic Site.

A complete and detailed analysis of data from each station is beyond the scope of this report; however, Appendix 2 summarizes monthly temperature and precipitation for all stations with daily observations used in this report. Raw data and summaries are available from ROMN upon request.

Park and Catchment Climate Indices

Station observations provide valuable information on the conditions at that specific location. Foremost, station-level observations can extend back to the late 19th century, thereby providing a dataset for understanding recent changes and trends. Furthermore, because they are not modeled from any other dataset, they are the foundation of all other climate datasets. However, care should be taken when generalizing beyond the specific location of the station, especially when considering variables such as precipitation that show large local-scale variability. When attempting to generalize to a park-level scale, these point-based observations are difficult to work with for the following reasons:

- Micro-scale climate - e.g., difference resulting from proximity to parking lots, walls, water, trees, vents, etc. that may affect representative measurements;
- Meso-scale climate – Relationship to individual storm events. This is especially problematic in summer when convective rainfall unevenly distributes rain.
- Data Errors – Errors related to the instrumentation or recording of the information
- Shortness and discontinuity of records – Some stations do not have 30 years worth of observation and/or have substantial data gaps.

To produce a robust and continuous climate record and to overcome some of weakness of the local station data, we calculated park-wide climate indices. Daily maximum temperature (TMAX) and precipitation (PPT) indices were calculated for GRKO using all available station observations. Maximum temperature was used, rather than average, because it is more consistently reported. To calculate the indices all station data were weighted according to the inverse square of the distance to the park, (stations closer to the park are given a greater weight) and adjusted for elevation (see Frakes et al. *in preparation*). This process creates a continuous time series representing the entire park. It is better than calculating an average of all stations because it can account for stations at different elevations, distances from the park, and for differences in the time series available from each station. It is important to note that while the park-level index is a powerful indicator of climate conditions within GRKO, it is never representative of any single point within the park, and it may be removing climate signals relevant to certain ecological processes (for more details on the derivation and use of indices, see Frakes et al. *in preparation*).

In the case of the GRKO park-wide index, it is largely based on the two stations closest to GRKO that have a consistent record of weather data from 1893 to the present day. The Deer Lodge Station (about 2 km S of GRKO) began reporting in 1893. In 1959 it was closed and the record was immediately picked up by Deer Lodge 3 W (about 4 km SW from GRKO), which has been reporting since then.

In addition to temperature and precipitation indices, two SNOTEL stations upstream of GRKO, Warm Springs and Rocker Peak, were used to calculate a daily snow water equivalents (SWE) index for the Clark Fork catchment at the park. In future reports, SWE will be calculated for the contributing watershed of the park. To compare across years, we used the mean SWE during April of each year which is the period of maximum SWE for the catchment, and a common way to express annual SWE (Mote et al. 2005).

Regional Datasets

Two gridded datasets were collected from web based databases and analyzed to examine climate in the regional area around GRKO. The SNODAS integrates surface-based and remotely sensed observations to create a daily 1-km gridded dataset that includes snow depth, SWE, and snow extent (NOHRSC 2004). PRISM (2007) is a spatially-explicit model that uses point-based measurements of precipitation,

temperature, wind and other climatic factors to produce continuous, digital grid estimates of monthly climate for the conterminous US at a 4-km resolution. Because the model is spatially explicit, it incorporates the point data with a digital elevation model and expert knowledge of complex and localized climatic extremes (e.g., rain shadows, coastal effects, and temperature inversions).

In addition to the gridded datasets, we acquired regional data on drought and stream flow. NOAA (NOAA-NCDC 2007) produces monthly drought indices for the region encompassing GRKO (Montana Climate Division 1). We present information on the Palmer Drought Severity Index (PDSI), a meteorological drought index used to assess the severity of dry or wet spells of weather based in temperatures and rainfall. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. Since river flow is an excellent watershed-level integrator for climate, a complete hydrologic dataset for the Clark Fork River at Deer Lodge (USGS 12324200) was acquired and summarized here. This gauging station has recorded daily mean discharge since 10/1/1978 and has a 29-year period of record (USGS 2009).

Global Datasets

Long-term and large-scale atmospheric and ocean variations play a key role in understanding and predicting intra-seasonal and inter-annual variations in climate (CDC 2007). For instance, the Pacific Decadal Oscillation (PDO) which represents variation in sea surface temperature and atmospheric pressure in the northern Pacific Ocean correlates with the occurrence of drought induced fires in the Rocky Mountains (Schoennagel et. al 2005). We downloaded monthly records of a number of indices which are used to describe these global patterns in atmospheric and ocean behavior (Table 1). In a preliminary analysis and to determine whether any of these global indices may explain variations in climate at GRKO, we correlated each index with the derived park-wide index of TMAX, PPT, and SWE, and drought.

Table 1. Global atmospheric indices (NWS-CPC 2008) examined in the GRKO annual report and periods of record collected for each index.

Atmosphere / Ocean Index	Year Begin	Year End
Atlantic Multi-decadal Oscillation (AMO)	1856	2008
North Atlantic Oscillation (NAO)	1950	2008
Pacific Multi-decadal Oscillation (PDO)	1900	2008
Pacific North American Pattern (PNA)	1950	2008
Southern Oscillation Index (SOI)	1951	2008
Teleconnection Northern Hemisphere (TNH)	1950	2008

Reporting Framework

As much as possible, the following summaries consistently present the last 30 years of data to emphasize the short to intermediate time scales of climate variability. Generally, we present graphics and statistics to summarize intra-annual variability followed by similar analyses that emphasize inter-annual variability of each climate parameter. All calculations are done for the water year October 2006-September 2007. The water year presents a more ecologically relevant time period because it encompasses the period prior to and during the main growing season.

Results and Discussion

Temperature

The GRKO WY2007 growing season (as defined by the last and first frosts) ranged from May 7 to September 9 (Table 2). For most of the growing season, maximum temperatures were slightly higher than normal but only July 2007 was much hotter than it has been in the past 30 years (about 8°F hotter; Figure 2). Compared to the past 30 years, the rest of the year tended to be warm with only October and January exhibiting cooler than average maximum temperatures. Like July, March 2007 was much hotter than it has been in the past (Figure 2).

Table 2. The number of frost free days, first and last frost dates for active stations within and around Grant-Kohrs Ranch National Historic Site during 2007.

Station Name	Station ID	# Frost Free Days (minimum temp>32° F)	Last Frost of Spring	First Frost of Fall
ANACONDA	240199	167	5/6/2007	9/9/2007
DEER LODGE 3 W	242275	144	5/7/2007	9/9/2007
DRUMMOND AVIATION	242500	156	5/31/2007	9/9/2007

The mean maximum daily temperature in 2007, 62.6°F, was above the mean from the past 30 years (Figure 3). This is consistent with trend that many of the warmest water years since 1978 have been in the past decade. Here, we define the warmest and coldest years as those in the top or bottom 20% of the past 30 years. Moreover, during this relatively short period of time (30 years) temperatures have warmed significantly even when 1978 (a particularly cold year) is removed from the analysis ($r^2 = 0.18$, $F_{1,27} = 7.1$, $P = 0.013$).

GRKO tends to be warmer than the surrounding region (Figure 4) and this pattern is consistent across all months of the year.

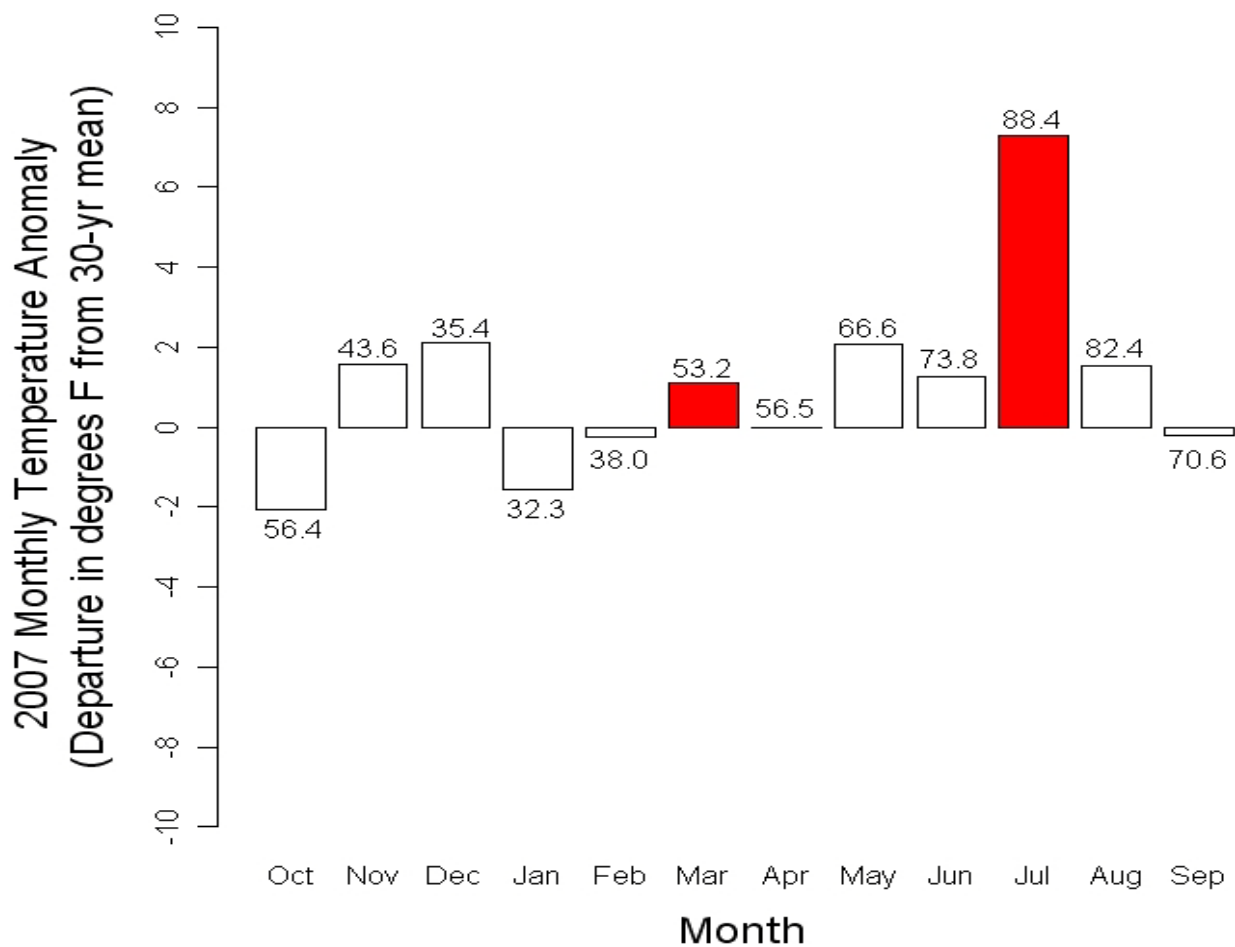


Figure 2. Monthly temperature anomalies for the water year 2007 from Grant-Kohrs Ranch National Historic Site. Temperatures are derived from the park-wide index based on maximum daily temperatures. The monthly mean temperature in 2007 is compared to the monthly mean based on the last 30 years. Colored bars indicate that 2007 was in the top (red) or bottom (blue) 20% of the past 30 years. The values above or below each bar indicate the monthly average maximum temperature in degrees Fahrenheit. In 2007, March and July were both hotter than most years since 1978 (>80%).

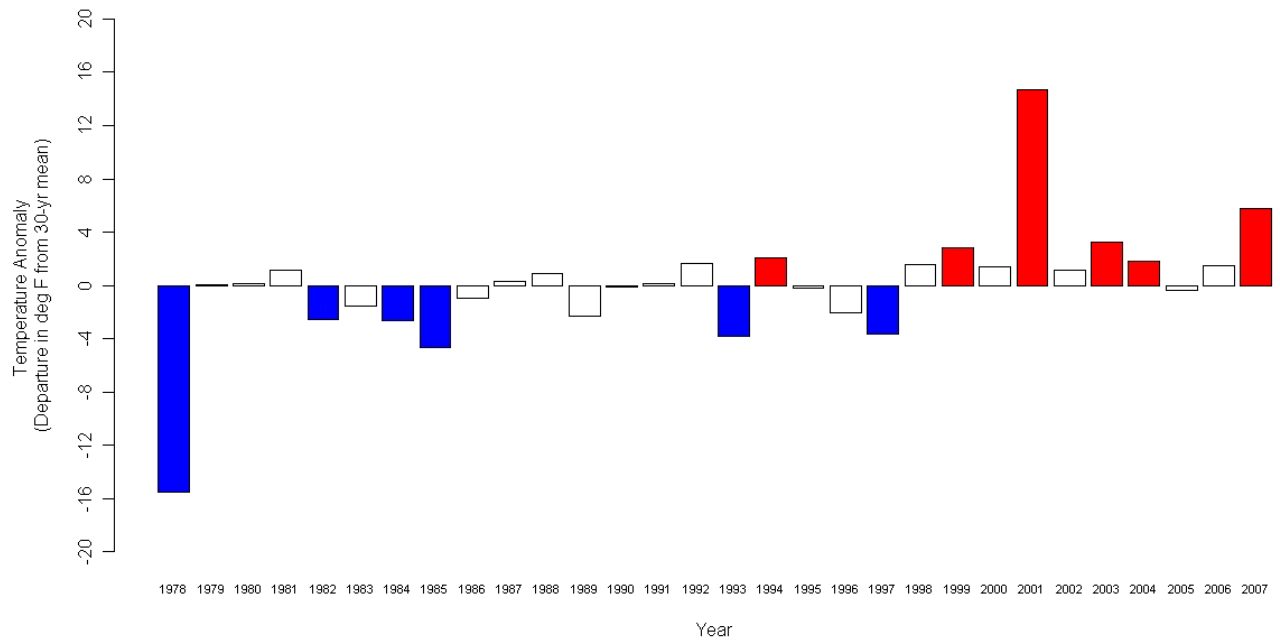


Figure 3. Annual temperature anomalies from Grant-Kohrs Ranch National Historic Site for the water years 1978 -2007. Temperatures are derived from the park-wide index based on maximum daily temperatures. The annual temperature for each year is compared to the mean of the last 30 years, 56.8°F. Colored bars indicated the six years with the coldest (blue) and hottest (red) temperatures since 1978.

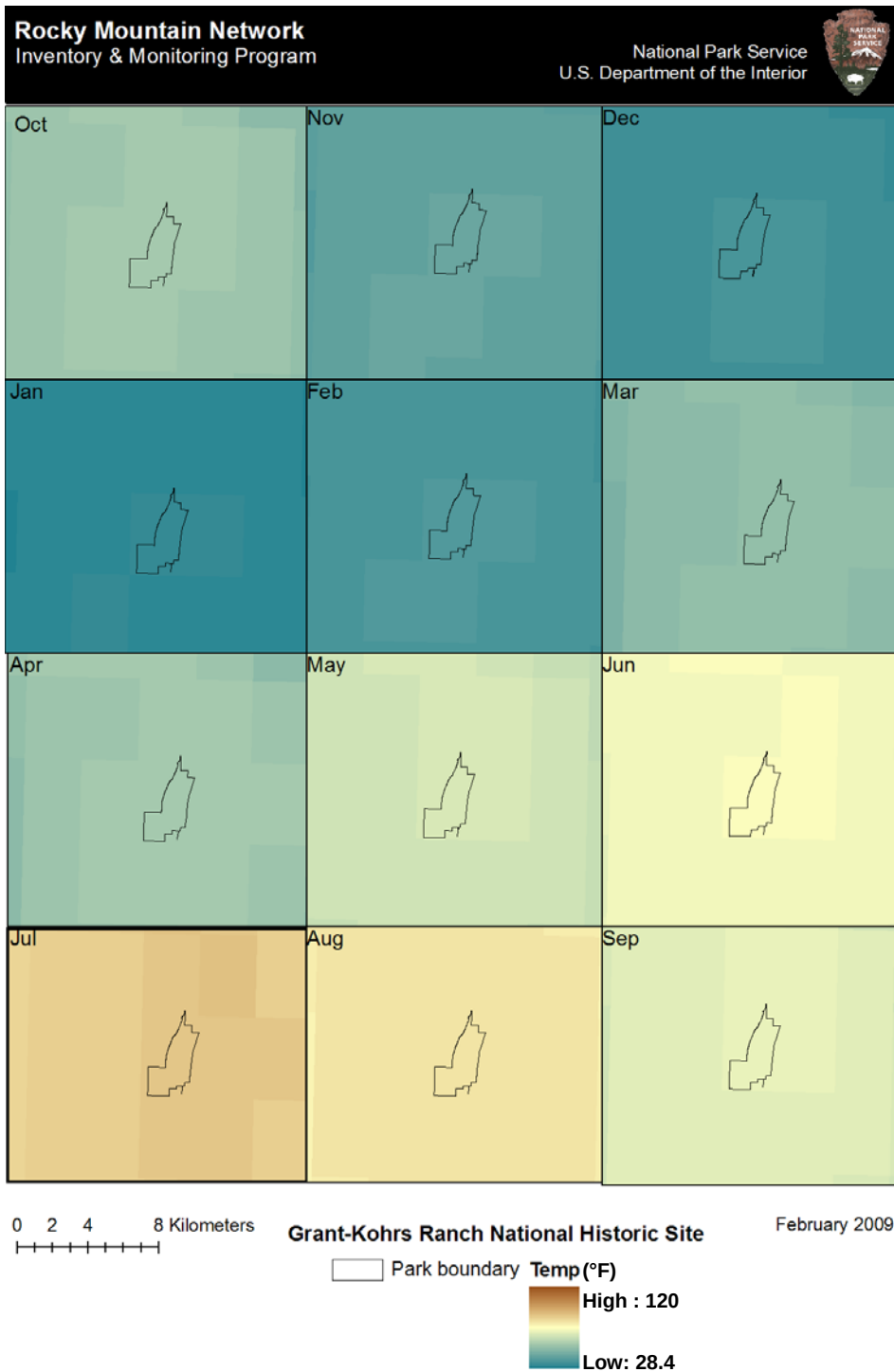


Figure 4. Monthly maximum temperatures for Grant-Kohrs Ranch National Historic Site and surrounding region, 2007 water year. Source: PRISM (2007).

Precipitation

Monthly precipitation totals in GRKO were highly variable in 2007. The summer tended to be dry but a few months in spring and fall were wetter than average (Figure 5). August received about one inch less rain than normal, making it one of the driest Augusts in the past 30 years. Compared to the last 30 years, January 2007 was also very dry. In contrast, October, April, and May were wet and all fell within the top 20% wettest since 1978 (Figure 5)

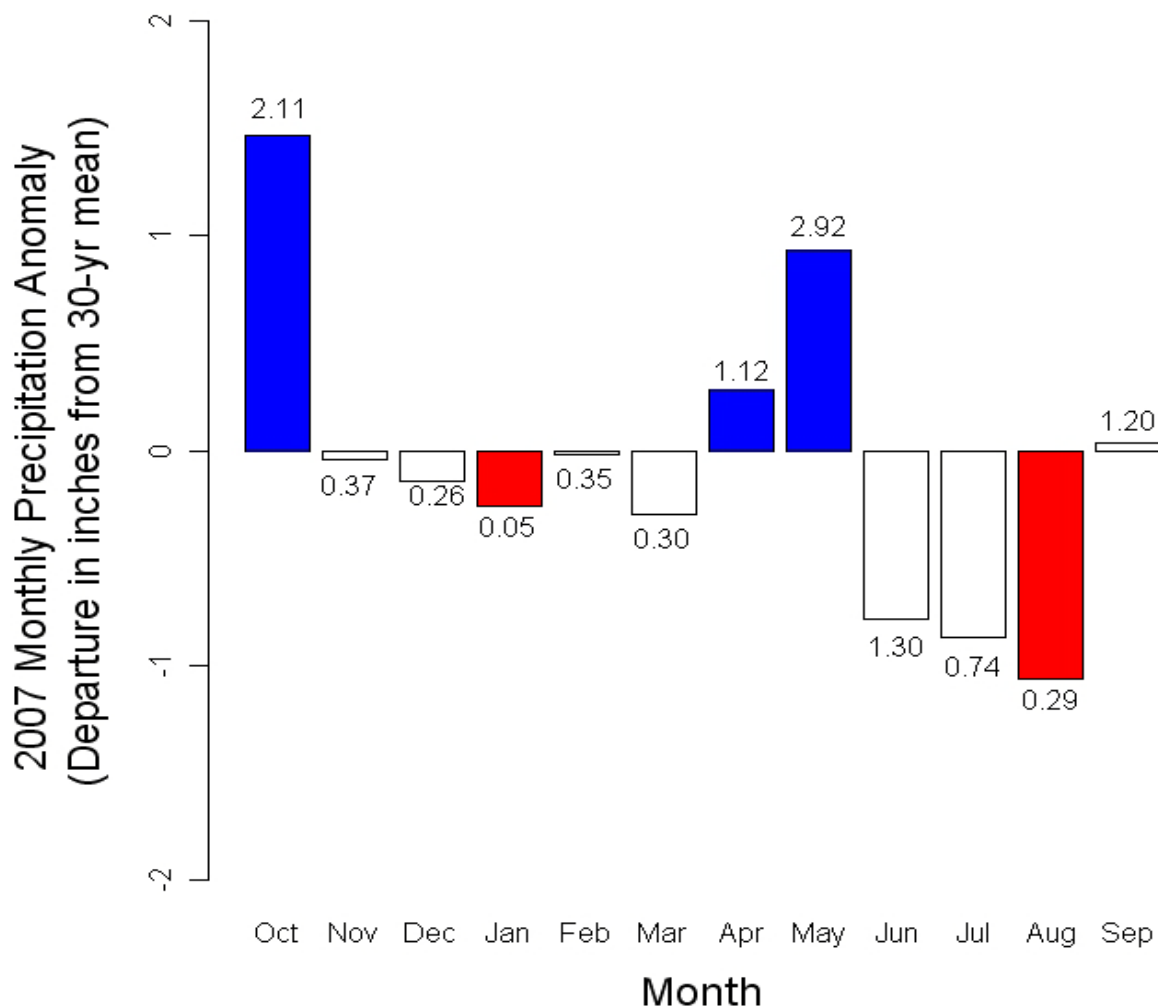


Figure 5. Monthly precipitation anomalies for the water year 2007 from Grant-Kohrs Ranch National Historic Site. Precipitation is derived from the park-wide index. The monthly total precipitation in 2007 is compared to the monthly mean total based on the last 30 years. Colored bars indicate that 2007 was in the top (blue) or bottom (red) 20% of the past 30 years. The values above or below each bar indicate the monthly total precipitation in inches. In 2007, August and January were both drier than most years since 1978 (>80%). October, April, and May were wetter than most years since 1978.

Despite a few wetter than average months, GRKO received 11.0 inches of precipitation which is slightly less than normal annual precipitation compared to the average of last 30 years, 11.7 inches (Figure 6). The past few years have also been fairly normal, but 2002-2004 water years were some of the wettest of the past 30 years. Unlike temperature, there has not been a significant linear trend in precipitation over this time period ($F_{1,27}=1.6$, $P=0.221$).

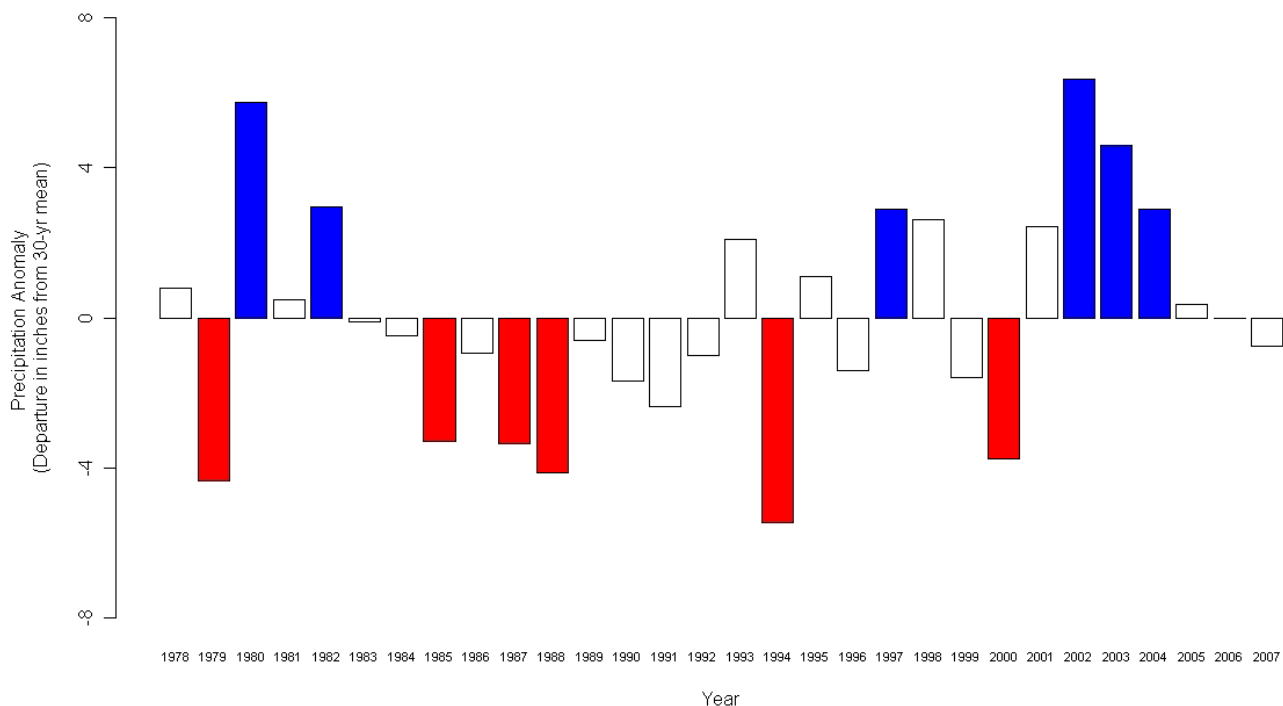


Figure 6. Annual precipitation anomalies from Grant-Kohrs Ranch National Historic Site for the water years 1978 -2007. Precipitation is derived from the park-wide index. The annual total precipitation for each year is compared to the mean of the last 30 years of 11.7 inches. Colored bars indicated the wettest (blue) and driest (red) years since 1978. Precipitation during 2007 was typical of the past 30 years.

For most months, GRKO was drier or had equivalent precipitation compared to the surrounding region (Figure 7). May and November were the wettest periods, particularly at higher elevations (Figure 7).

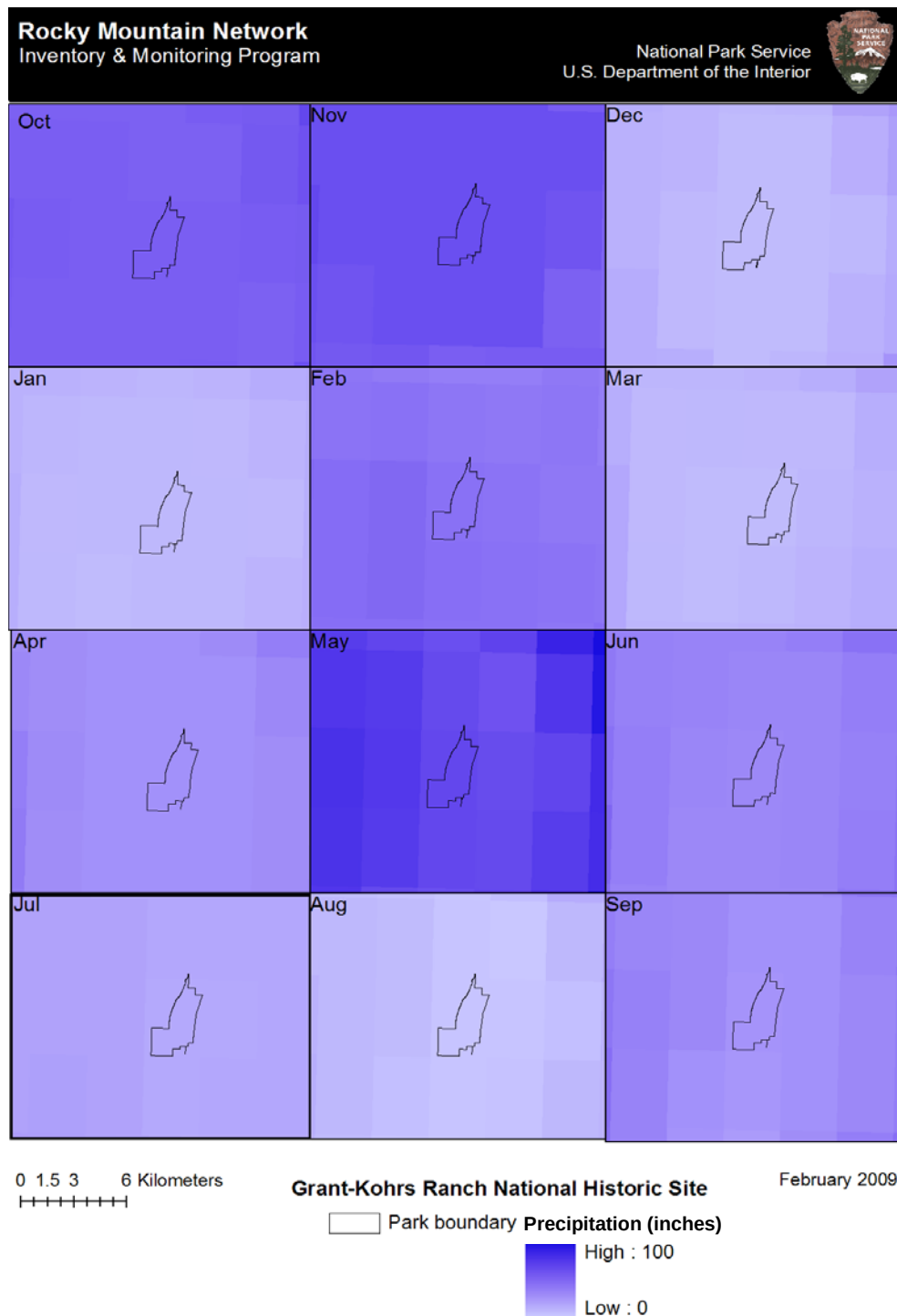


Figure 7. Monthly accumulated precipitation for Grant-Kohrs Ranch National Historic Site and surrounding region for the 2007 water year. Source: PRISM (2007).

Snow Water Equivalent

For SWE, the water year of 2007 (October 2006-April 2007) was typical of the past 30 years around GRKO (Figure 8). SWE is the amount of water contained within the snowpack and can be thought of as the depth of water that would theoretically result if the entire snowpack instantaneously melted. As with most years, April had the maximum mean SWE (18.3 in). May and June of 2007 had close to 3 in less SWE than normal, but were not in the lowest 20% of all years.

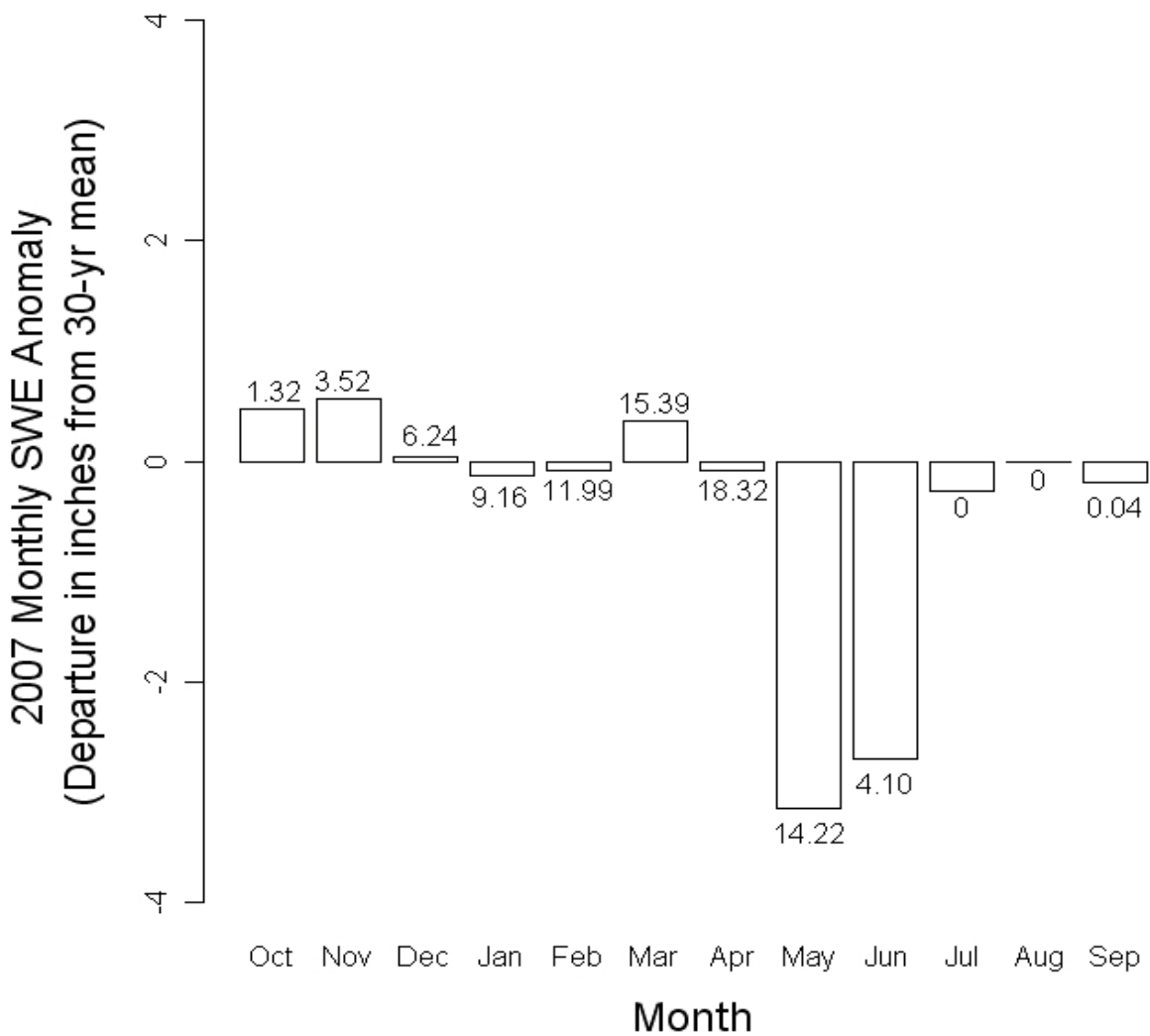


Figure 8. Monthly snow-water equivalent anomalies for the water year 2007 in the region of Grant-Kohrs Ranch National Historic Site. SWE are derived from the park-wide index. The monthly mean SWE in 2007 is compared to the monthly mean based on the last 30 years. Colored bars indicate that 2007 was in the top (red) or bottom (blue) 20% of the past 30 years. The values above or below each bar indicate the monthly average SWE in inches. Monthly SWE of 2007 was typical of the past 30 years.

Compared to the last 30 years, the SWE in April 2007 for the region around GRKO was almost exactly average (Figure 9). There is not a significant trend in SWE over the 30 years ($F_{1,27}=0.2$, $P=0.632$) which is contrary to findings that April 1 SWE from 1950-1997 has declined between 15-30% throughout much of Wyoming and Montana (Mote et al. 2005).

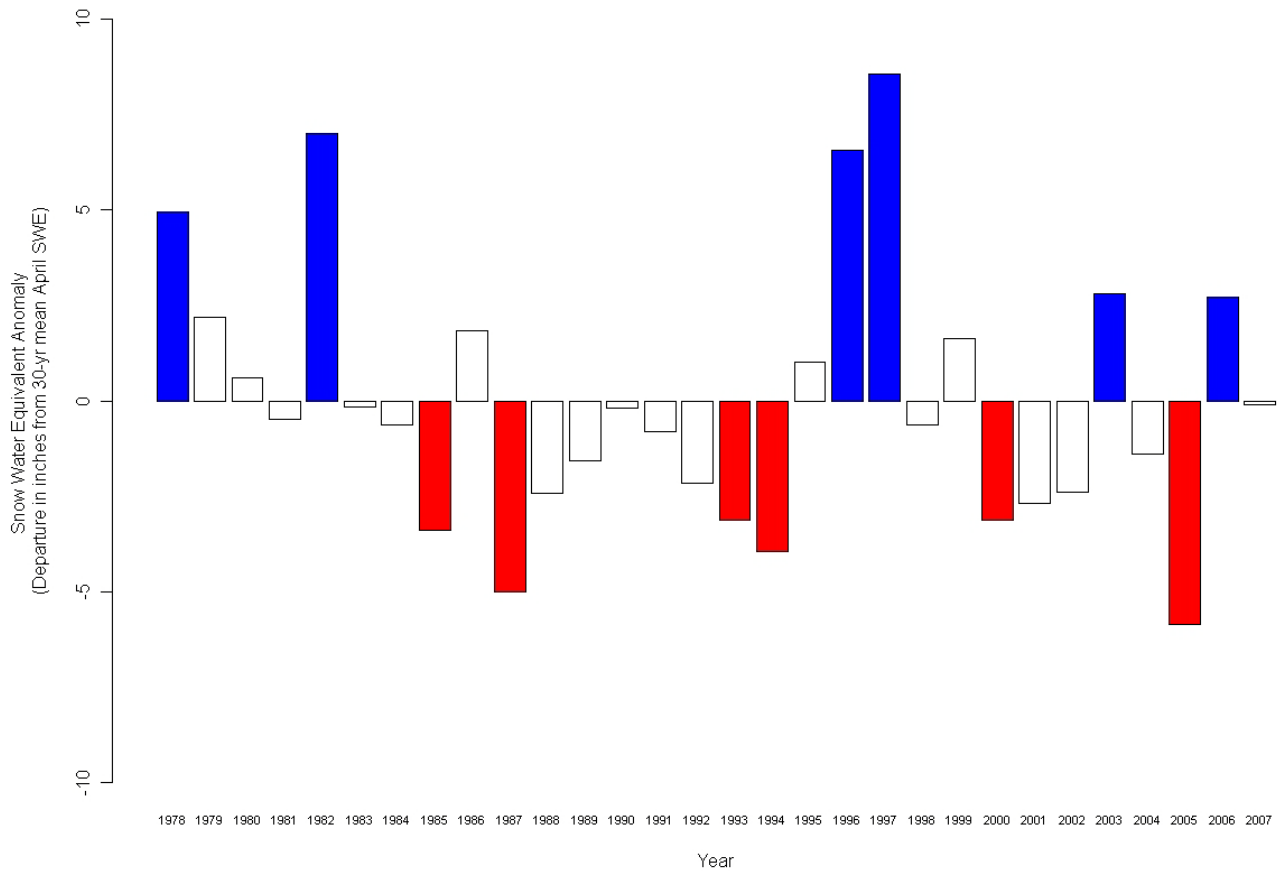


Figure 9. Snow-water equivalent anomalies in the region of Grant-Kohrs Ranch National Historic Site for 1978 -2007. SWEs are derived from the park-wide index. The mean SWE during April of each year is compared to the mean of the last 30 Aprils (18.4 in). April represents the month with the maximum SWE in this region. Colored bars indicated the wettest (blue) and driest (red) times since 1978. The SWE of 2007 was typical of the past 30 years.

Drought

The Palmer Drought Severity Index (PDSI) is a widely used index of temperature and rainfall information that represents the dryness of an area and is particularly suited for describing long-term drought (NWS-CPC 2008). Based on the PDSI, most months during the water year of 2007 at GRKO were drought-free (Figure 10). However, August and September 2007 had a moderate drought as indicated by PDSI values of less than -2 (Figure 10). 2007 was a dry year, but within the range of normal conditions for the area (Figure 11). This is in contrast to the early part of the 21st century that was characterized by five steady years of severe and extreme drought.

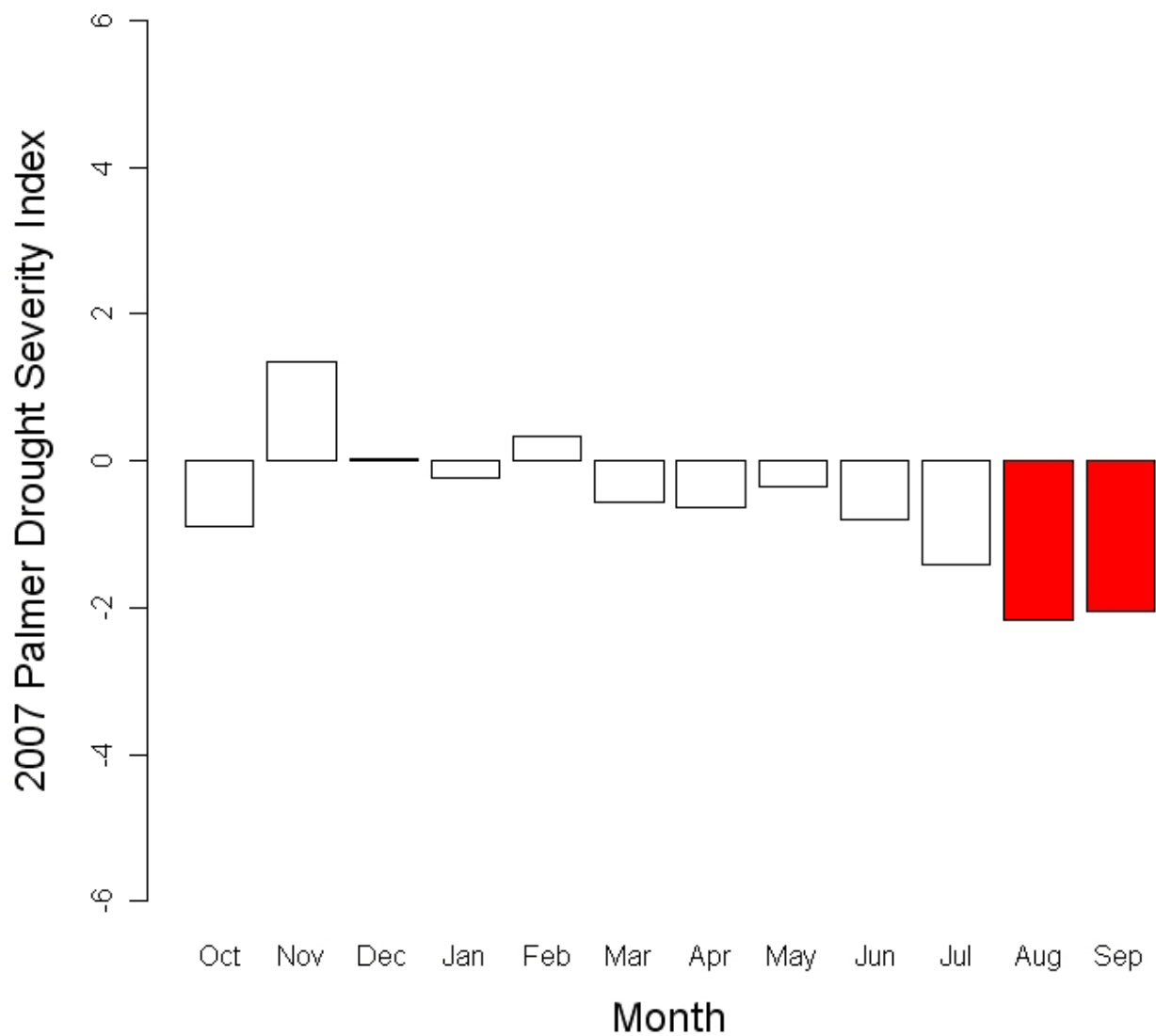


Figure 10. Monthly Palmer Drought Severity Index (PDSI) for Montana Climate Division 1, water year 2007. PDSI is an index value of normal (-1.99 to 1.99), drought (-2 to -2.99), severe drought (-3.0) to -3.99), extreme drought (<-4.00), moist (2 to 2.99) and very moist (> 3.00) conditions. Colored bars indicated wet (blue) or drought (red) conditions. For Grant-Kohrs Ranch National Historic Site, which is within Climate Division 1, August –September of 2007 was a period of drought.

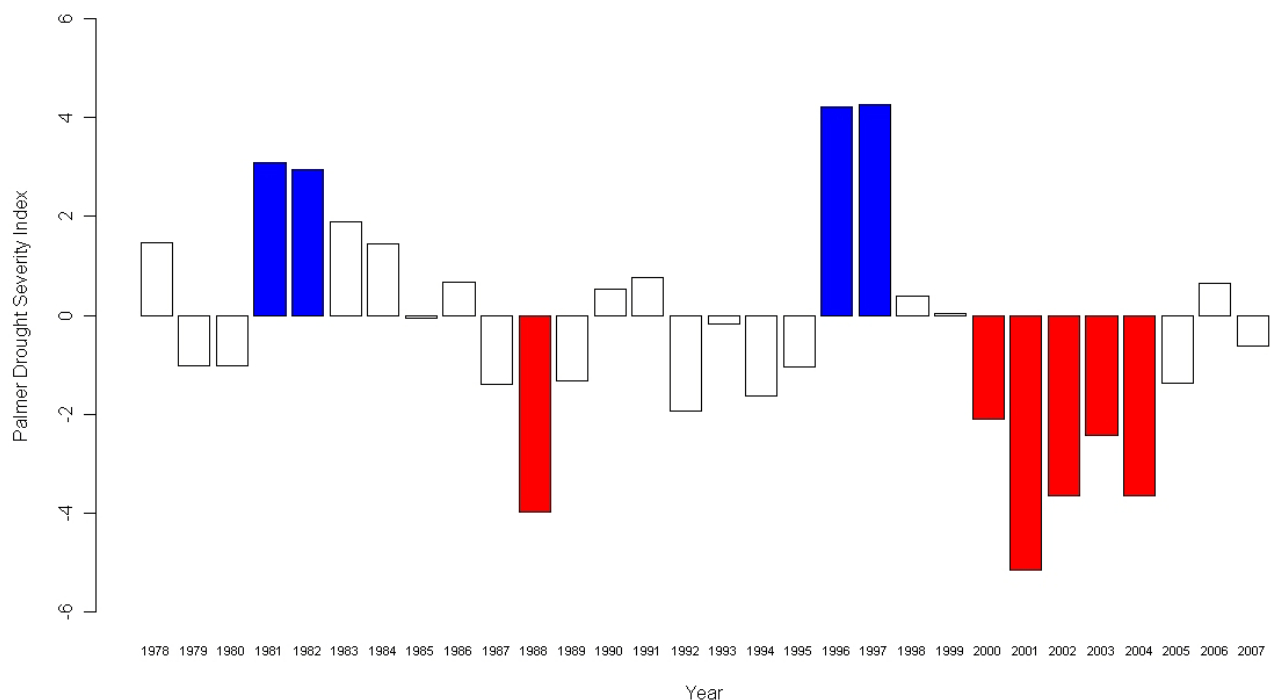


Figure 11. Annual average Palmer Drought Severity Index (PDSI) for Montana Climate Division 1 from 1978-2007. PDSI is an index value of normal (-1.99 to 1.99), drought (-2 to -2.99), severe drought (-3.0 to -3.99), extreme drought (<-4.00), moist (2 to 2.99) and very moist (> 3.00) conditions. Colored bars indicated wet (blue) or drought (red) conditions. For Grant-Kohrs Ranch National Historic Site, which is within Climate Division 1, drought conditions have been common during the past decade.

River Flow

As with drought, the daily flow in the Clark River at Deer Lodge, MT during 2007 was typical of the past 30 years (Figure 12). The exception to this was higher than average flow during the months of May and June and unusually low flows during the month of January.

Peak flow is a useful metric for snow-melt dominated systems such as the Clark Fork River. Peak flow which occurred in June was close to the 30 year average in 2007 at Deer Lodge (Figure 12), which represents a change from almost consistent below normal peaks since 2000. It is likely that snow melt in May and June (Figure 8) and drought-free conditions in the winter and spring of 2007 (Figure 10) contributed to the normal peak flow.

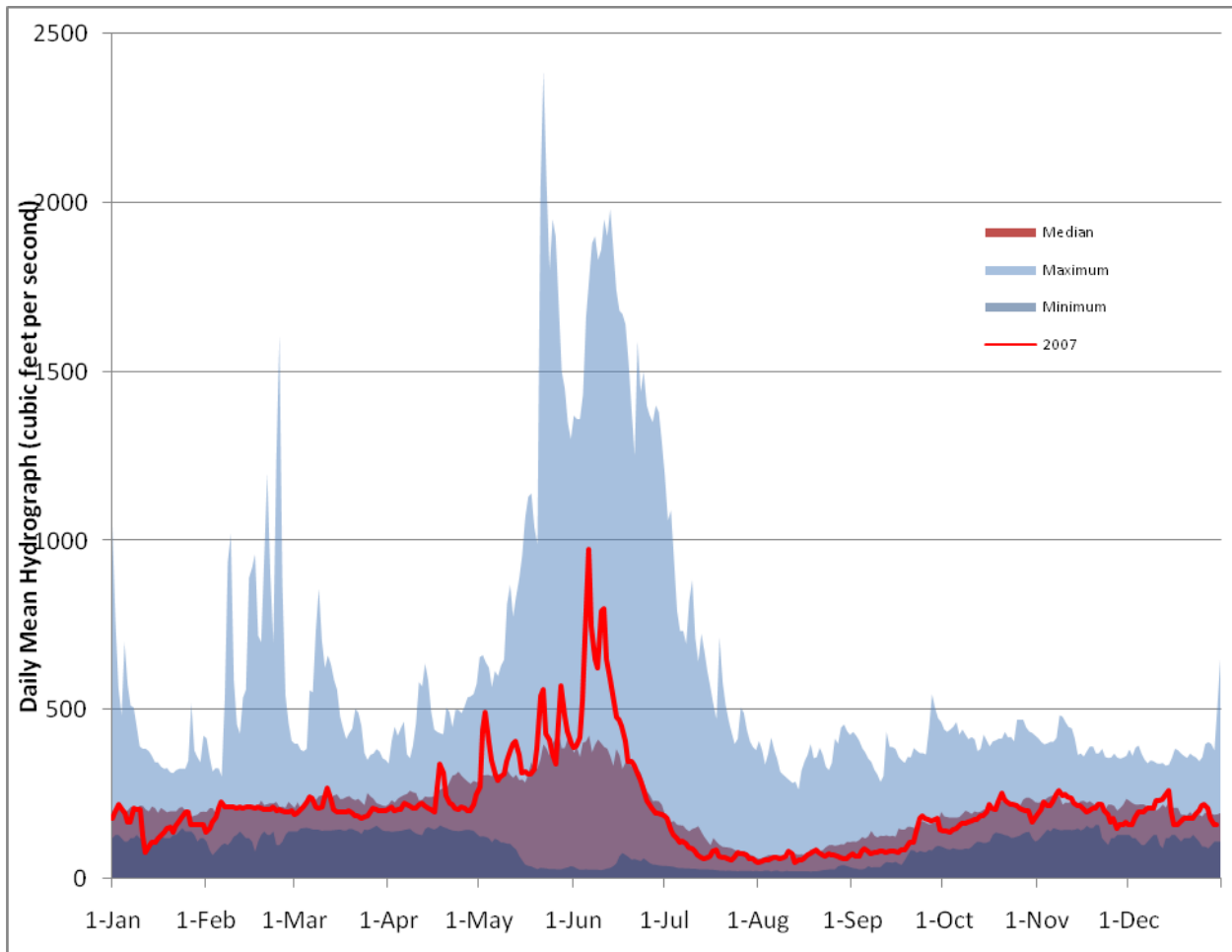


Figure 12. The 2007 daily mean hydrograph is measured in cubic feet per second (cfs), for the USGS Clark Fork River gage, directly upstream of Grant-Kohrs Ranch National Historic Site. The 30-yr median, maximum, and minimum flows are shown for comparison. Flows were higher than average during May and June 2007 but close to the lowest recorded during January 2007. Data from USGS (2009).

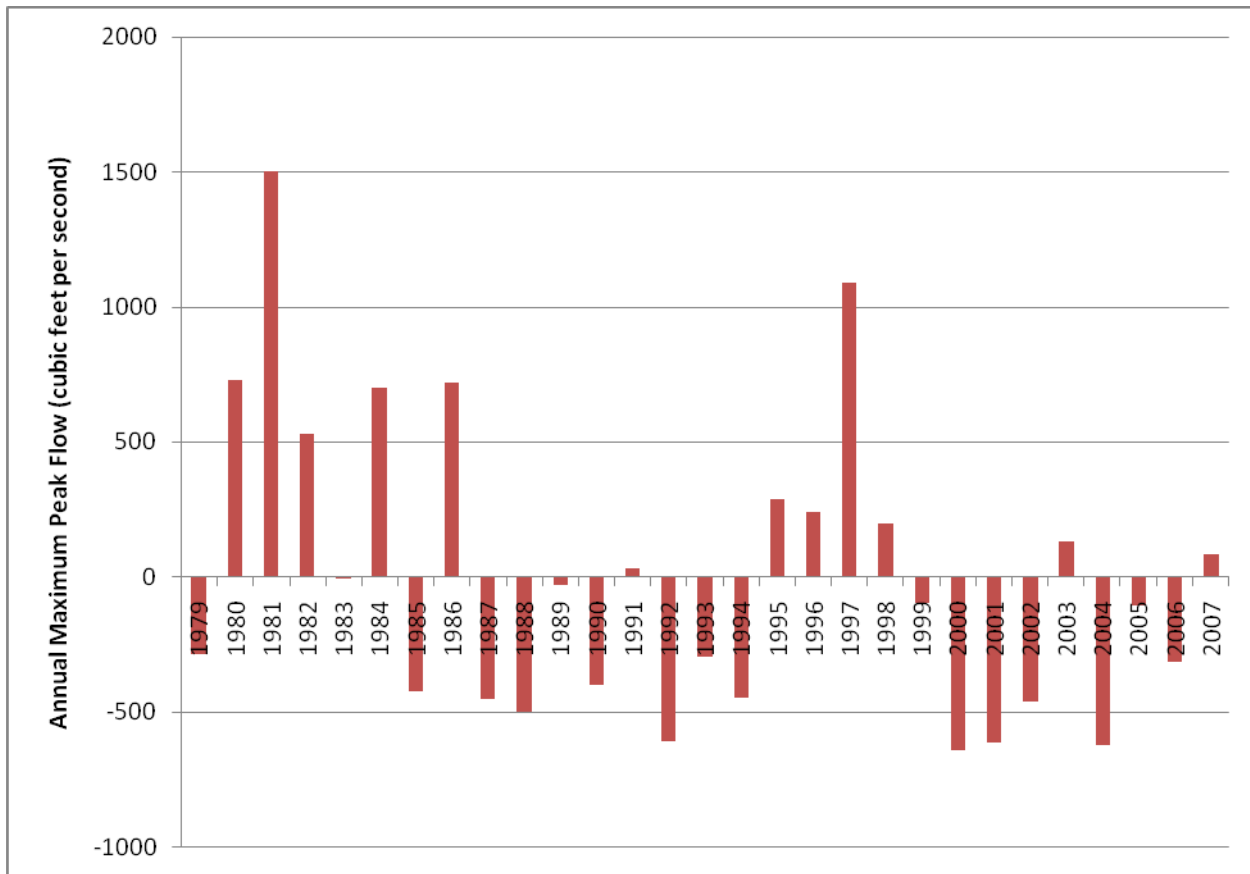


Figure 13. Annual peak flow (in cubic feet per second) departure from the 30-yr mean for the USGS Clark Fork River gage, directly downstream of Grant-Kohrs Ranch National Historic Site. Flow was about normal in 2007, after a number of years with low flows.

Correlation among Atmospheric Indices and Climate Parameters

The three atmospheric indices that best correlated with variation in climate at GRKO were the Atlantic Multi-decadal Oscillation (AMO), Tropical Northern Hemisphere (TNH) and the North Atlantic Oscillation (NAO). The AMO is based on variability in sea-surface temperatures in the North Atlantic, the TNH describes variability in the position of the jet stream in North America, and the NAO is based on winter variability in atmospheric pressure (Climate Prediction Center, 2008).

Average annual temperature correlated best with the AMO. AMO is generally correlated with precipitation and temperature across North America, with the strongest correlation with summer temperatures. AMO is currently in a warm phase, which tends to coincide with droughts within the US. We found a correlation between AMO and precipitation, but we did not detect a relationship between AMO and drought at GRKO. Instead, annual trends in precipitation and drought correlated best with the NAO. The NAO is generally associated with winter storm events in the Eastern US. To our knowledge, it is not often the best predictor of climate in the Western US. More detailed analysis and study of NAO and GRKO climate may help with understanding this relationship.

A correlation of the annual average SWE with the ocean/atmosphere indices suggests that the Climate Prediction Center's (CPC) Tropical/Northern Hemisphere (TNH) index may influence annual snow conditions (Table 3). This is consistent with the known pattern of positive TNH phases corresponding to

colder and drier conditions in the Western US (NWS-CPC 2008). More research and analyses will be needed to determine which atmospheric index correlates most strongly with the climate at GRKO. It will be interesting to determine if there is a strong enough relationship between the indexes to increase our ability to produce reasonable short and longer-term predictions of climate at GRKO.

Table 3. Correlation coefficients between the six atmospheric indices (NWS-CPC 2008) and the climate at Grant-Kohrs National Historic Site from 1978-2007. The park-wide index was used for temperature, precipitation, and snow water equivalent. The Palmer-Drought Severity Index was used to describe drought in Montana Climate Division 1 (Note: These are *preliminary* analyses for the prototype report; future analyses may include statistical interpretations).

Atmosphere / Ocean Index	Temperature (mean F)	Precipitation (total inches)	Snow-Water Equivalent (mean inches)	Drought (PDSI)
Atlantic Multi-decadal Oscillation (AMO)	0.44	0.46	-0.20	0.06
North Atlantic Oscillation (NAO)	-0.40	-0.47	-0.16	-0.35
Pacific Multi-decadal Oscillation (PDO)	0.18	-0.14	0.05	-0.09
Pacific North American Pattern (PNA)	0.40	0.20	-0.15	0.03
Southern Oscillation Index (SOI)	-0.21	0.06	-0.03	0.21
Teleconnection Northern Hemisphere (TNH)	-0.19	-0.29	-0.25	-0.31

Conclusions

1. Maximum temperatures for GRKO were above normal in 2007. Locally and regionally, maximum temperatures were unusually high during the summer months, especially in July. Over the past 30 years, 2007 was also one of the warmest on record, especially at the park scale (Figure 3).
2. Compared to the last 30 years, precipitation, snow-water equivalents, and river flow during 2007 were normal (Figure 6, 9 and 13, respectively). August was a dry month (Figure 5), resulting in a moderate drought in August and September (Figure 10). Overall, however, 2007 was not a drought year (Figure 11).
3. The AMO may be a useful predictor of annual temperature and precipitation at GRKO.
4. In general, there has been an increase in temperature, decrease in SWE, and trend toward earlier peak flows throughout the Western US during the last 50 or so years associated with human impacts on the atmosphere (Barnett et al. 2008). These trends are expected to continue in the absence of drastic policy changes (Barnett et al. 2008). Since the trends in the local climate at GRKO have been consistent with models of the Western US, predictive models of climate and hydrology in the West should provide meaningful insights into future GRKO climate. In other words, it is reasonable to expect that GRKO will continue to experience hotter years in the future.

Literature Cited

- AMS [American Meteorological Society]. 2009. Glossary of Meteorology, 2nd edition. <<http://amsglossary.allenpress.com/glossary>>. Viewed 2009 January.
- Barnett T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A. A. Mirin, D.R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the Western United States. *Science* 319: 1080.
- CDC [Climate Diagnostics Center]. 2007. Northern Hemisphere Teleconnection Patterns, <<http://www.cpc.noaa.gov/data/teledoc/telecontents.shtml>>. Viewed October 2007.
- Frakes, B., J. Burke, I. Ashton, and D. Pillmore (in preparation) Weather and Climate Protocol. The Rocky Mountain Inventory and Monitoring Network, National Park Service.
- Mote, PW, AF Hamlet, MP Clark, and DP Lettenmaier. 2005. Declining mountain snowpack in Western North America. *Bulletin of the American Meteorological Society* 86 (1):39-49.
- NOAA-NCDC [National Oceanic and Atmospheric Administration, National Climatic Data Center]. 2007. Climate Division Data. <<http://www.ncdc.noaa.gov/oa/ncdc.html>>. Viewed on October 2007.
- NOHRSC [National Operational Hydrologic Remote Sensing Center]. 2004. Snow Data Assimilation System (SNODAS) data products at NSIDC [National Snow and Ice Data Center]. Boulder, CO. <http://nsidc.org/data/docs/noaa/g02158_snodas_snow_cover_model/index.html>. Viewed on October 2007.
- NRCS [Natural Resource Conservation Service]. 2007a. SNOTEL Data and Products. <<http://www.wcc.nrcs.usda.gov/snow/>>. Viewed on October 2007.
- NRCS [Natural Resource Conservation Service]. 2007b. Snow Course and Monthly SNOTEL Historical Data. <<http://www.wcc.nrcs.usda.gov/snow/snowhist.html>>. Viewed on October 2007.
- NWS-COOP [National Weather Service Cooperative Network]. 2007. Cooperative Observer Program, Locate Weather Observation Station Record. <<http://www.ncdc.noaa.gov/oa/climate/stationlocator.html>>. Viewed on October 2007.
- NWS-CPC [National Weather Service, Climate Prediction Center]. 2008. Climate Prediction Center. <http://www.cpc.noaa.gov/products/monitoring_and_data/us.shtml>. Viewed on October 2007.
- PRISM [Parameter-elevation Regressions on Independent Slopes Model]. 2007. PRISM Group. Oregon State University, Corvallis, OR. <<http://prism.oregonstate.edu>>. Viewed on October 2007.
- Schoennagel, T., T. T. Veblen, W.H. Romme, J.S. Sibold, and E.R. Cook. 2005. ENSO and PDO variability affect drought -induced fire occurrence in rocky mountain subalpine forests. *Ecological Applications* 15(6):2000-2014.
- USGS [U.S. Geologic Survey]. 2009. National Water Information System: Web Interface. <<http://waterdata.usgs.gov/nwis>>. Viewed on October 2008.

Appendix A. Common Climate Acronyms

Many acronyms are used in this report to describe climate parameters, units, agencies, and global atmospheric indices. Here, we include the main ones that appear in order to facilitate understanding. They are listed in no particular order except that the six atmospheric indices that are used in the report appear at the bottom after the Climate Prediction Center (CPC) acronym that produces them.

Table 4. Common acronyms used in this report.

Acronym	Definition and source
NRCS-SC	National Resource Conservation Service – Snow Course
NOAA	National Oceanographic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NSIDC	National Snow and Ice Data Center
COOP	National Weather Service Cooperative Network
SNOTEL	Snowpack Telemetry– the Natural Resource Conservation Service snowpack and related climate data monitoring network
TMAX	ROMN produced index to quantify maximum daily temperature for a park
PPT	ROMN produced index to quantify total daily precipitation for a park
SWE	ROMN produced index to quantify mean snow water equivalence for the snow pack in a park. Otherwise simply Snow Water Equivalence at SNOTEL or Snow Course sites to identify the water contents of a column of snow.
PRISM	Parameter-elevation Regressions on Independent Slopes Model; Oregon State University
SNODAS	Snow Data Assimilation System from the National Snow and Ice Data Center (NSIDC)
CFS	Cubic feet per second
PDSI	NOAA's Palmer Drought Severity Index reported with Climate Division Statistics
CPC	NOAA's Climate Prediction Center – It produces the following six atmospheric indices
AMO	Atlantic Multi-Decadal Oscillation
PDO	Pacific Decadal Oscillation
PNA	Pacific North America atmospheric index
SOI	Southern Oscillation Index (i.e., El Niño and La Niña)
NAO	North Atlantic Oscillation atmospheric index
TNH	Tropical/Northern Hemisphere atmospheric index

Appendix B. Supplementary Tables

Table 5. Inventory of all climate data collected for the 2007 Annual Climate Report of Grant-Kohrs Ranch National Historic Site.

Station Name	Station ID	Elevation (m)	Distance to GRKO (km)	Begin	End
SNOTEL - ROCKER PEAK	12c11s	2438	38.428	1967	Present
SNOTEL - WARM SPRINGS	13c43s	2377	35.397	1977	Present
COOP - ANACONDA	240199	1609.3	33.237	1894	Present
COOP - DEER LODGE	242273	1382.0	1.962	1893	1959
COOP - DEER LODGE 3 W	242275	1478.3	4.123	1959	Present
COOP - DRUMMOND AVIATION	242500	1219.2	42.495	1963	Present
COOP - DRUMMOND FAA AP	242511	1293.0	42.404	1927	1963
COOP - EAST ANACONDA	242604	1681.0	35.324	1905	1980
COOP - EAST ANACONDA 2	242606	1585.3	34.264	1980	1982
COOP - WARM SPRINGS CREEK	248687	1478.9	23.732	1909	1912
SNODAS - Snow Data Assimilation System from NOAA, NOHRSC		Gridded GIS		10/1/2003	Present
PRISM - Parameter-elevation Regressions on Independent Slopes Model		Gridded GIS		1971	June,2008
Clark Fork River Flow Data, Deer Lodge USGS	2324200	1372.3		1978	present

Table 6. The maximum (red), average (black) and minimum (blue) temperatures (Fahrenheit) for three weather stations near Grant-Kohrs Ranch National Historic Site during the 2007 water year. Temperatures are rounded to the nearest whole degree.

Stations	Temp	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Summary
240199 Anaconda	Max	55	44	37	34	40	52	56	66	76	90	82	70	90
	Avg	42	33	26	23	29	39	42	51	59	71	63	54	44
	Min	29	22	15	12	19	26	28	36	43	53	45	38	12
242275 Deer Lodge 3 W	Max	56	44	35	32	38	53	56	66	73	88	82	70	88
	Avg	41	31	25	23	27	39	41	50	57	68	61	51	43
	Min	25	19	15	10	16	25	27	33	40	49	40	32	10
242500 Drummond Aviation	Max	58	42	32	33	40	55	59	69	79	95	84	73	95
	Avg	43	31	22	22	31	41	43	52	60	72	62	54	44
	Min	28	20	13	12	22	27	27	34	41	50	39	35	12

Table 7. The 2007 maximum 24-hour (blue), total accumulated (black), and number of precipitation days (green) by month for stations near Grant-Kohrs Ranch National Historic Site. Precipitation is measured in inches.

Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Summary
ANACONDA 240199	.84 2.34 13	.34 1.17 12	.24 .69 9	.08 .3 9	.41 1.08 16	.57 .97 9	1.14 1.98 12	1.04 3.5 14	.47 1.62 9	.87 1.24 9	.14 .59 9	.92 1.83 11	1.14 17.31 132
DEER LODGE 3 W - 242275	.48 2.11 8	.18 .36 3	.14 .25 2	.04 .04 1	.18 .33 3	.2 .29 4	.97 1.1 3	1.1 2.91 9	.45 1.29 4	.26 .73 6	.15 .29 3	.75 1.18 4	1.1 10.88 50
DRUMMOND AV. - 242500	.62 1.73 7	.11 .46 11	.24 .56 8	.02 .13 8	.28 1.04 14	.23 .35 4	.84 1.36 9	1.06 2.71 12	.8 1.89 9	.8 .98 3	.08 .13 3	1.1 1.89 9	1.1 13.23 97
ROCKER PEAK SNTL – 12c11s	.7 3.9 12	.3 1.8 18	.3 1.9 13	.3 1.3 8	.3 2.7 18	.3 1.9 13	.5 2.0 13	1.3 4.6 13	1.1 3.0 9	.4 1.3 5	.9 1.3 4	.4 2.2 11	1.3 27.9 137
WARM SPRGS SNTL – 13c43s	1.3 4.0 14	.5 4.2 23	.7 3.4 17	.7 2.6 13	.8 5.6 20	.5 3.3 15	.6 3.4 20	1.5 6.1 15	1.5 4.7 15	.2 .3 2	.3 .6 4	.5 2.2 9	1.5 40.4 167

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

National Park Service
U.S. Department of the Interior



Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov