



Greater Yellowstone Network

Climate of 2009

Natural Resource Report NPS/GRYN/NRR—2010/262



ON THE COVER

Yellowtail Dam and Bighorn Lake, Bighorn Canyon National Recreation Area
Courtesy of Bighorn Canyon National Recreation Area

Greater Yellowstone Network

Climate of 2009

Natural Resource Report NPS/GRYN/NRR—2010/262

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Executive summary

This report describes the climate of 2009 for parks in the Greater Yellowstone Inventory and Monitoring Network (GRYN) and surrounding areas. The GRYN comprises Bighorn Canyon National Recreation Area, Grand Teton National Park (including John D. Rockefeller, Jr. Memorial Parkway), and Yellowstone National Park. This report focuses on temperature and precipitation, while providing supplemental information on snowpack, streamflow, and the GRYN area drought status. The report includes a series of maps that convey GRYN area climatic conditions, as well as records from individual observing stations used to highlight variability at finer-scales within the GRYN.

When averaged across the entire calendar year, 2009 precipitation was near to slightly above the 1971–2000 average in Yellowstone and Grand Teton national parks, and somewhat below average in Bighorn Canyon National Recreation Area. Average maximum temperature (T_{max}) and average minimum temperature (T_{min}) were roughly average to slightly below average across the GRYN. In Yellowstone and Grand Teton, snow water equivalent was close to average during most of the water year, but spring storms pushed April and May snowpack above average at some key stations. In the Bighorn Mountains, snowmelt was more rapid than usual, but this was offset by above average peak snowpack at some locations, producing melt out dates very close to average. Total annual runoff in GRYN streams was 90–122% of 1971–2000 averages. Calendar year 2009 continued the recovery from drought that began in 2008. The wet months of June and October balanced unusually dry September, November, and December. By the end of the year, only the northern portions of Bighorn Canyon had any drought classification.

1 Introduction

1.1 Background

Climate is a primary driver of almost all physical and ecological processes in the Greater Yellowstone Inventory and Monitoring Network (GRYN). The effects of climate are especially visible in the strong zonation and steep elevational gradients displayed by vegetation types in the Greater Yellowstone Ecosystem (GYE) (Despain 1990). Because Yellowstone and Grand Teton national parks are major sources of runoff for the Columbia and Missouri River basins, climate variability in the GRYN has profound implications across large portions of North America. It is imperative that the parks of the GRYN have a climate monitoring system in place that allows for the characterization of GRYN climate and provides climate data for use in monitoring and predicting the dynamics of other natural resource vital signs.

This report is the third installment in an annual series detailing the climate (temperature, precipitation, snowpack, drought, and streamflow) of the GRYN. The GRYN comprises three National Park Service units: Bighorn Canyon National Recreation Area, Grand Teton National Park (including the John D. Rockefeller, Jr. Memorial Parkway), and Yellowstone National Park.

The purpose of the GRYN annual climate report series is twofold: First, these reports detail recent climatic events from both local (single weather stations) and park-level perspectives. Second, these reports place GRYN climate in a regional setting, and consider recent events in a historical context, based primarily on a standard 30-year climatological reference or “normal” period (currently 1971–2000). The content is generally divided into discussions of precipitation and temperature and further sub-divided into regional- and station-level reviews. Information on recent precipitation and temperature variability is supplemented by sections on snowpack, streamflow, and GRYN area drought status. The locations of stations cited in this report are shown in figures 1 and 2. Links to all stations used in this report and station metadata are available in appendices A, B, and C.

Those interested in additional climate-related information for the GRYN and surrounding areas should seek:

- Western Regional Climate Center (<http://www.wrcc.dri.edu/>)
- Western Water Assessment (<http://wwa.colorado.edu/>)
- Drought Monitor (<http://drought.unl.edu/dm/monitor.html>)
- NOAA (National Oceanic Atmospheric Administration) National Weather Service Climate Prediction Center (<http://www.cpc.ncep.noaa.gov/>)
- Natural Resources Conservation Service National Water and Climate Center (<http://www.wcc.nrcs.usda.gov/>)
- USGS (U.S. Geological Survey) Water National Information System (<http://waterdata.usgs.gov/nwis>)

- Idaho State Climate Services (<http://snow.ag.uidaho.edu/index.html>)
- Montana Climate Office (<http://www.cfc.umt.edu/mco/>)
- Wyoming State Climate Office (<http://www.wrds.uwyo.edu/wrds/wsc/wsc.html>)

1.2 Approach and methodology

Yellowstone and Grand Teton national parks can be divided into four climate zones (Tercek et al., forthcoming; fig. 1). Zone 1 weather stations are located in or near the northern range of Yellowstone National Park, which recognized as an ecological unit containing distinct vegetation, as well as being the winter home of Yellowstone’s northern elk herd (National Research Council 2002). This part of Yellowstone experiences its highest precipitation during late spring and early summer months (May and June). Zone 1a weather stations have patterns of seasonal and long-term variability similar to zone 1, but they are located primarily southwest of Yellowstone and Grand Teton. Zone 2 weather stations are located on Yellowstone’s central plateau and in Grand Teton, and have highest precipitation during winter months. Zone 2a stations are located in high elevation areas in eastern Yellowstone (fig. 1). Even though the map (fig. 1) shows zone 2a overlapping to some degree with zone 2 (fig. 1), zone 2a differs from other parts of the GRYN because it had long-term climatic patterns, during the period 1895–2008, that were similar to zone 1 during the summer and to zone 2 during the winter (Tercek et al., forthcoming).

Given the relatively sparse network of climate stations and complex topography of the GRYN area, grid-based estimates of precipitation and temperature were used to provide an overview of climatic conditions in the area. These estimates are generated via a statistical modeling technique that interpolates precipitation and temperature values between actual climate observing stations while also accounting for the effects of aspect and elevation. Known as the Parameter-elevation Regression on Independent Slopes Model (PRISM; <http://www.prism.oregonstate.edu/>), this approach has a long history of use in the western United States, and it has been shown to provide highly robust products in a wide variety of studies (Daly et al. 2008). Records from individual precipitation and temperature observing stations are included as a way to highlight intra-regional variability. Snowpack and streamflow measurements are presented as both integrators of multiple aspects of GRYN area climate (e.g., temperature, precipitation, relative humidity) and as key drivers of ecosystem processes. In the final section, drought conditions “broad brush” overview of GRYN area climates throughout the year.

The GRYN parks and surrounding areas are home to dozens of networks and sensor platforms monitoring a wide range of climatic and hydrological variables. The process of selecting networks and specific stations included in this report is described in the Rocky Mountain Climate Protocol (Rocky Mountain Climate Working Group 2010). Generally, the selection criteria were:

1. Networks and stations provide good spatial coverage within the GRYN—networks and stations represent the major climatic and ecological zones within the parks and surrounding areas.
2. Networks and stations provide a sufficient length of record to allow the assessment of trends and provide historical context for current observations.

3. Instrumentation at individual stations is relatively consistent over the life of the record.
4. Instrumentation and siting standards used in selected networks are suitable for providing consistent, continuous, and long-duration records of climate and streamflow.

The agencies responsible for the initial data collection (e.g., National Weather Service) and the parties responsible for archiving these data (e.g., Western Regional Climate Center) performed basic quality control measures. The report authors also performed a series of quality checks involving visual inspection of the time series, comparison with historical observations and observations from surrounding sites, and logical consistency tests (e.g., confirming that minimum daily temperatures were lower than the daily maximum temperatures). In the case of National Weather Service Cooperative Observer (COOP) station data, the authors compared archived observations with the original datasheets provided by observers. Point observations provided by the COOP stations were also compared to corresponding estimates from the PRISM datasets.

Results for temperature, precipitation, and drought are reported on a calendar-year basis. Results for snowpack or snow water equivalent (SWE) and streamflow are reported for the water year (previous October through current September—October 2008 through September 2009 in this report), to capture the full winter contribution to GRYN area moisture status and hydrology. Following standard climatological practice, temperature, precipitation, and snowpack observations for the reporting year are compared against a 30-year climatological reference or “normal” period (currently 1971–2000). Lists of individual stations used in this report and links to station data are found in the appendices.

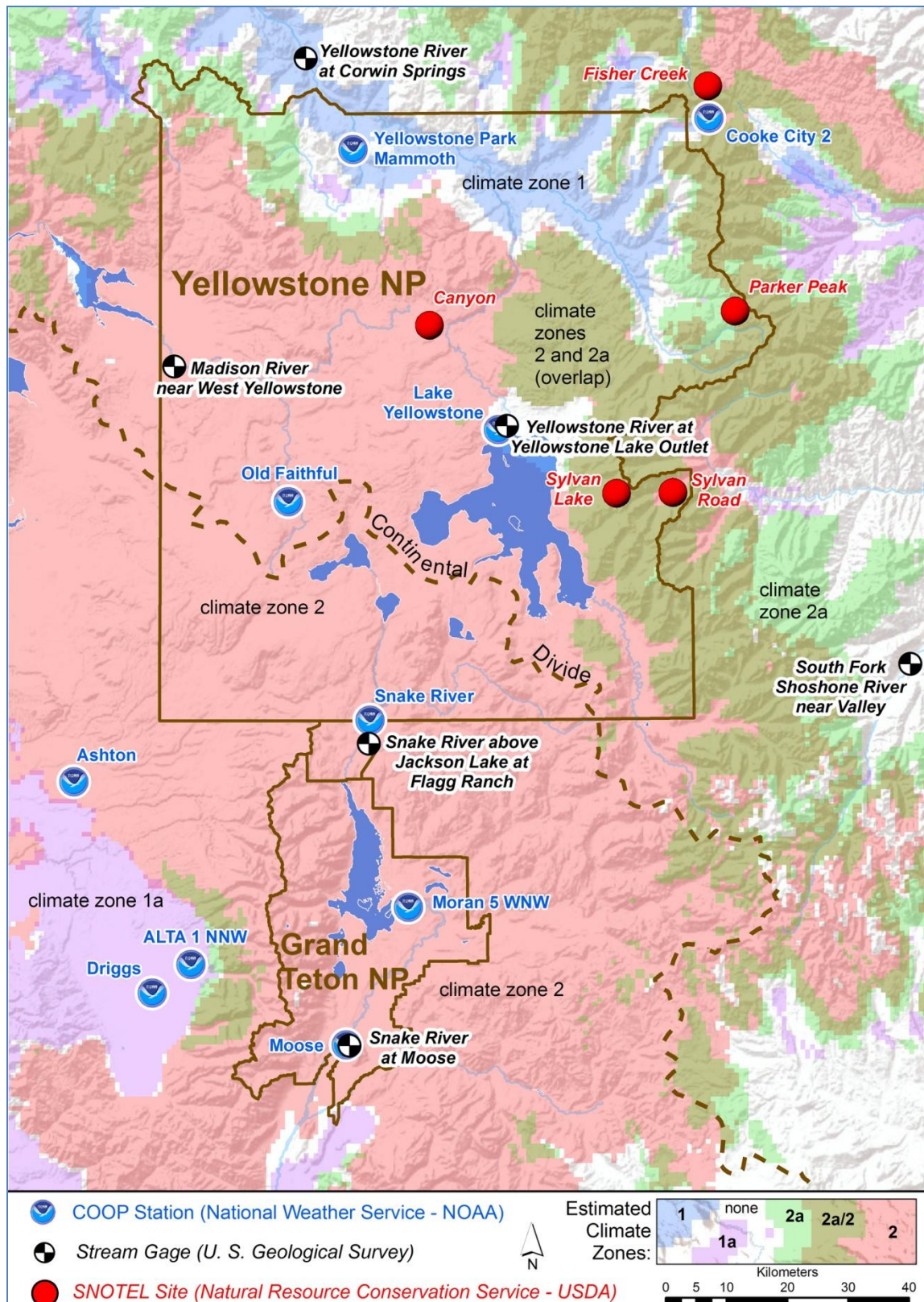


Figure 1. Map showing key climate stations and stream gauges in and near Yellowstone and Grand Teton National Park. Estimated climate zone boundaries are shown in the background. Darker green areas indicate overlap between zones 2 and 2a.

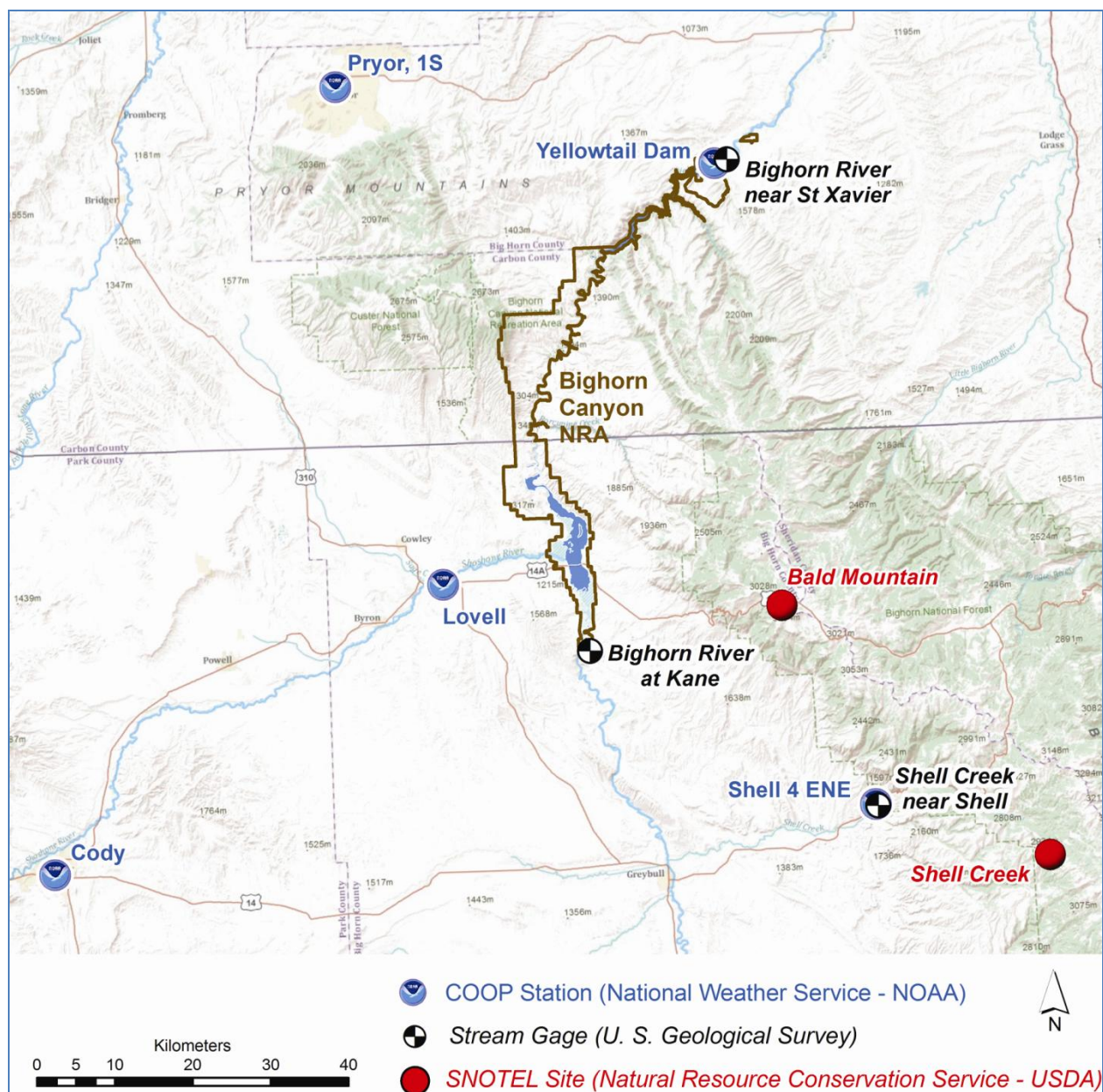


Figure 2. Map showing key climate stations and stream gauges in and near Bighorn Canyon National Recreation Area.

2 Regional summaries: Grid maps showing departure from 1971–2000 averages

2.1 Precipitation

Grid-based estimates of precipitation generated via the PRISM approach were used to provide an overview of precipitation conditions in the GRYN (fig. 3). This section provides only a generalized description of conditions. It is important to remember that there was significant variability across the region, and some areas did not follow the patterns described here.

When averaged across the entire calendar year, 2009 precipitation was near average to slightly above average in Yellowstone and Grand Teton, and somewhat below average in Bighorn Canyon.

Following relatively wet conditions in December 2008 (Gray et al. 2009) and January and February 2009 became progressively drier (fig. 3). In January, west-central Yellowstone and northern Grand Teton had roughly 50–95% of 1971–2000 average precipitation, while southern Grand Teton and eastern Yellowstone maintained above average precipitation (fig. 3). By February, all three GRYN park units had below average precipitation, with some areas south of Bighorn Canyon experiencing less than 25% average.

March and April saw a return to wetter conditions in Yellowstone and Grand Teton (fig. 3). Some higher elevation areas experienced more than 200% average precipitation in April. Northern Bighorn Canyon experienced increased precipitation during March, but there was less recovery in the south. By April, all of Bighorn Canyon had again become drier, with southern regions experiencing less than 75% average precipitation.

Late spring and early summer were characterized by a marked shift toward wetter conditions (fig. 3). During May, conditions across the GRYN ranged from near average to quite dry, with most of Yellowstone and Grand Teton experiencing 75–95% average precipitation and Bighorn Canyon below 25% in some areas. In contrast, June was unusually wet, with large portions of all three GRYN units experiencing more than 200% average precipitation.

July and August had variable precipitation throughout the region (fig. 3). Much of the GRYN experienced near average precipitation during August, but some of the areas that were drier than average during July, such as southern Yellowstone and Grand Teton (50–75% of average), returned to near average precipitation during August. In contrast, Bighorn Canyon had below average precipitation during both months, and some parts of that park experienced only 25–50% average precipitation during August.

The last third of 2009 brought a series of wet–dry oscillations (fig. 3). September was quite dry throughout the entire GRYN, with most of the region experiencing less than 50% precipitation. In contrast, October precipitation was 125–175% of average in most of the GRYN, with the exception of southern Bighorn Canyon. November was once again quite dry, with less than 50% average precipitation in many locations. Dry conditions were somewhat ameliorated in December, but precipitation remained far below average overall.

2.2 Temperature

As with temperature, grid-based estimates generated via the PRISM approach were used to provide an overview of temperature conditions in the GRYN (figs. 4 and 5). This section provides only a generalized description of conditions. It is important to remember that there was significant variability across the region, and some areas did not follow the patterns described here.

When averaged across the entire calendar year, average maximum temperature (Tmax) and average minimum temperature (Tmin) were roughly average to moderately below the 1971–2000 average across the GRYN.

Despite an unusually cool December 2008 (Gray et al. 2009), the winter months of 2009 were in most locations near average to moderately warmer than the 1971–2000 average (figs. 4 and 5). During January and February, average Tmax and average Tmin generally were 0–4°F above the 1971–2000 averages throughout most of the region. Scattered areas were warmer.

Overall, early spring temperatures were near average, but there was significant variability throughout the GRYN (figs. 4 and 5). In Yellowstone and Grand Teton, daytime temperatures (Tmax) in most locations increased slightly from 0–2°F above average in March to 2–4°F above average in April; and nighttime temperatures (Tmin) were generally near average to moderately (up to 4°F) above average for both months. In Bighorn Canyon, most locations saw daytime temperatures move from slightly (1–2°F) below average in March to moderately (2–4°F) below average in April, while nighttime temperatures had the opposite trend.

In general, temperatures throughout the region became cooler than average as late spring turned to early summer, but the opposite trend occurred in some areas (figs. 4 and 5). In most of Yellowstone and Grand Teton, Tmax moved from roughly 0–4°F above average in May to roughly 0–4°F below average in June, while Tmin was near average to slightly above (as much as 2°F) average during this period. In most of Bighorn Canyon, Tmax moved from slightly above average in May to roughly 2–8°F below average in June, while Tmin during this period remained either near average or decreased to slightly below average.

During July and August, most areas in Yellowstone and Grand Teton had daytime temperatures (Tmax) that ranged from near average to roughly 2°F below average, and nighttime temperatures (Tmin) that were generally near average. Bighorn Canyon had cooler Tmax values, which were 2–4°F below average to the north of the recreation area and 2–8°F below average to the south (figs. 4 and 5).

The last third of 2009 brought warm–cold oscillations that somewhat reflected the precipitation patterns for this period, described in the last section of this report. September was quite warm throughout the GRYN, with Tmax 4–6°F, and Tmin 2–4°F above average in many areas. In contrast October was unusually cold, with Tmax more than 6°F below average, and Tmin 2–4°F below average. November was again warm, with day and nighttime temperatures roughly 2–6°F above average in most locations; and December was unusually cool, with Tmax generally 2–8°F below average and Tmin 2–6°F below average at most locations (figs. 4 and 5).

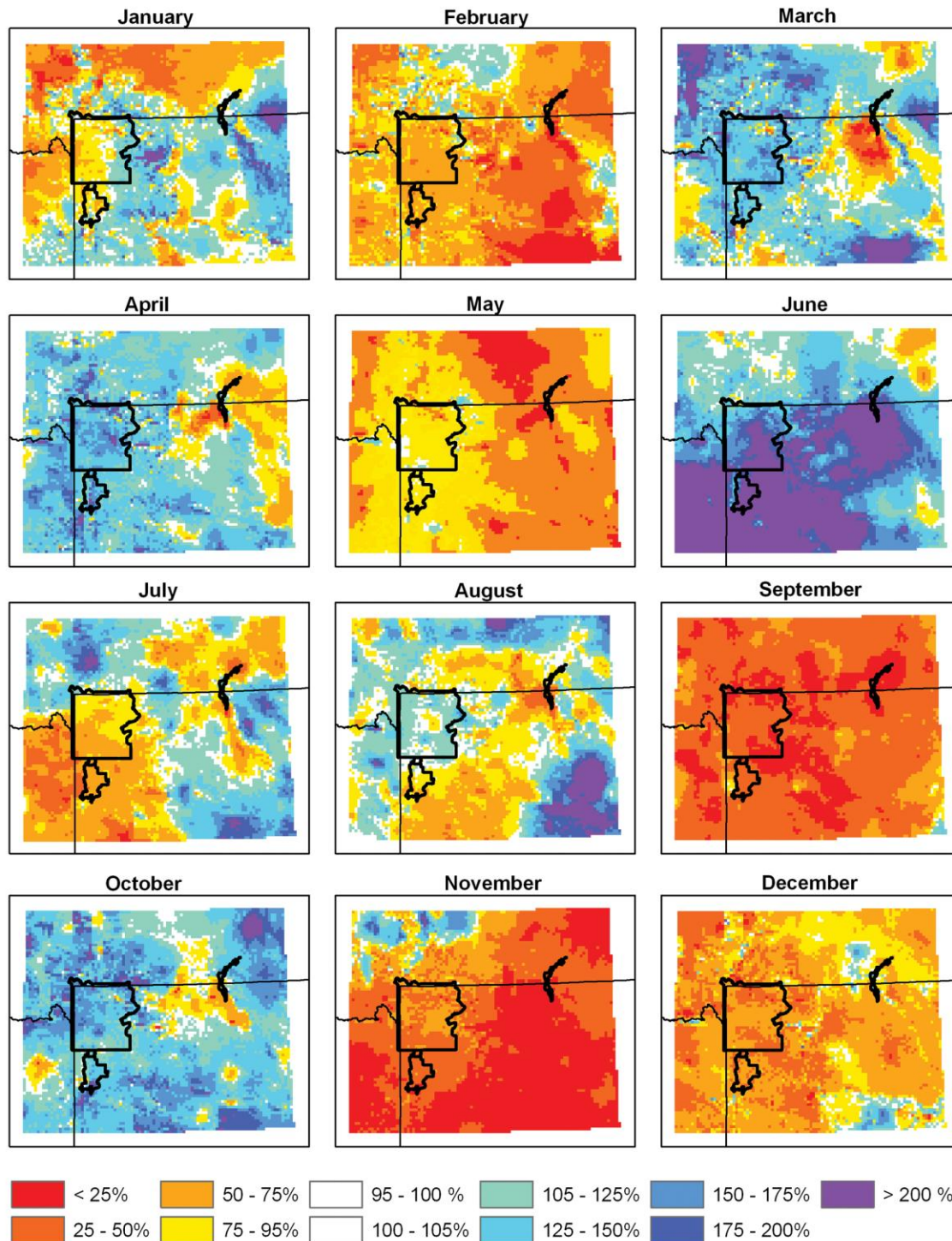


Figure 3. Maps showing percent of average precipitation versus 1971–2000 for each month in calendar year 2009. Colors show estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM interpolates precipitation values between actual observation stations, and corrects these interpolated estimates for changes in topography across the region. For more information, see <http://www.prism.oregonstate.edu/>.

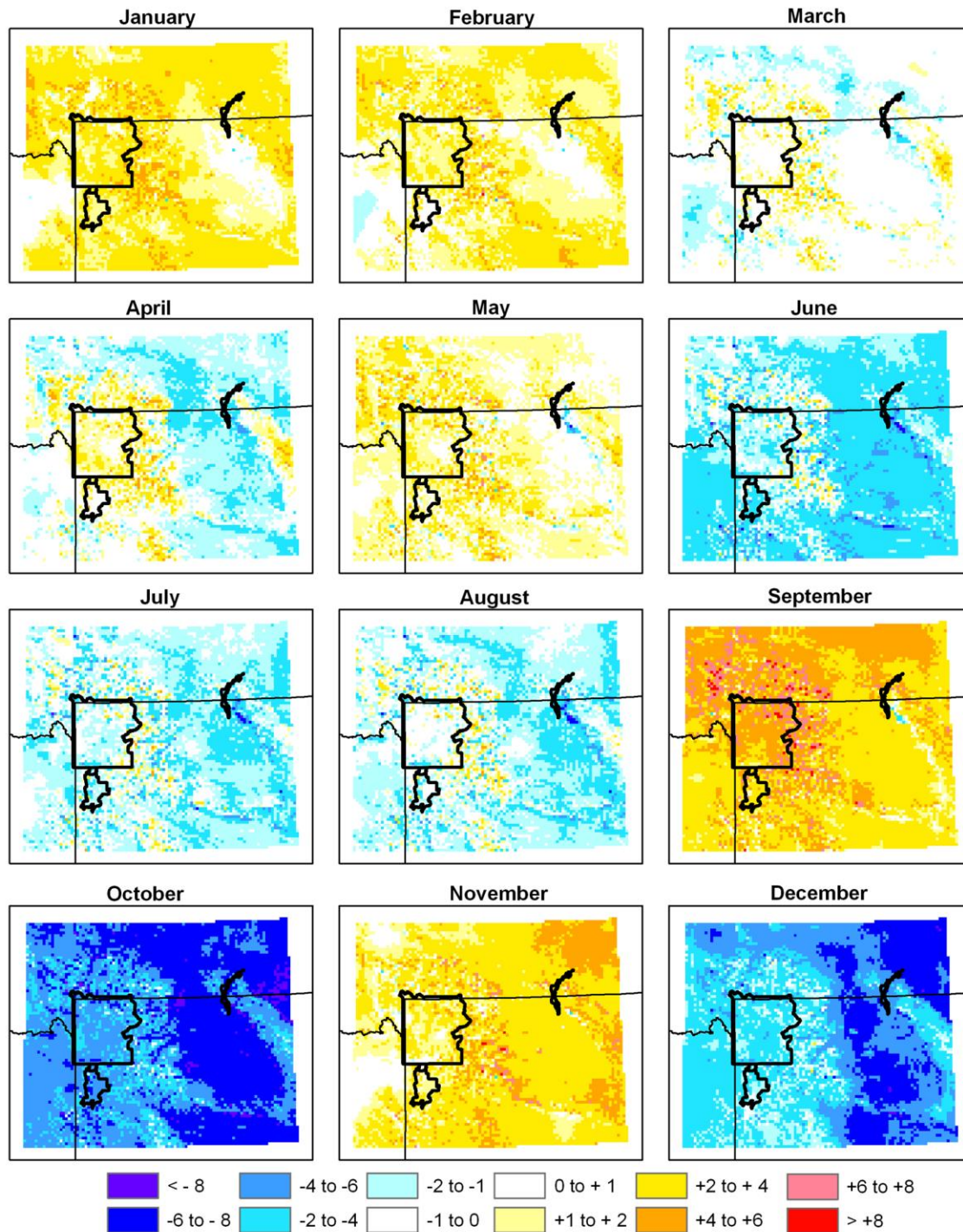


Figure 4. Maps showing departures from average maximum daily temperatures for each month in calendar year 2009 versus 1971–2000. Departure values are reported in degrees Fahrenheit. Maps were created using estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM interpolates precipitation values between actual observation stations, and corrects these interpolated estimates for changes in topography across the region. For more information, see <http://www.prism.oregonstate.edu/>.

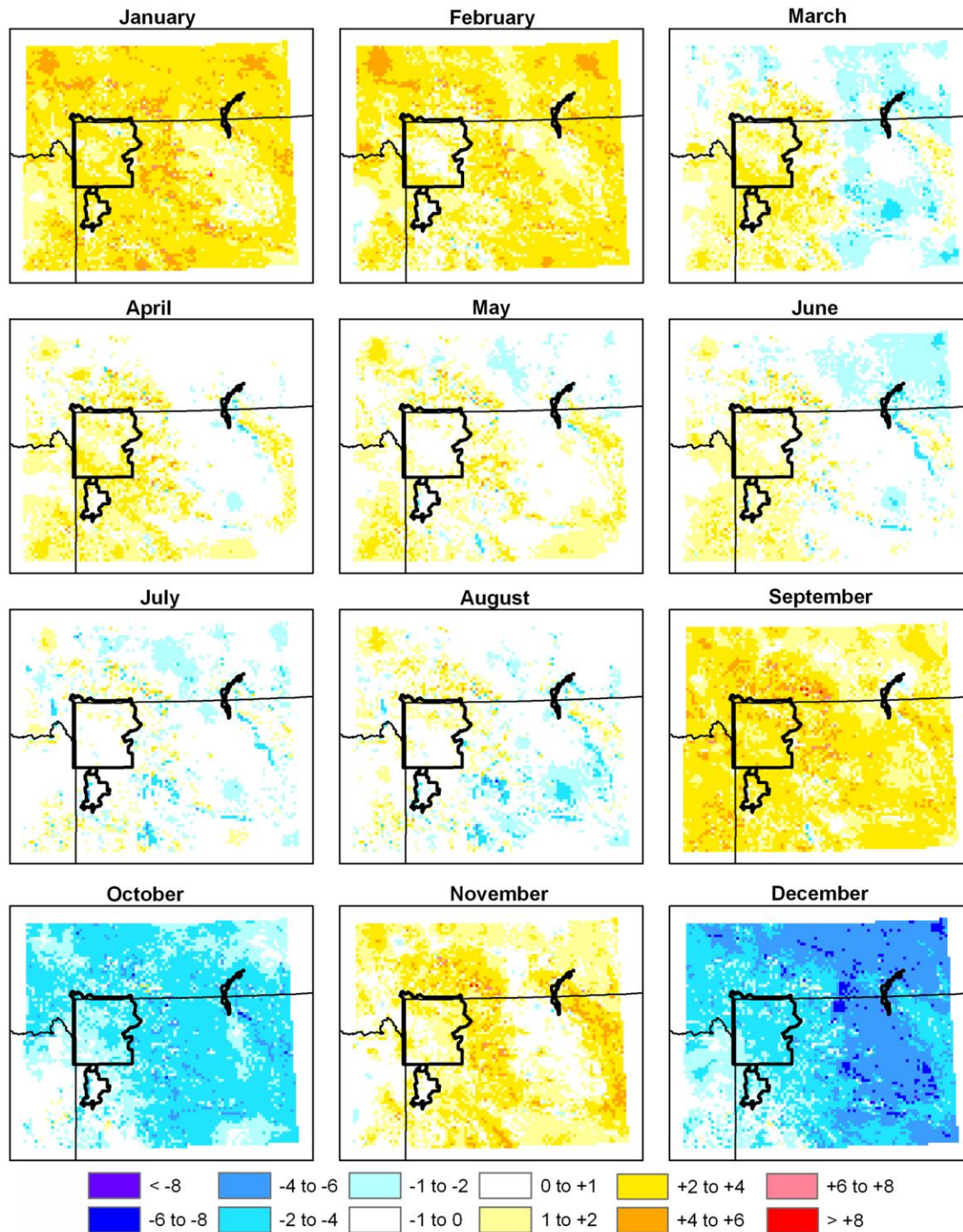


Figure 5. Maps showing departures from average minimum daily temperatures for each month in calendar year 2009 versus 1971–2000. Departure values are reported in degrees Fahrenheit. Departure values are reported in degrees Fahrenheit. Maps were created using estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM interpolates precipitation values between actual observation stations, and corrects these interpolated estimates for changes in topography across the region. For more information, see <http://www.prism.oregonstate.edu/>.

3 Summaries of climate station data

3.1 Precipitation

While PRISM-based estimates provide an overview of month-to-month precipitation variability across the entire GRYN area, records from select National Weather Service COOP stations (see Appendix A for station details) show key aspects of local variability within and around the three park units.

3.1.1 Total annual precipitation across the GRYN

Individual weather stations in or near Yellowstone and Grand Teton reported total annual precipitation that was near average to slightly wet (fig. 6, table 1). Stations in zones 1 and 1a (fig. 1) ranged from 101% of 1971–2000 averages in Mammoth YNP to 125% of average in Cooke City 2W, MT. Likewise, zone 2 and 2a stations reported annual precipitation that was 90–134% of average (fig. 6, table 1). In contrast, weather stations in and near Bighorn Canyon reported total annual precipitation that was generally below the 1971–2000 average (fig. 7, table 1). COOP weather stations ranged from 67% average at Yellowtail Dam to 94% of average at Shell 1NE. SNOTEL stations, which in Bighorn Canyon are located at higher elevation, ranged from 77% average at Bald Mountain to 91% average at Shell Creek (fig. 7, table 1).

3.1.2 Seasonal precipitation patterns in Yellowstone and Grand Teton

January and February were characterized by a shift from roughly average or above average precipitation to drier conditions, but zone 2, which includes Grand Teton and southern Yellowstone (fig. 1) was drier than other areas. Zones 1, 1a, and 2a had January precipitation ranging from 91% of the 1971–2000 average in Mammoth to 172% average at both Cooke City and Sylvan Road. In contrast, zone 2 had only 48% of January average precipitation at Ashton, Idaho, 105% average at Moose, Wyoming, and 158% at Canyon Village, which was much wetter than other stations in this zone (fig. 6, table 1). By February, Yellowstone and Grand Teton had generally below average precipitation, ranging from 47% average at Old Faithful to 122% average at Ashton, Idaho (fig. 6, table 1).

March and April saw a return to wetter conditions across both parks (fig. 6, table 1). Lake Yellowstone reported 208% of March average precipitation, while southern zone 2 stations were less extreme. Moose and Moran (zone 2 stations) both reported ~135% of March average precipitation, and Ashton, which was the driest station, reported 75% of the March average. April precipitation ranged from 80% average at Fisher Creek to 252% average at Canyon Village (fig. 6, table 1).

Dry conditions in May gave way to remarkably high precipitation across all of Yellowstone and Grand Teton in June. Ashton, Idaho, recorded 305% average precipitation in June, while Moran, Wyoming, and Canyon Village had 275% and 267% of average, respectively. The driest location was Mammoth Hot Springs, which received 108% average precipitation during June (fig. 6, table 1).

July and August saw the northern and southern regions on different trajectories (fig. 6, table 1). In Yellowstone, northern zone 1 weather stations (map, fig. 1), remained near average during both July and August (July: 88% average at Lake Yellowstone to 110% at Cooke City; August: 76% average at Lake Yellowstone to 138% at Cooke City), while many southern zone 2 stations

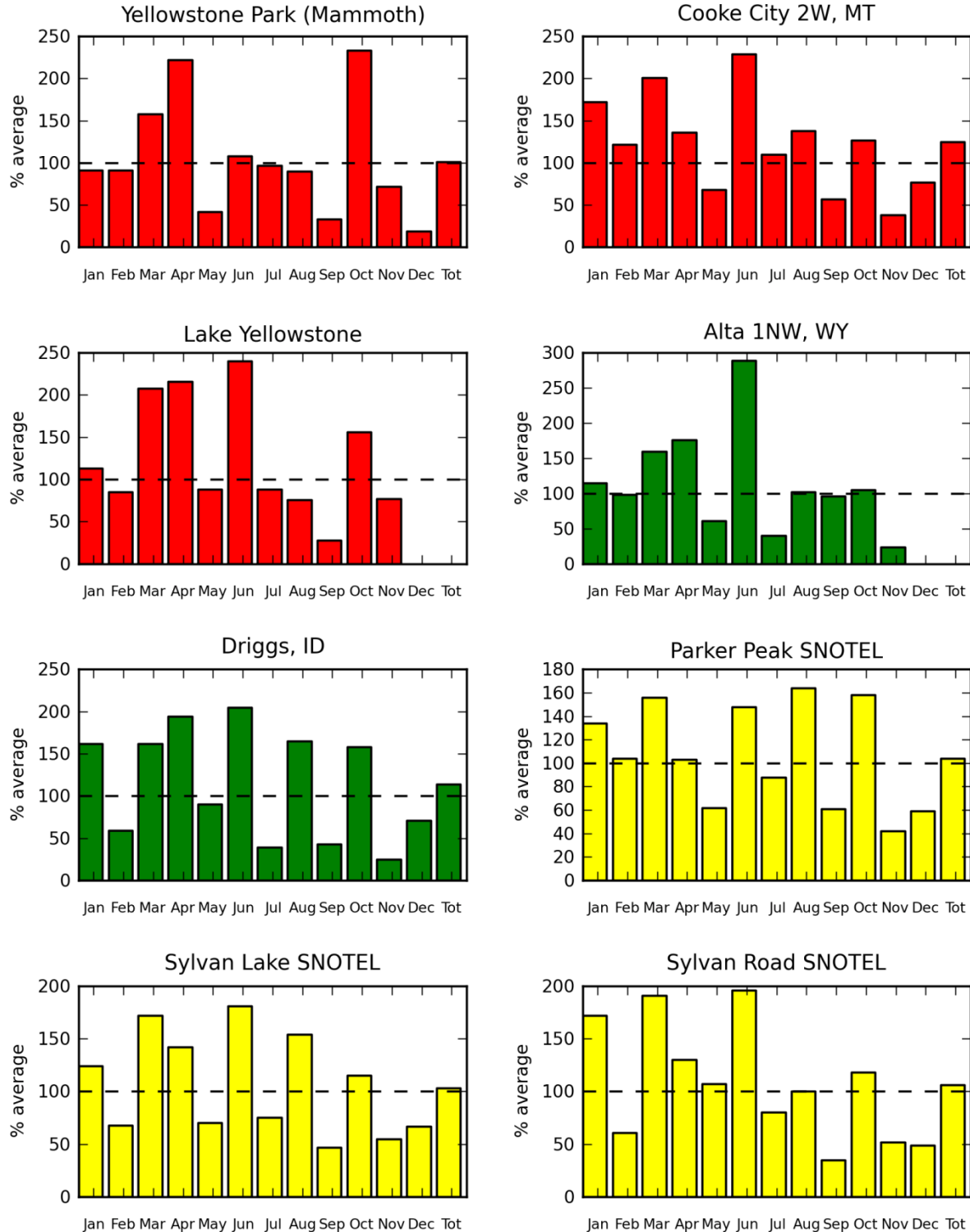


Figure 6. Departure of 2009 precipitation from 1971–2000 average at key climate stations in and near Yellowstone and Grand Teton National Parks. Colors indicate the climate zone for each station. Red = zone 1, Green = zone 1a, Blue = zone 2, Yellow = zone 2a. Cody (black) is an outlying station located between Yellowstone and Bighorn Canyon. Climate zone boundaries and stations locations are shown in Figure 1. Missing bars indicate months in which there were insufficient data to calculate a total.

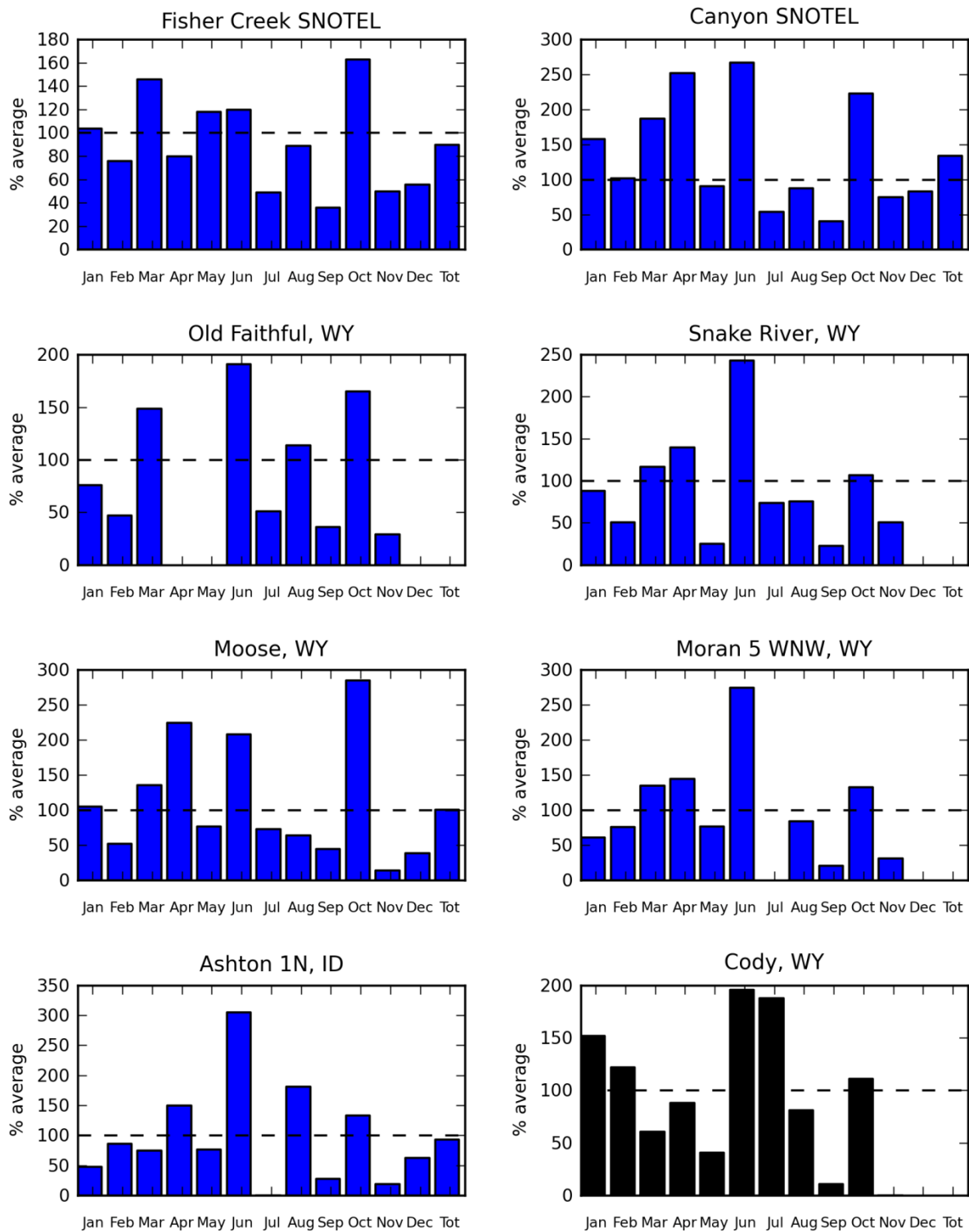


Figure 6. Continued.

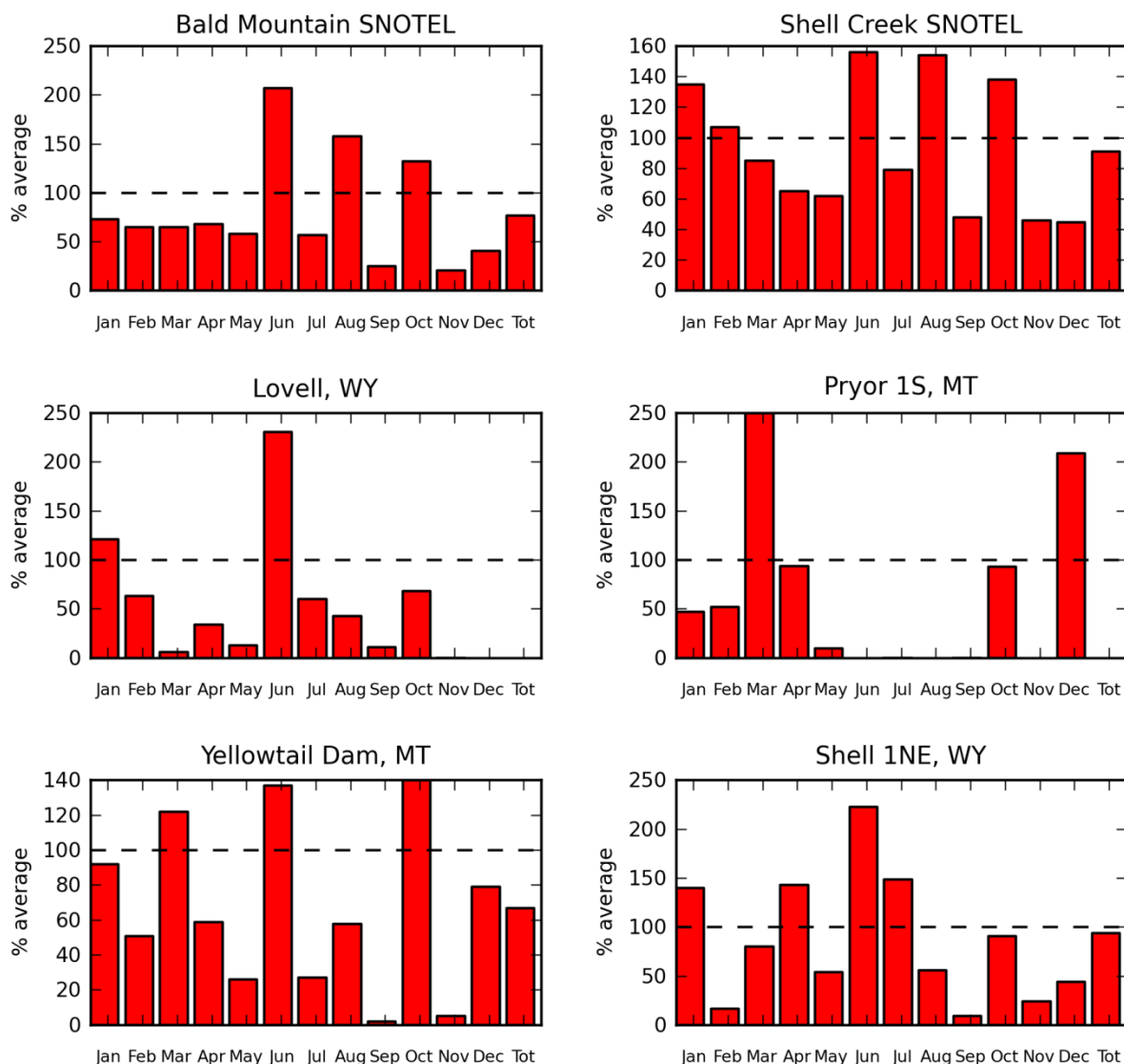


Figure 7. Departure of 2009 precipitation from 1971–2000 average at key climate stations in and near Bighorn Canyon National Recreation Area. Colors indicate the climate zone for each station. Red = zone 1, Green = zone 1a, Blue = zone 2, Yellow = zone 2a. Cody (black) is an outlying station located between Yellowstone and Bighorn Canyon. Climate zone boundaries and stations locations are shown in Figure 1. Missing bars indicate months in which there were insufficient data to calculate a total.

went from dry in July (49–74% average) to roughly average or wet in August (76–181% average). At the same time, some stations in Grand Teton remained dry during both months. Moose, Wyoming, for example, reported 73% and 64% during July and August respectively (fig. 6, table 1).

The last four months of 2009 were characterized by wide swings in precipitation throughout Yellowstone and Grand Teton (fig. 6, table 1). The unusually wet month of October was bookended by the extremely dry months of September and November. Following this, December offered slight relief but precipitation was still well below average. September precipitation

Table 1. Total Monthly Precipitation in inches and percentage of average monthly precipitation versus 1971–2000 averages for select Greater Yellowstone Network area stations during 2009

Station Name	Station ID	Climate Zone	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Cooke City 2W, MT	241995	YNP GRTE: 1	3.94	2.18	4.01	2.42	1.83	6.53	2.38	2.86	1.11	2.02	0.78	1.73	31.79
			172	122	201	136	68	229	110	138	57	127	38	77	125
Lake Yellowstone	485345	YNP + GRTE: 1	2.16	1.26	3.6	3.2	1.82	4.99	1.46	1.28	0.45	2.06	1.32	(-)	(-)
			113	85	208	216	88	240	88	76	28	156	77	(-)	(-)
Mammoth YNP	489905	YNP + GRTE: 1	0.8	0.58	1.71	2.42	0.85	2.09	1.54	1.29	0.42	2.21	0.68	0.15	14.74
			91	91	158	222	42	108	97	90	33	233	72	19	101
Alta 1NW, WY	480140	YNP + GRTE: 1a	2.7	1.76	3.17	3.74	2.12	6.13	0.72	1.57	1.65	2.15	0.51	(-)	(-)
			115	98	160	176	61	289	40	102	96	105	24	(-)	(-)
Driggs, ID	102676	YNP + GRTE: 1a	2.1	0.61	2.03	2.58	1.93	2.67	0.5	1.72	0.5	1.94	0.3	1.03	17.91
			162	59	162	194	90	205	39	165	43	158	25	71	114
Ashton 1N, ID	100470	YNP + GRTE: 2	1.08	1.43	1.2	2.21	1.84	5.01	(-)	1.95	0.33	1.87	0.39	1.41	(-)
			48	86	75	150	77	305	(-)	181	28	133	19	63	(-)
Moose, WY	486428	YNP + GRTE: 2	2.69	1.09	2.25	3.22	1.56	3.53	1.03	0.91	0.6	3.59	0.3	0.97	21.74
			105	52	136	225	77	208	73	64	45	285	14	39	101
Moran 5 WNW, WY	486440	YNP + GRTE : 2	1.97	1.81	3.02	2.9	1.78	4.21	(-)	1.07	0.3	2.12	0.89	(-)	(-)
			61	76	135	145	77	275	(-)	84	21	133	31	(-)	(-)
Old Faithful, WY	486845	YNP + GRTE: 2	1.75	0.98	3.18	(-)	(-)	4.09	0.84	1.59	0.57	2.79	0.69	(-)	(-)
			76	47	149	(-)	(-)	191	51	114	36	165	29	(-)	(-)
Canyon	SNOTEL	YNP + GRTE: 2	3.1	1.8	3.4	3.8	2	5.9	1	1.2	0.6	2.9	1.5	1.9	29.1
			158	102	187	252	91	267	54	88	41	223	75	83	134
Snake River, WY	488315	YNP + GRTE: 2	3.45	1.57	3.16	3.17	0.69	5.62	1.24	1.28	0.42	2.09	1.74	(-)	(-)
			88	51	117	140	25	243	74	76	23	107	51	(-)	(-)

Table 1. Continued

Station Name	Station ID	Climate Zone	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Fisher Creek	SNOTEL	YNP + GRTE: 2	7.8	4.6	8	4.1	5.7	4.6	1.3	2.1	1	5.5	3.2	4.1	52
			104	76	146	80	118	120	49	89	36	163	50	56	90
Parker Peak	SNOTEL	YNP + GRTE: 2a	3.9	2.7	4.2	3.2	2.3	4.3	1.5	2.3	1.1	3.8	1.3	1.6	32.2
			134	104	156	103	62	148	88	164	61	158	42	59	104
Sylvan Lake	SNOTEL	YNP + GRTE: 2a	4.7	2.1	5.5	5.1	3	5.6	1.5	2	0.9	3.1	2.4	2.6	38.5
			124	68	172	142	70	181	75	154	47	115	55	67	103
Sylvan Road	SNOTEL	YNP + GRTE: 2a	5.5	1.4	4.2	3.5	3	4.9	1.2	1.3	0.6	2.6	2.3	1.7	32.2
			172	61	191	130	107	196	80	100	35	118	52	49	106
Bald Mountain	SNOTEL	Bighorn Canyon	2.4	1.5	2.2	2.6	2.3	6.2	1.2	1.9	0.6	3.3	0.6	1.3	26.1
			73	65	65	68	58	207	57	158	25	132	21	41	77
Shell Creek	SNOTEL	Bighorn Canyon	3.5	1.6	2.2	2.2	2.3	5.3	1.5	2	1.1	2.9	1.1	1	26.7
			135	107	85	65	62	156	79	154	48	138	46	45	91
Lovell, WY	485770	Bighorn Canyon	0.29	0.1	0.02	0.2	0.16	2.29	0.45	0.26	0.08	0.44	0	(-)	(-)
			121	63	6	34	13	231	60	43	11	68	0	(-)	(-)
Pryor 1S, MT	246747	Bighorn Canyon	0.31	0.3	3.1	1.76	0.31	(-)	0	(-)	0	1.6	(-)	1.17	(-)
			47	52	250	94	10	(-)	0	(-)	0	93	(-)	209	(-)
Yellowtail Dam, MT	249240	Bighorn Canyon	0.79	0.37	1.7	1.23	0.81	3.03	0.39	0.57	0.03	2.65	0.05	0.69	12.31
			92	51	122	59	26	137	27	58	2	140	5	79	67
Shell 1NE, WY	488124	Bighorn Canyon	0.8	0.08	0.47	1.37	0.86	3.14	1.4	0.29	0.12	0.78	0.13	0.22	9.66
			140	17	80	143	54	223	149	56	9	91	24	44	94
Cody, WY	481840	N/A	0.7	0.33	0.31	1	0.81	3.09	2.28	0.73	0.12	0.98	0	(-)	(-)
			152	122	61	88	41	196	188	81	11	111	0	(-)	(-)

Note: Percentages of average monthly precipitation versus 1971–2000 averages are given in the second line of data for each station. Station IDs are from National Weather Service Cooperative Observer stations. Monthly statistics are not reported if more than 3 days of data are missing. Individual months are not used for calculating annual statistics if more than 5 days of data are missing.
(-) Indicates missing data.

reports included 21% of the 1971–2000 average at Moran Junction, 33% average at Mammoth, and 36% average at Old Faithful. Alta, WY, which was the wettest station during September, received 96% average precipitation. October, in contrast, saw 285% average precipitation at Moose, Wyoming (the wettest station), and no stations in Yellowstone or Grand Teton reporting below 100% average. During November, Moose was again one of the precipitation extremes for the region, but this time as the driest location, reporting only 14% of average. Lake Yellowstone had the wettest November, with 77% average precipitation. December was 19–83% of average.

3.1.3 Seasonal precipitation patterns in Bighorn Canyon

During January, climate stations north and east of Bighorn Canyon (fig. 2; Bald Mountain, Pryor, and Yellowtail Dam) had precipitation below (47–92%) the 1971–2000 averages, while stations south and west of the national recreation area (Cody, Lovell, Shell, Shell Creek) were above (121–152%) average (fig. 7, table 1). By February, most of the region was experiencing below average precipitation (17–65%), with the exception of Shell Creek and Cody, which reported 107% and 122% respectively.

With a few exceptions, weather stations in the region experienced below average precipitation during March, April and May. Yellowtail Dam and Pryor reported 122% and 250% average during March, respectively, and Shell reported 143% during April. Otherwise, precipitation across the region covered the range 6–94% during these months (fig. 7, table 1).

A wet June gave way to the variable months of July and August, which in their turn served as the transition to an extremely dry September. June precipitation was uniformly above average, ranging from 137% at Yellowtail Dam to 231% at Lovell. July and August were characterized by a wide range of precipitation values: 0–188% in July and 43–158% in August. September precipitation ranged from 0% at Pryor to 48% at Shell Creek (fig. 7, table 1).

The average to wet month of October was followed by two generally dry months. With the exception of Lovell, which reported 68% of average, October precipitation was 91–140% of average. November ranged from 0% average at Lovell to 46% at Shell Creek. Likewise, December values ranged from 41–79%, with the exception of Pryor, which reported 209% average (fig. 7, table 1).

3.2 Temperature

Overall, calendar-year 2009 saw temperatures that were generally near average to slightly below average (figs. 8–10). There were, however, notable exceptions like September, which saw Mammoth report average maximum temperatures (Tmax) 8.4 degrees above the 1971–2000 average, and October, in which Tmax at Mammoth was 11.5 degrees below average (tables 2 and 3; figs. 8 and 9). In many cases, monthly Tmin was not as far below average as Tmax, or was above average in months when Tmax was near or below average (tables 2 and 3; figs. 8–10). A notable example of this occurred during June at Moose, Wyoming, where Tmax was 5°F below average, and Tmin was 2.87°F above average (tables 2 and 3).

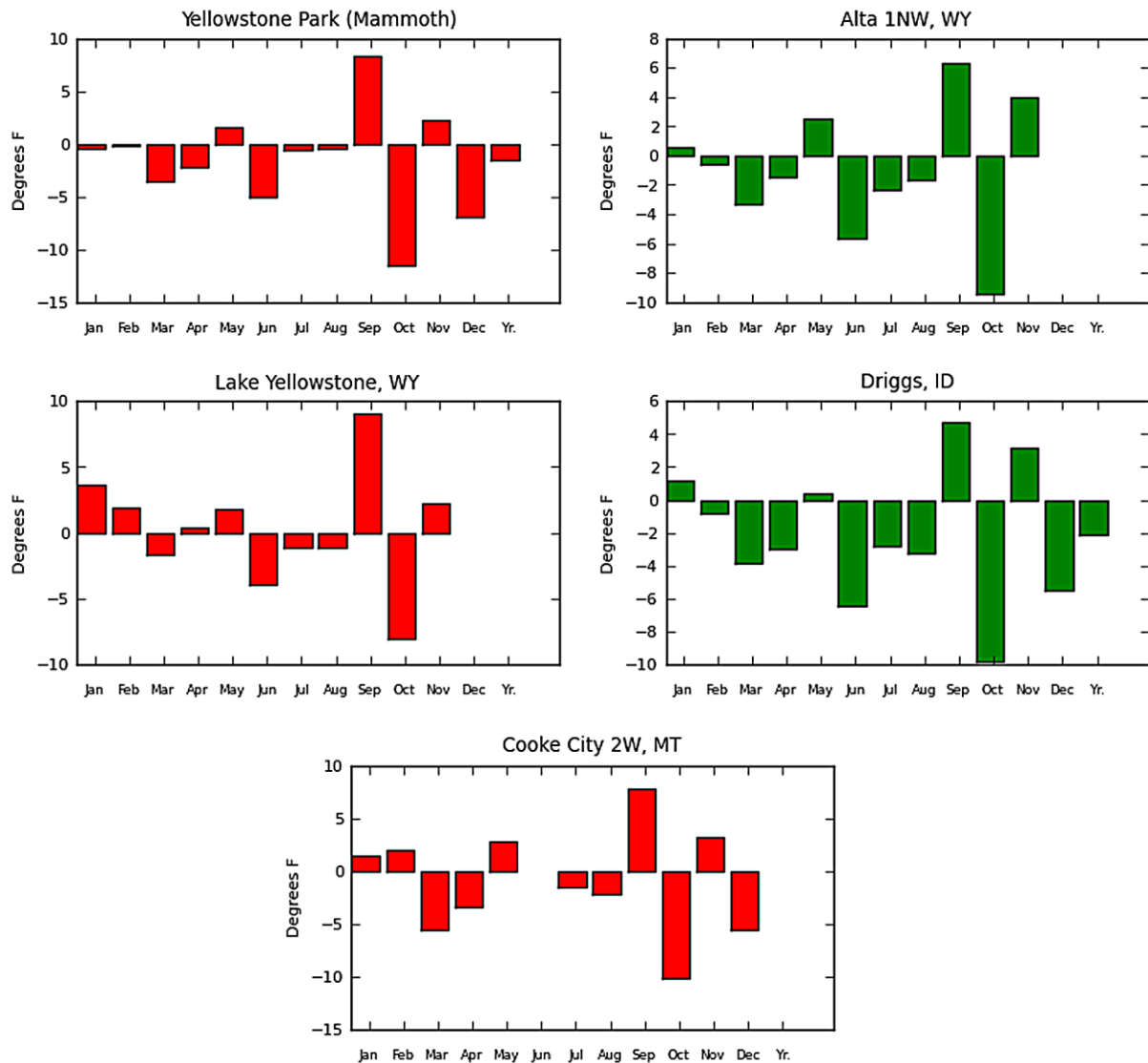


Figure 8. Departure of 2009 average maximum daily temperatures from 1971–2000 average at key climate stations in an near Yellowstone and Grand Teton national parks. Colors indicate the climate zone for each station. Red = zone 1, Green = zone 1a, Blue = zone 2. Climate zone boundaries and stations locations are shown in Figure 1. SNOTEL stations (zone 2a) are not presented because of concerns about temperature data reliability. Missing bars indicate months in which there were insufficient data to calculate an average.

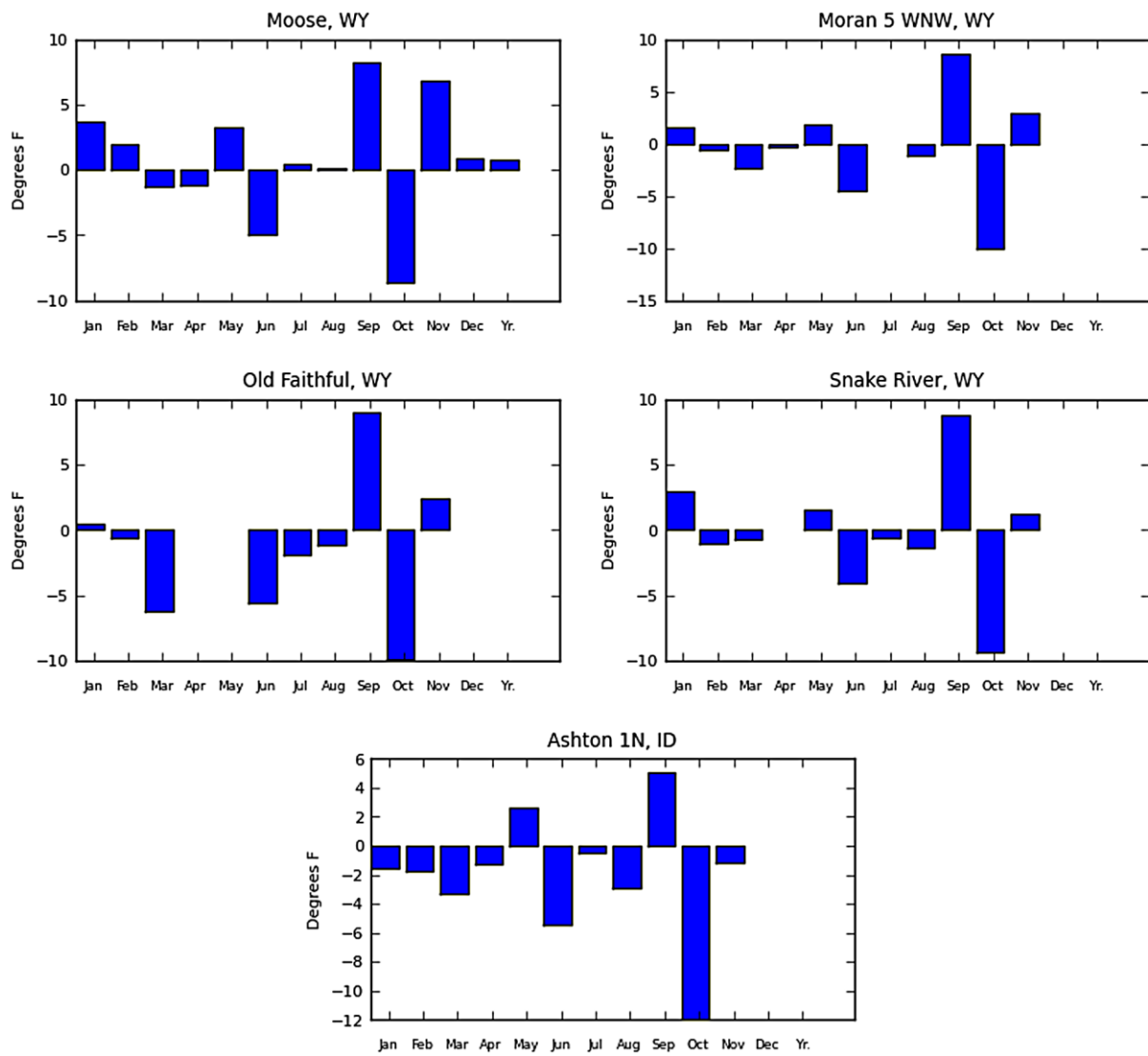


Figure 8. Continued.

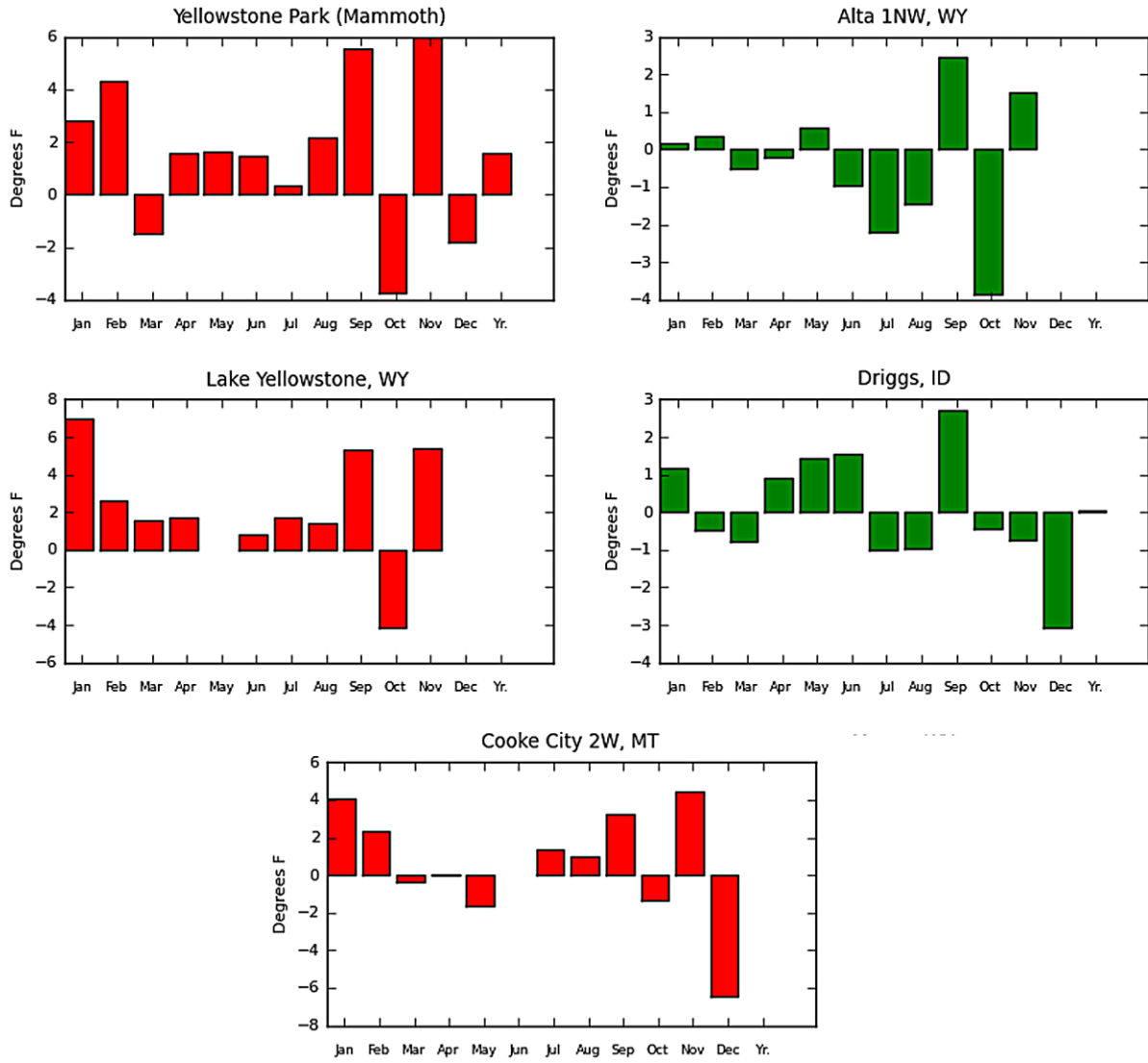


Figure 9. Departure of 2009 average minimum daily temperatures from 1971–2000 average at key climate stations in an near Yellowstone and Grand Teton national parks. Colors indicate the climate zone for each station. Red = zone 1, Green = zone 1a, Blue = zone 2. Climate zone boundaries and stations locations are shown in Figure 1. SNOTEL stations (zone 2a) are not presented because of concerns about data reliability. Missing bars indicate months in which there were insufficient data to calculate an average.

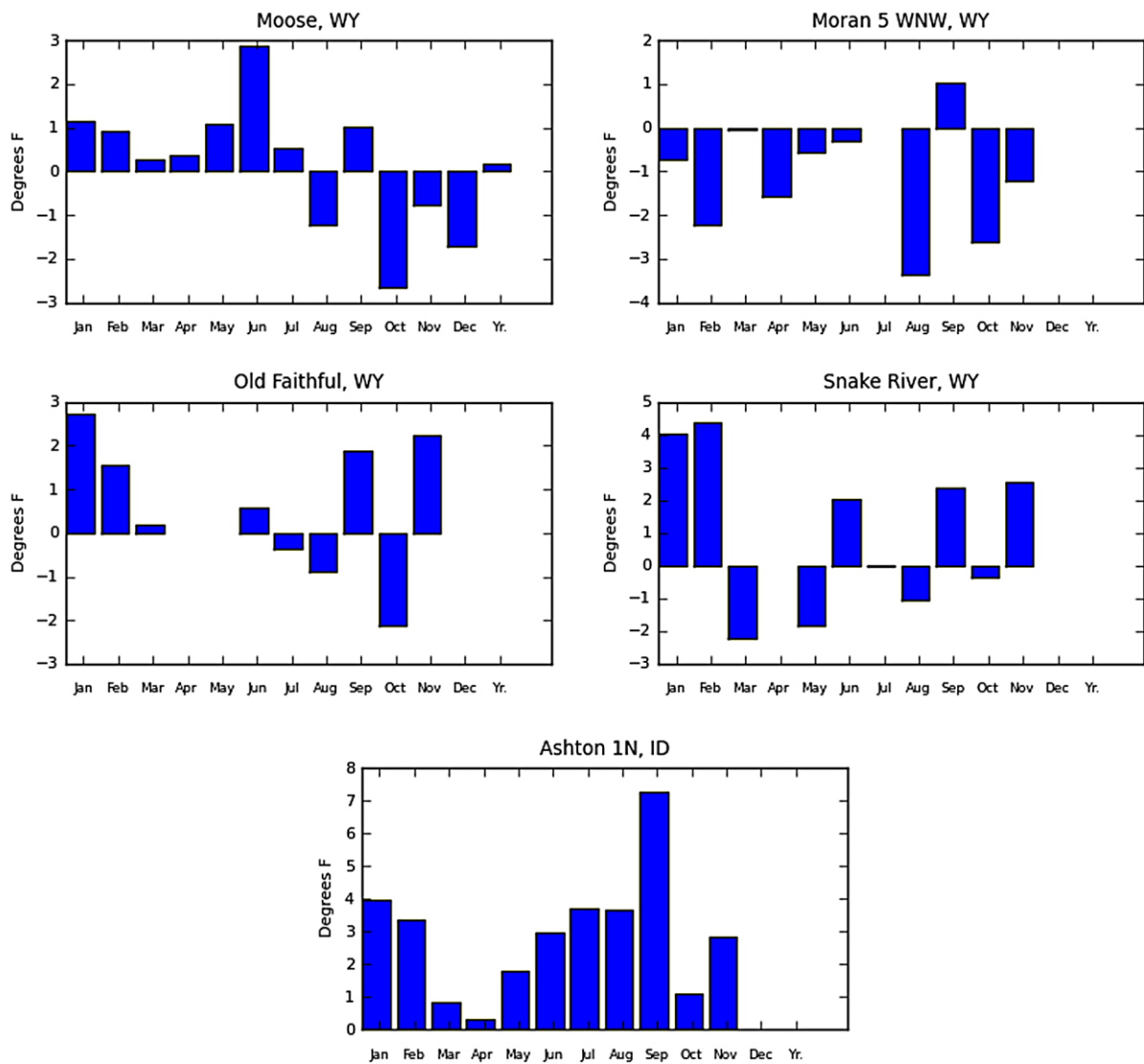


Figure 9. Continued.

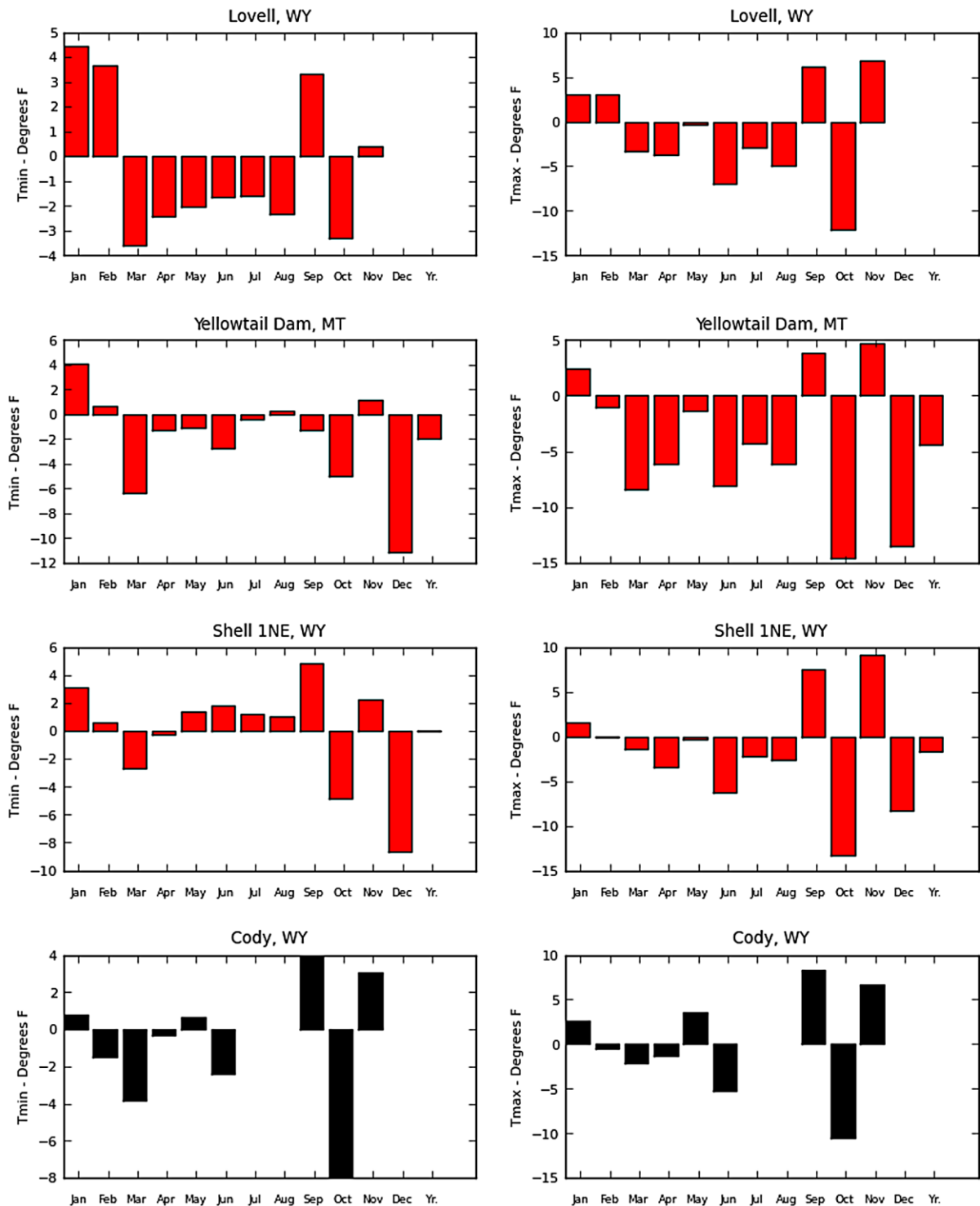


Figure 10. Departure of 2009 average maximum and average minimum daily temperatures at key climate stations in and near Bighorn Canyon National Recreation Area. SNOTEL stations are not presented because of concerns about data reliability. Missing bars indicate months in which there were insufficient data to calculate an average.

Table 2. Average maximum daily temperatures in degrees Fahrenheit for select Greater Yellowstone Network area stations during 2009

Station Name	Station ID	Climate Zone	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Cooke City 2W, MT	241995	YNP GRTE: 1	25.10 1.50	32.32 1.92	31.19 -5.61	40.83 -3.47	56.48 2.78	(-) (-)	71.48 -1.52	69.74 -2.26	69.43 7.83	38.74 -10.16	34.80 3.20	17.52 -5.58	(-) (-)
Lake Yellowstone	485345	YNP + GRTE: 1	26.40 3.60	30.18 1.88	33.55 -1.65	42.57 0.37	52.85 1.85	57.13 -3.97	69.23 -1.17	69.26 -1.14	69.30 9.00	40.16 -8.04	35.30 2.20	(-) (-)	(-) (-)
Mammoth YNP	489905	YNP + GRTE: 1	28.71 -0.49	33.93 -0.17	36.84 -3.56	46.63 -2.27	60.45 1.55	64.20 -5.10	78.03 -0.57	77.48 -0.42	75.20 8.40	42.29 -11.51	39.57 2.27	22.32 -6.88	50.47 -1.56
Alta 1NW, WY	480140	YNP + GRTE: 1a	29.61 0.61	33.18 -0.62	36.68 -3.32	47.00 -1.50	62.13 2.53	64.17 -5.63	75.84 -2.36	75.71 -1.69	74.23 6.33	45.58 -9.42	42.07 3.97	(-) (-)	(-) (-)
Driggs, ID	102676	YNP + GRTE: 1a	29.90 1.20	32.29 -0.81	36.39 -3.81	48.03 -2.97	61.97 0.37	64.76 -6.44	76.03 -2.77	75.00 -3.20	73.53 4.73	46.81 -9.79	42.90 3.20	24.29 -5.51	50.99 -2.15
Ashton 1N, ID	100470	YNP + GRTE: 2	27.90 -1.60	32.68 -1.72	38.61 -3.29	52.07 -1.23	67.06 2.66	68.10 -5.50	81.13 -0.47	79.10 -2.90	77.93 5.03	48.61 -11.99	40.63 -1.17	(-) (-)	(-) (-)
Moose, WY	486428	YNP + GRTE: 2	29.10 3.70	32.86 1.96	38.32 -1.28	47.97 -1.23	63.87 3.27	65.80 -5.00	79.52 0.42	78.42 0.12	76.87 8.27	46.61 -8.59	43.93 6.83	26.39 0.89	52.47 0.78
Moran 5 WNW, WY	486440	YNP + GRTE : 2	28.26 1.56	32.18 -0.62	38.23 -2.37	48.47 -0.33	60.29 1.79	64.70 -4.50	(-) (-)	76.16 -1.14	76.13 8.53	44.61 -10.09	39.40 2.90	(-) (-)	(-) (-)
Old Faithful, WY	486845	YNP + GRTE: 2	27.45 0.45	31.93 -0.57	33.39 -6.21	(-) (-)	(-) (-)	59.97 -5.53	72.55 -1.95	72.32 -1.18	71.67 9.07	40.03 -9.87	36.90 2.40	(-) (-)	(-) (-)
Snake River, WY	488315	YNP + GRTE: 2	28.71 3.01	30.25 -1.05	37.04 -0.76	(-) (-)	57.23 1.53	62.57 -4.03	74.90 -0.60	73.65 -1.35	73.97 8.77	42.84 -9.36	36.10 1.20	(-) (-)	(-) (-)
Lovell, WY	485770	Bighorn Canyon	32.10 3.00	40.75 3.05	45.58 -3.32	55.27 -3.73	67.97 -0.33	71.70 -7.00	83.65 -2.95	80.55 -4.95	79.77 6.17	48.45 -12.05	50.20 6.80	(-) (-)	(-) (-)
Yellowtail Dam, MT	249240	Bighorn Canyon	42.68 2.48	45.11 -0.99	45.58 -8.42	57.30 -6.10	71.35 -1.35	74.63 -8.07	86.74 -4.26	84.84 -6.16	83.03 3.83	51.55 -14.55	53.76 4.76	28.19 -13.51	60.40 -4.36
Shell 1NE, WY	488124	Bighorn Canyon	30.39 1.59	38.68 -0.02	47.81 -1.39	56.27 -3.43	68.84 -0.26	73.40 -6.30	85.23 -2.17	83.06 -2.54	81.53 7.53	48.26 -13.34	51.87 9.17	24.74 -8.26	57.51 -1.62
Cody, WY	481840	N/A	37.55 2.65	40.04 -0.46	46.35 -2.15	55.40 -1.30	69.03 3.53	70.33 -5.27	(-) (-)	(-) (-)	79.30 8.30	48.94 -10.56	50.63 6.73	(-) (-)	(-) (-)

Note: Monthly average maximum daily temperature departures from 1971–2000 averages are given in the second line of data for each station in degrees Fahrenheit.
Station IDs are from National Weather Service Cooperative Observer stations. Monthly statistics are not reported if more than 5 days of data are missing. Individual months are not used for calculating annual statistics if more than 5 days of data are missing. Temperature data for YNP + GRTE zone 2a are not presented because that zone contains only SNOTEL stations.
(-) Indicates missing data.

Table 3. Average minimum daily temperatures in degrees Fahrenheit for select Greater Yellowstone Network area stations during 2009

Station Name	Station ID	Climate Zone	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Cooke City 2W, MT	241995	YNP GRTE: 1	6.15 4.05	6.54 2.34	9.77 -0.33	17.60 0.00	24.87 -1.63	(-) (-)	39.00 1.40	37.52 1.02	32.17 3.27	20.23 -1.37	14.97 4.47	-4.13 -6.43	(-) (-)
Lake Yellowstone	485345	YNP + GRTE: 1	3.90 7.00	1.15 2.65	5.86 1.56	16.30 1.70	(-) (-)	33.30 0.80	39.19 1.69	37.94 1.44	33.90 5.30	16.75 -4.15	15.43 5.43	(-) (-)	(-) (-)
Mammoth YNP	489905	YNP + GRTE: 1	11.42 2.82	15.79 4.29	16.19 -1.51	26.97 1.57	35.55 1.65	42.57 1.47	46.74 0.34	47.26 2.16	41.37 5.57	23.35 -3.75	22.90 6.00	6.87 -1.83	28.08 1.56
Alta 1NW, WY	480140	YNP + GRTE: 1a	10.97 0.17	13.96 0.36	19.10 -0.50	26.50 -0.20	35.77 0.57	41.73 -0.97	46.19 -2.21	45.03 -1.47	41.27 2.47	26.23 -3.87	20.63 1.53	(-) (-)	(-) (-)
Driggs, ID	102676	YNP + GRTE: 1a	9.48 1.18	10.93 -0.47	18.32 -0.78	27.43 0.93	35.23 1.43	42.34 1.54	45.29 -1.01	43.84 -0.96	39.30 2.70	27.35 -0.45	17.67 -0.73	5.74 -3.06	26.91 0.03
Ashton 1N, ID	100470	YNP + GRTE: 2	12.48 3.98	16.74 3.34	21.94 0.84	29.63 0.33	38.68 1.78	45.27 2.97	49.90 3.70	47.97 3.67	43.77 7.27	29.42 1.12	21.73 2.83	(-) (-)	(-) (-)
Moose, WY	486428	YNP + GRTE: 2	2.06 1.16	3.71 0.91	12.68 0.28	22.17 0.37	32.10 1.10	40.27 2.87	42.52 0.52	39.87 -1.23	34.53 1.03	21.84 -2.66	13.43 -0.77	0.30 -1.70	22.12 0.16
Moran 5 WNW, WY	486440	YNP + GRTE : 2	1.57 -0.73	2.07 -2.23	12.45 -0.05	19.83 -1.57	29.94 -0.56	37.30 -0.30	(-) (-)	37.94 -3.36	34.73 1.03	22.97 -2.63	14.30 -1.20	(-) (-)	(-) (-)
Old Faithful, WY	486845	YNP + GRTE: 2	1.23 2.73	2.56 1.56	8.70 0.20	(-) (-)	(-) (-)	34.87 0.57	38.35 -0.35	35.61 -0.89	30.17 1.87	18.29 -2.11	10.44 2.24	(-) (-)	(-) (-)
Snake River, WY	488315	YNP + GRTE: 2	2.13 4.03	4.39 4.39	5.78 -2.22	(-) (-)	24.79 -1.81	35.23 2.03	37.10 0.00	34.06 -1.04	28.77 2.37	18.16 -0.34	11.07 2.57	(-) (-)	(-) (-)
Lovell, WY	485770	Bighorn Canyon	9.13 4.43	15.57 3.67	18.81 -3.59	28.77 -2.43	39.45 -2.05	48.07 -1.63	52.68 -1.62	49.48 -2.32	43.93 3.33	27.29 -3.31	19.00 0.40	(-) (-)	(-) (-)
Yellowtail Dam, MT	249240	Bighorn Canyon	21.81 4.11	22.61 0.71	21.61 -6.39	34.93 -1.27	43.45 -1.05	49.70 -2.70	56.81 -0.39	56.39 0.29	45.87 -1.33	33.52 -4.98	28.83 1.13	9.35 -11.15	35.41 -1.92
Shell 1NE, WY	488124	Bighorn Canyon	6.94 3.14	12.61 0.61	18.61 -2.69	29.37 -0.23	39.10 1.40	48.40 1.80	53.26 1.26	50.74 1.04	44.30 4.90	24.10 -4.80	18.53 2.23	-1.71 -8.61	28.69 0.00
Cody, WY	481840	N/A	15.29 0.79	17.39 -1.51	21.87 -3.83	32.17 -0.33	41.58 0.68	46.57 -2.43	(-) (-)	(-) (-)	48.87 3.97	27.90 -8.00	27.73 3.03	(-) (-)	(-) (-)

Note: Monthly average minimum daily temperature departures from 1971–2000 averages are given in the second line of data for each station in degrees Fahrenheit. Station IDs are from National Weather Service Cooperative Observer stations. Monthly statistics are not reported if more than 5 days of data are missing. Individual months are not used for calculating annual statistics if more than 5 days of data are missing. Temperature data for zone YNP + GRTE zone 2a are not presented because that zone contains only SNOTEL stations.
(-) Indicates missing data.

Despite the fact January and February had above average T_{min} values in most locations, there were still extremely cold days during these months (figs. 11 and 12). The Snake River and Mammoth stations, for example, both reported T_{min} about 4°F above average during these months (figs. 8 and 9), and yet these stations recorded some individual daily temperatures near -15°F and -30°F, respectively (fig. 11). These cold days early in the year combined with a generally colder than average December (figs. 8–10), to produce a year that had an unusually large number of readings below 0°F (table 4). For example, Cooke City, which typically has no days below zero, had 51 days below this threshold during 2009 (table 4).

In Yellowstone and Grand Teton, the onset of spring, measured as the last date less than 28°F, was generally 1–3 weeks early, and the beginning of fall, measured as the earliest date less than 28°F, was generally 1–3 weeks late (table 4). Despite this, the growing season, measured as accumulated growing degree days (AGDD) was about average in most of Yellowstone and Grand Teton (table 4). This may have been due in part to cooler than average T_{max} during June–August (table 2, fig. 8). Since AGDD is calculated as the sum of the differences between daytime mean temperature and 40°F (or 50°F), cooler temperatures during the summer months effectively shorten the growing season.

In Bighorn Canyon, the onset of spring was close to the 1971–2000 averages (table 4). The beginning of fall was about a week early at Shell and Yellowtail Dam, and close to average in Cody (table 4). Growing season length, measured as accumulated growing degree days, ranged from close to average to as much as 20% below average at Yellowtail Dam (table 4).

As mentioned above, September was unusual for its heat and October for its cold. November was generally warmer than average, but the stations at Moose, Moran, and Driggs were notable for having above average T_{max} and below average T_{min} (figs. 8 and 9, tables 2 and 3).

Climate Zone 1

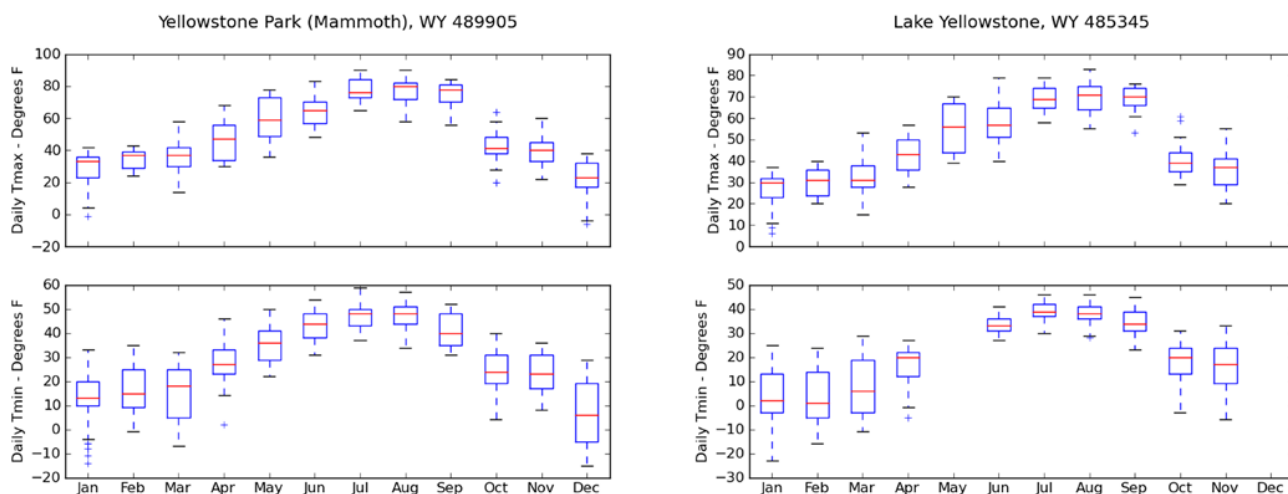
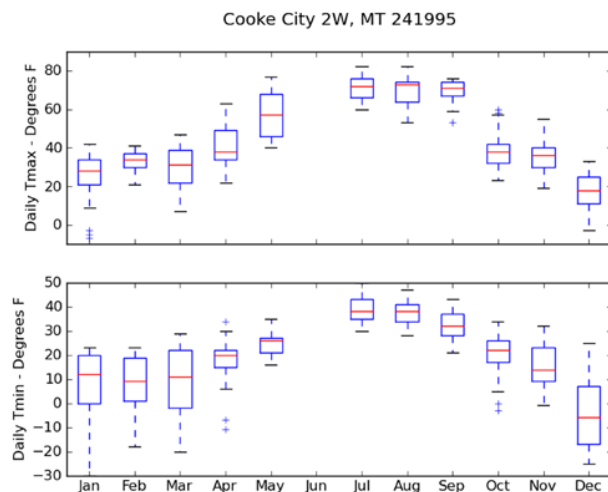


Figure 11. Boxplots of average maximum and average minimum daily temperatures at key climate stations in and near Yellowstone and Grand Teton national parks during 2009. Horizontal lines indicate the median value. Boxes indicate the 25th and 75th percentiles. Whiskers extend 1.5 times the interquartile Range (IQR). Crosses indicate values exceeding 1.5 times the IQR.



Climate Zone 1a

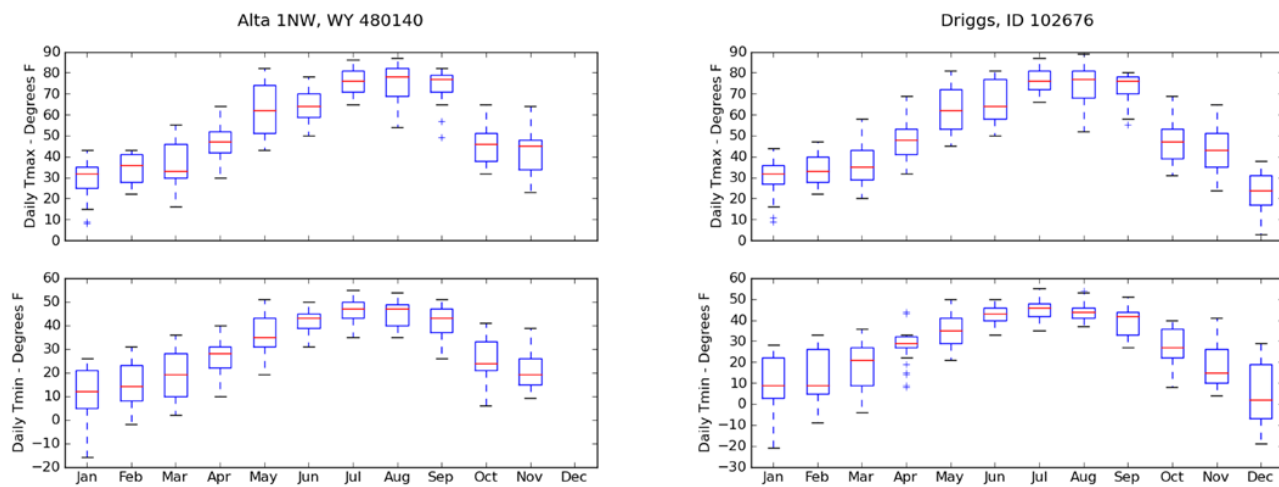


Figure 11. Continued.

Climate Zone 2

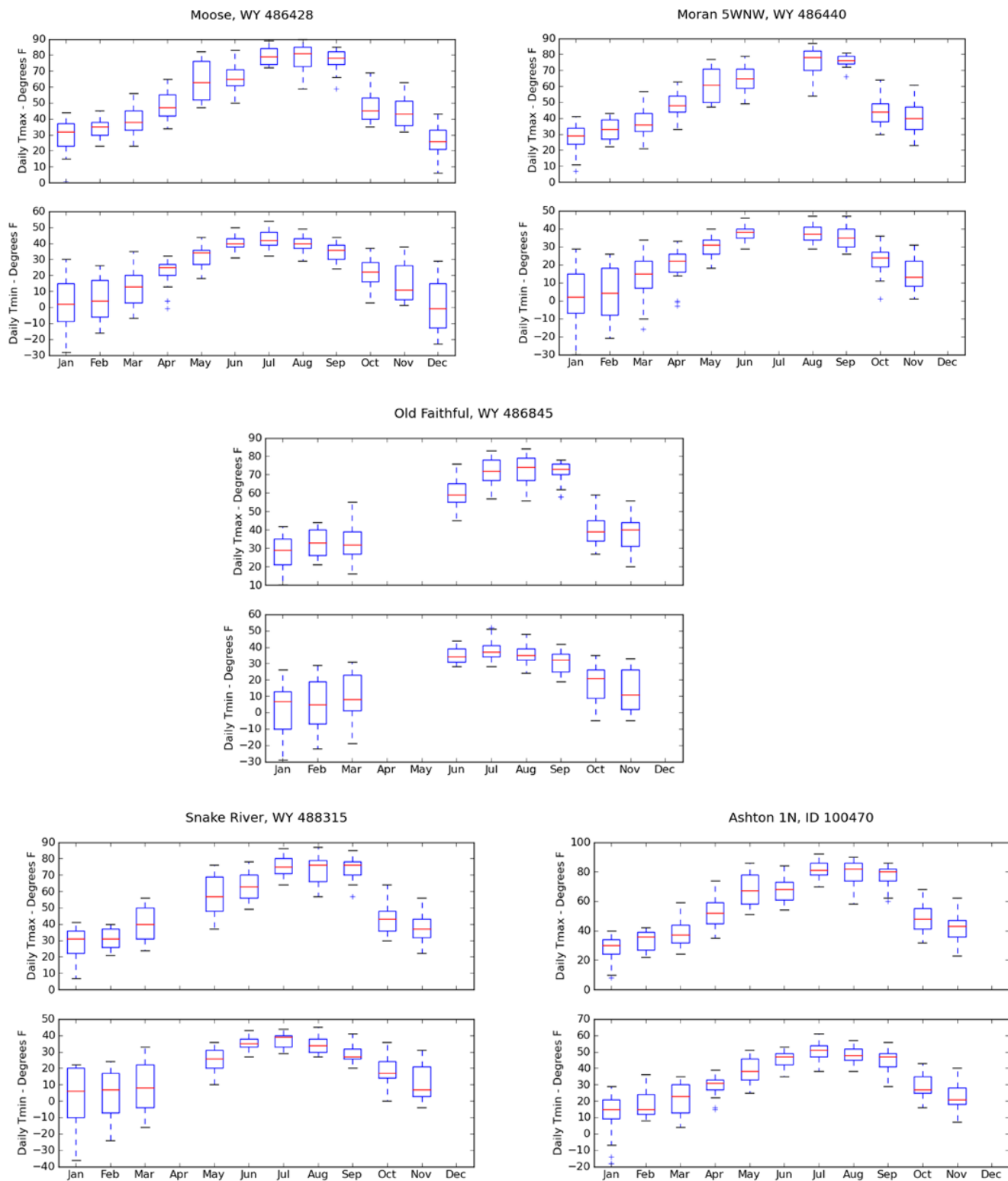


Figure 11. Continued.

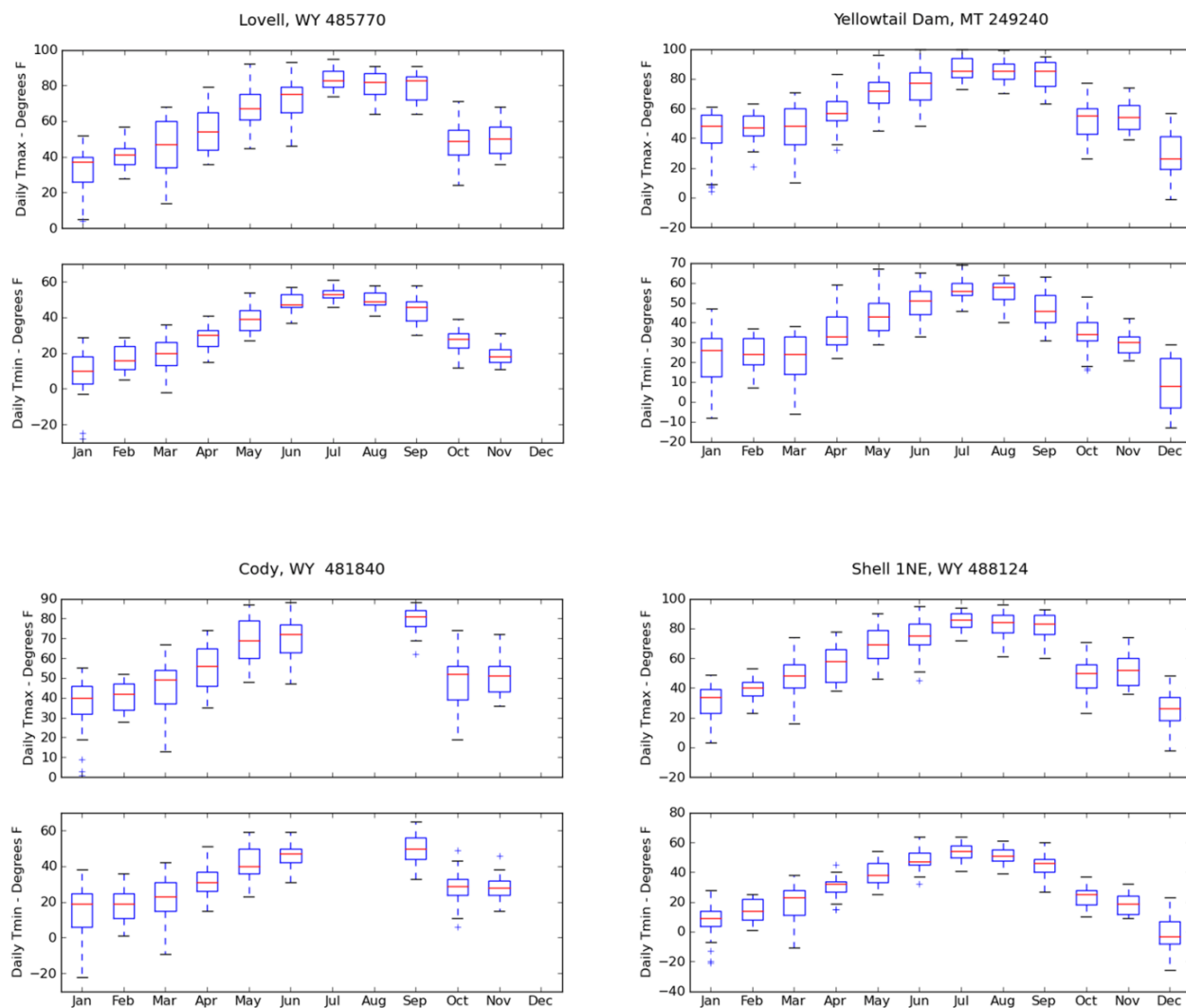


Figure 12. Boxplots of average maximum and average minimum daily temperatures at key climate stations in and near Bighorn Canyon National Recreation Area during 2009. Horizontal lines indicate the median value. Boxes indicate the 25th and 75th percentiles. Whiskers extend 1.5 times the interquartile Range (IQR). Crosses indicate values exceeding 1.5 times the IQR.

Table 4. First and last freeze and frost dates, accumulated growing degree days, and days above or below critical temperature thresholds for key stations in the Greater Yellowstone Network during 2009

Station Name	Station ID	Climate Zone	Last date in spring ≤ 28 F	Earliest date in fall ≤ 28 F	Last date in spring ≤ 32 F	Earliest date in fall ≤ 32 F	AGDD 40	AGDD 50	# days ≥ 80 F	# days ≥ 90 F	# days ≤ 0 F	# days ≤ 32 F
Cooke City 2W, MT	241995	YNP GRTE: 1	6/4 (6/25)	9/8 (8/28)	7/10 (7/13)	9/8 (8/13)	(-) ((1606))	(-) ((473))	5 ((0))	0 ((0))	51 ((0))	266 ((272))
Lake Yellowstone	485345	YNP + GRTE: 1	6/12 (6/29)	9/9 (8/25)	7/9 (7/16)	9/8 (8/13)	1464 ((1422))	401 ((388))	2 ((0))	0 ((0))	(-)* ((62))	(-)* ((283))
Mammoth YNP	489905	YNP + GRTE: 1	5/13 (5/23)	10/3 (9/17)	6/8 (6/14)	9/21 (9/8)	2742 ((2731))	1281 ((1200))	45 ((31))	2 ((0))	23 ((0))	215 ((215))
Alta 1NW, WY	480140	YNP + GRTE: 1a	5/13 (6/3)	9/8 (9/10)	6/23 (6/30)	9/8 (8/30)	2635 ((2656))	1169 ((1151))	29 ((5))	0 ((0))	(-)* ((0))	(-)* ((221))
Driggs, ID	102676	YNP + GRTE: 1a	5/21 (6/1)	9/22 (9/9)	5/22 (6/26)	9/9 (8/31)	2552 ((2756))	1051.5 ((1194))	27 ((39))	0 ((0))	27 ((0))	207 ((222))
Moose, WY	486428	YNP + GRTE: 2	5/22 (6/12)	9/9 (9/3)	7/9 (7/2)	9/8 (8/22)	2449 ((2338))	1016 ((925))	50 ((27))	2 ((0))	50 ((24))	234 ((250))
Moran 5 WNW, WY	486440	YNP + GRTE : 2	(-) (6/16)	(-) (9/1)	(-) (7/10)	(-) (8/17)	(-) ((1971))	(-) ((675))	(-) ((0))	(-) ((0))	(-) ((0))	(-) ((247))
Old Faithful, WY	486845	YNP + GRTE: 2	(-) (6/28)	9/8 (8/23)	7/30 (7/15)	9/8 (8/9)	(-) ((1721))	(-) ((545))	10 ((0))	0 ((0))	(-)^ ((64))	(-)^ ((273))
Snake River, WY	488315	YNP + GRTE: 2	6/23 (7/5)	9/8 (8/15)	7/31 (7/21)	9/1 (8/8)	1566 ((1778))	471 ((571))	19 ((0))	0 ((0))	48 ((66))	257 ((286))
Lovell, WY	485770	Bighorn Canyon	5/1 (5/1)	10/3 (10/2)	5/11 (5/16)	9/22 (9/19)	3612 ((4086))	1891 ((2215))	73 ((81))	12 ((0))	(-)* ((0))	(-)* ((190))

Table 4. Continued

Station Name	Station ID	Climate Zone	Last date in spring <= 28 F	Earliest date in fall <= 28 F	Last date in spring <= 32 F	Earliest date in fall <= 32 F	AGDD 40	AGDD 50	# days ≥ 80 F	# days ≥ 90 F	# days ≤ 0 F	# days ≤ 32 F
Yellowtail Dam, MT	249240	Bighorn Canyon	4/25 (4/19)	10/9 (10/15)	5/11 (5/7)	9/9 (10/2)	4531 ((5217))	2517 ((2951))	88 ((96))	36 ((41))	17 ((0))	158 ((142))
Shell 1NE, WY	488124	Bighorn Canyon	5/13 (5/10)	9/22 (10/1)	6/8 (5/24)	9/22 (9/18)	3796 ((4101))	2085 ((2220))	82 ((87))	23 ((0))	30 ((0))	205 ((199))
Cody, WY	481840	N/A	5/13 (5/6)	10/3 (10/1)	6/8 (5/18)	9/21 (9/21)	(-)# ((4047))	(-)# ((2107))	56 ((68))	5 ((0))	(-)\$ ((0))	(-)\$ ((173))

Note: Values for 2009 are shown in the first line for each station. 1971 – 2000 averages appear in the second line for each station.

* Temperature data for the entire month of December were missing, so # days ≤ 0F, 32F were not calculated.

^ 26 days of temperature data missing during December

21 days of temperature data missing during the growing season.

\$ 12 days of temperature data missing during December

Data for YNP + GRTE zone 2a are not presented because that zone contains only SNOTEL stations.

4 Winter snowpack

The Natural Resources Conservation Service (NRCS) operates automated snow measurement (SNOTEL) stations throughout the GRYN. These stations offer the best available means for tracking the accumulation and loss of snowpack. As measured in terms of snow water equivalent (SWE)—the amount of liquid water held in a given volume of snow—snowpack across the region ranged from near average to above average during the 2009 water year.

In the Bighorn Mountains, snowmelt was more rapid than average, as indicated by the steep slope of the 2009 SWE traces in figure 13. At the Shell Creek station an above average peak snowpack (~120% average) offset this rapid melt to produce a melt out date of June 2, which was very close to average (fig. 13). At the Bald Mountain station, roughly average peak spring snows finished melting about 10 days early.

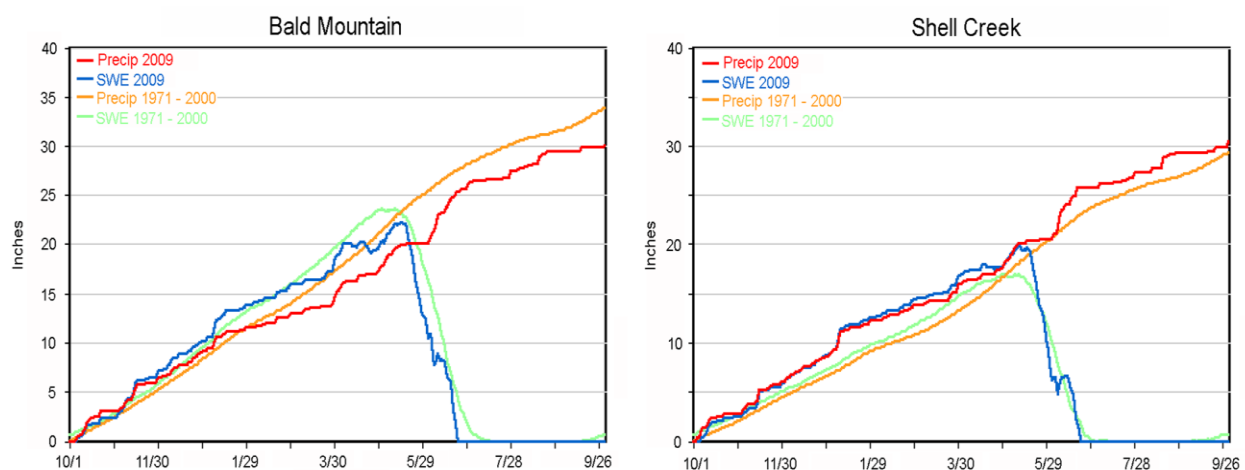


Figure 13. Daily measurements of snow water equivalent (SWE) and precipitation from representative sites near Bighorn Canyon National Recreation Area from October 2008 to September 2009. Values are compared to averages from the 1971–2000 period. Data courtesy of the Natural Resource Conservation Service. This provisional data is subject to change.

In Yellowstone and Grand Teton, SWE was close to average during most of the water year, but spring storms pushed April and May snowpack above average at some key stations. Parker Peak reported peak SWE that was 135% above the 1971–2000 average, but an unusually rapid melt off produced a melt out date that was about two weeks early. Canyon, Sylvan Road, Sylvan Lake, and Fisher Creek all had melt out dates that were close to average (fig. 14).

Like 2008, water year 2009 had roughly average snowpack when compared to 1971–2000 values, but it was nevertheless wetter than much of the previous decade (Gray et al. 2009).

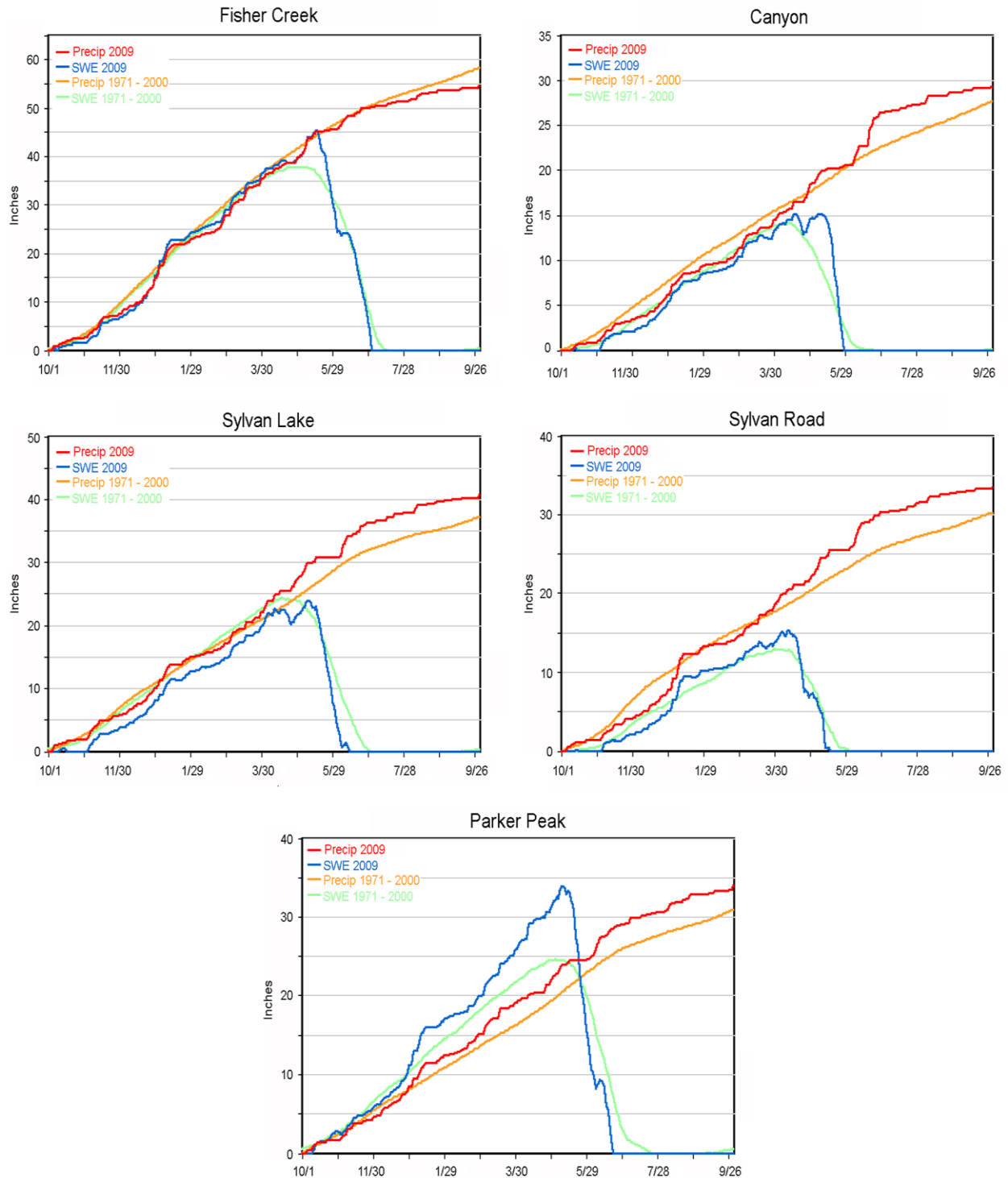


Figure 14. Daily measurements of snow water equivalent (SWE) and precipitation from representative sites in an near Yellowstone and Grand Teton National Parks from October 2008 to September 2009. Values are compared to averages from the 1971–2000 period. Data courtesy of the Natural Resource Conservation Service. This provisional data is subject to change.

5 Streamflow

The U.S. Geological Survey (USGS) monitors streamflow at numerous locations throughout the GRYN. Key aspects of GRYN area hydrology can be represented by a subset of these gauging stations (appendix 3). Following convention, we present data for the 2009 water year, which runs from October 2008 to September 2009.

The gauges at Shell Creek near Shell, Wyoming, and South Fork of the Shoshone River, near Valley, Wyoming, represent small, higher-elevation and relatively unregulated watersheds upstream from Bighorn Canyon and Bighorn Lake. Total discharge at Shell Creek (fig. 15) was below the 1971–2000 average until May and June, when rapid snowmelt (fig. 13) and high precipitation (fig. 7) pushed it to roughly double average. In contrast, the gauge on the South Fork of the Shoshone River (fig. 16) had near average discharge throughout the year. Total 2009 inflows to Bighorn Canyon and Bighorn Lake, as measured by the gauge on the Bighorn River at the Kane, Wyoming, station (fig. 15) were 107% of the 1971–2000 average.

Stream flows in Yellowstone were near average. As represented by gauges at the Yellowstone Lake Outlet and at Corwin Springs, Montana, in 2009 the Yellowstone River drainage showed total annual runoff at 119–122% of the 1971–2000 averages, with the timing of peak runoff very near averages (fig. 16). The gauge on the Madison River near West Yellowstone registered total annual discharge that was 90% of the 1971–2000 average.

The Snake River at Flagg Ranch, Wyoming gauge represents unregulated inflows to Grand Teton and Jackson Lake. During water year 2009 this gauge recorded total annual flows at 132% of the average for the period of record, with above average flows particularly noticeable during the rapid snowmelt of May and June (fig. 16). Total releases from Jackson Lake dam, measured by the gauge on the Snake River at Moose, Wyoming, were 117% of the 1995–2008 average (fig. 16).

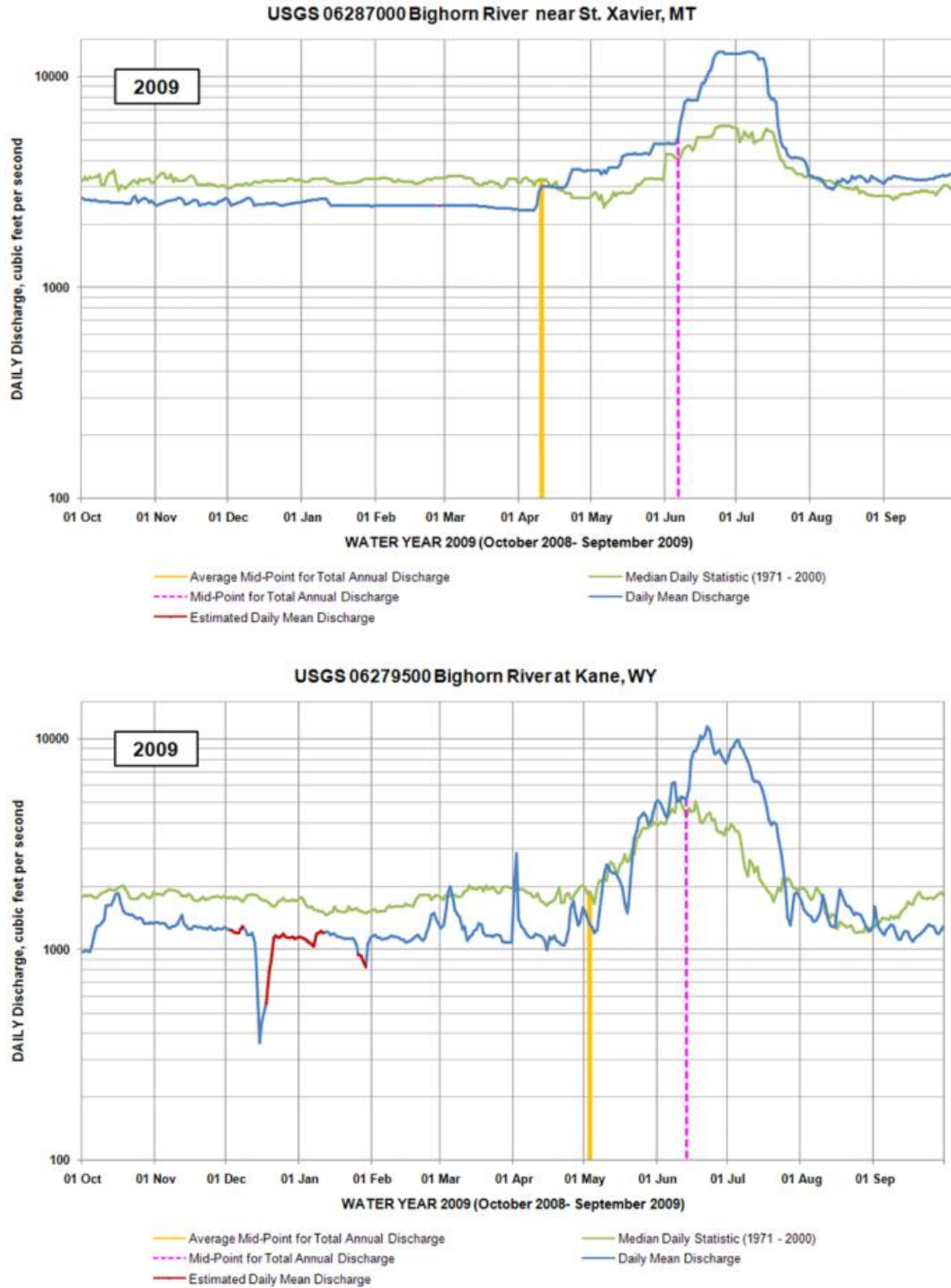


Figure 15. Streamflows from representative gauges in and near Bighorn Canyon Recreation Area for the 2009 water year (October 2008 through September 2009) are shown versus median daily flows for the period of record. Data courtesy the U.S. Geological Survey.

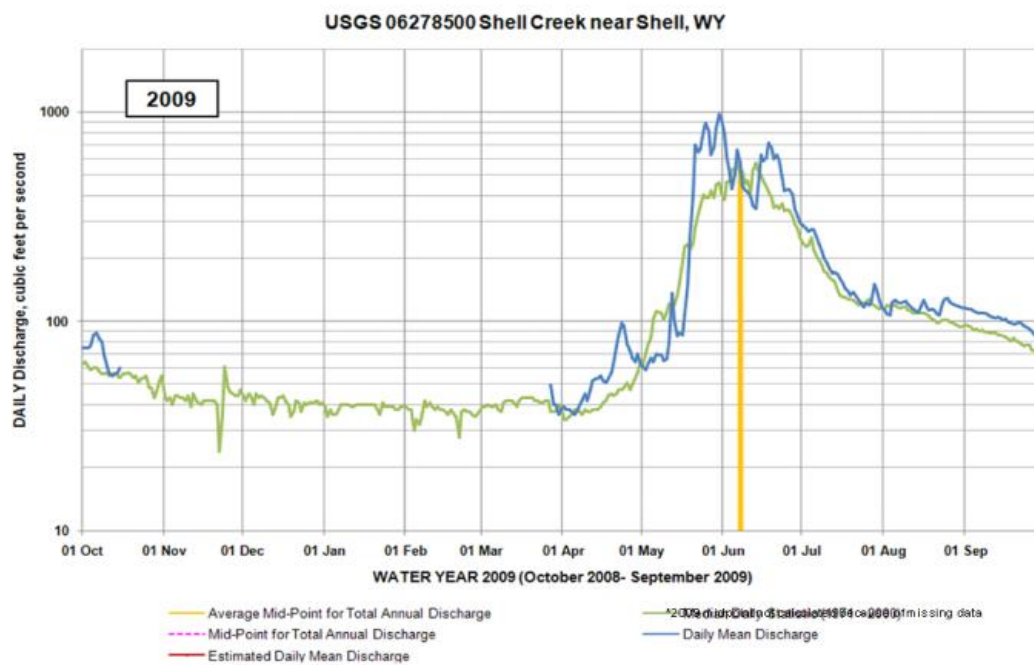


Figure 15. Continued.

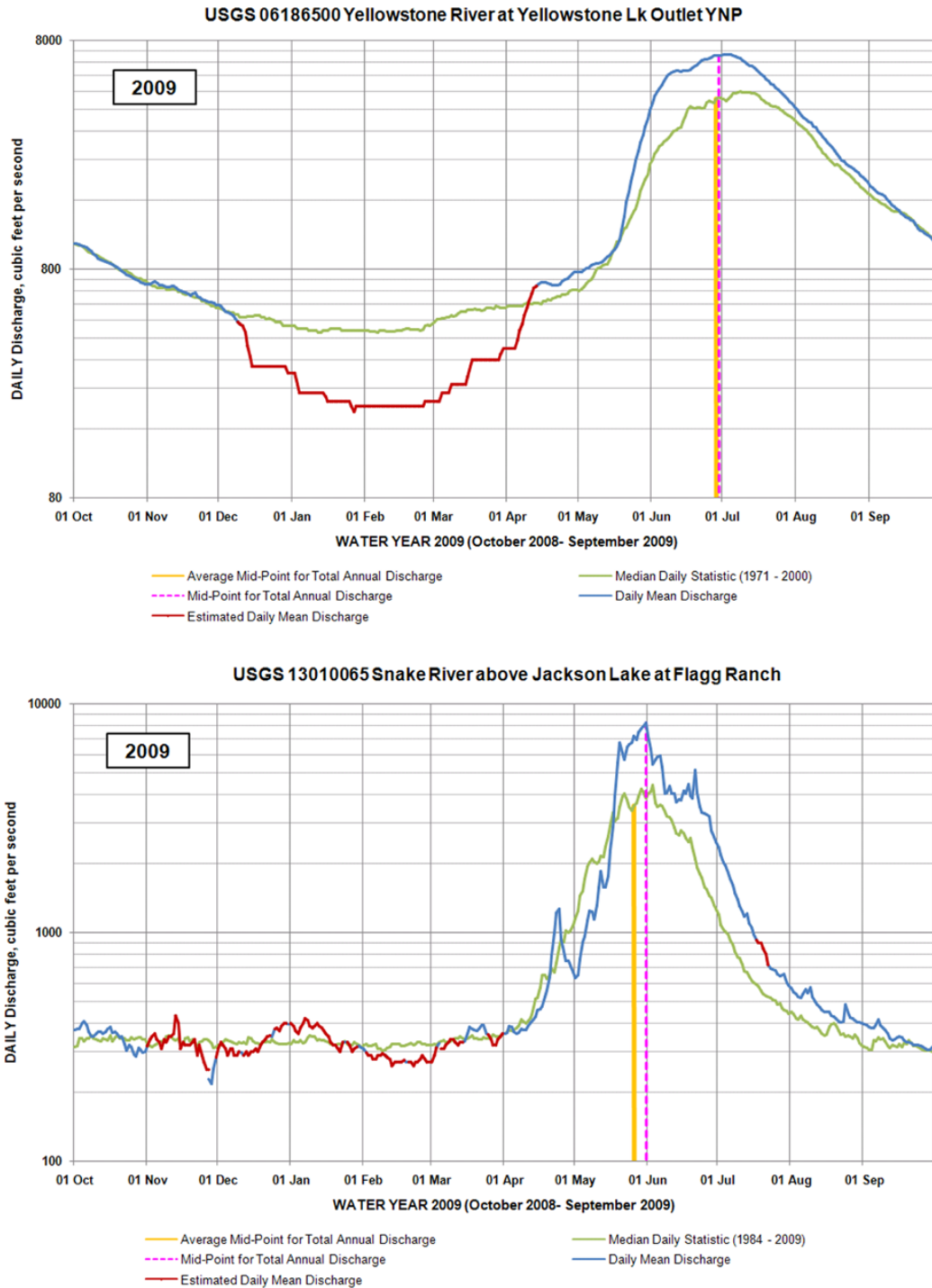


Figure 16. Streamflows from representative gauges in and near Yellowstone and Grand Teton national parks for the 2009 water year (October 2008 through September 2009) are shown versus median daily flows for the period of record. Data courtesy the U.S. Geological Survey.

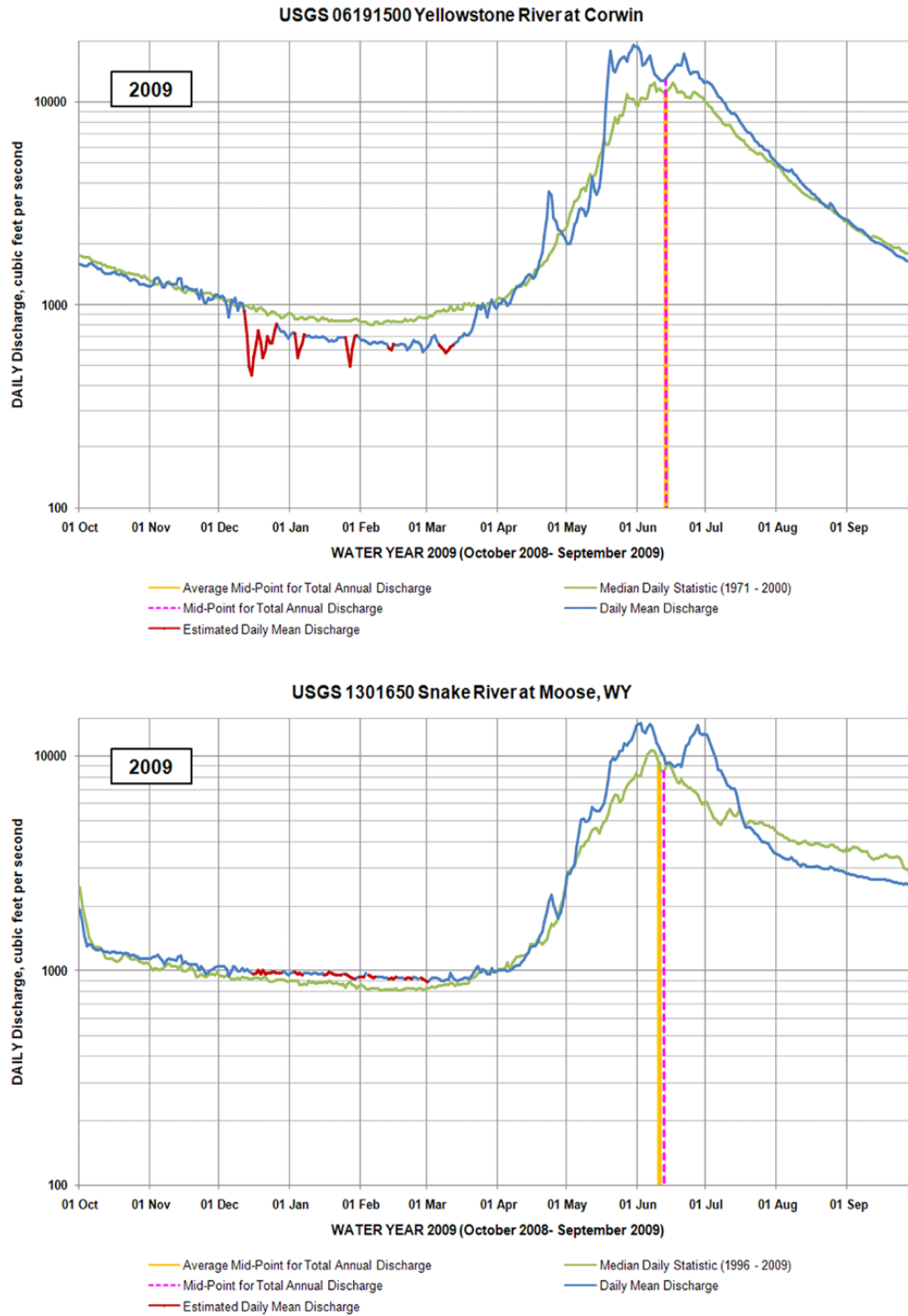


Figure 16. Continued.

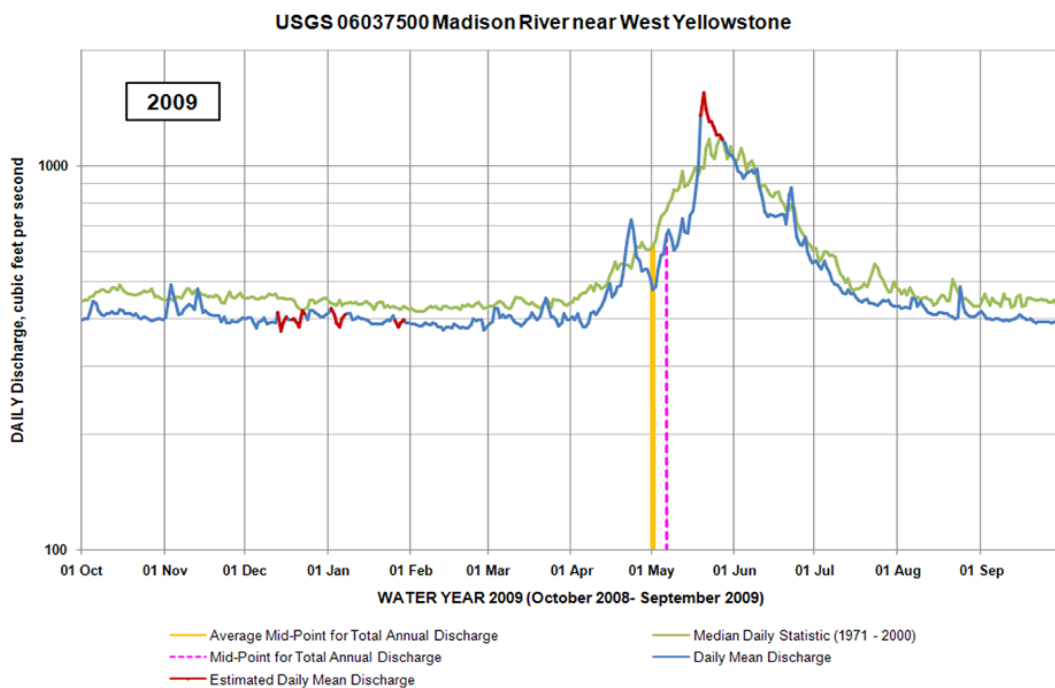
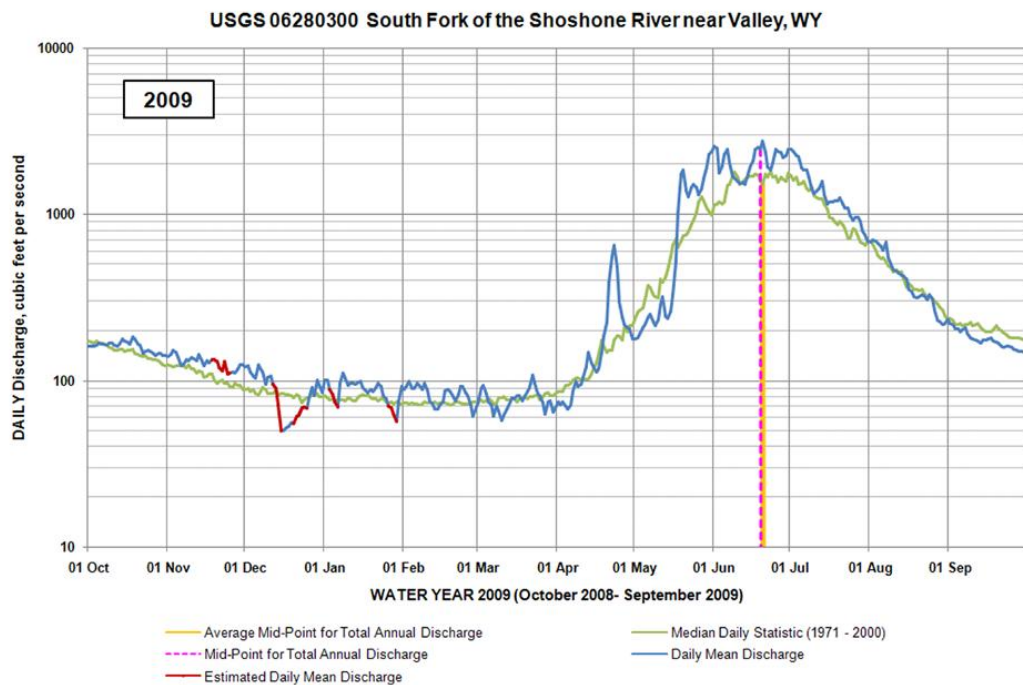


Figure 16. Continued.

6 Drought status

The Drought Monitor collaboration between federal, state, and academic partners tracks drought conditions across the nation on a weekly basis, and it incorporates data and expert input from a variety of state and federal agencies. The Drought Monitor is designed to provide a “broad brush,” regional perspective on drought, and therefore offers an ideal tool for tracking generalized drought conditions throughout the GRYN and surrounding areas. Drought classifications range from “abnormally dry” (D0) to “exceptional drought” (D4).

As shown by the Drought Monitor, calendar-year 2009 continued the recovery from drought that began in 2008. During January 2008, most of the GRYN had conditions ranging from abnormally dry (D0) to severe drought (D2; fig. 17). By August 2008, most areas had improved to abnormally dry (D0; fig. 18), and remained that way through the end of December (Gray et al. 2009). Drought conditions were almost entirely eliminated during 2009. The wet months of June and October were able to offset an unusually dry September, so that by the end of the year, only the northern portions of Bighorn Canyon had any drought classification (fig. 18).

The Standardized Precipitation Index (SPI) allows for a more detailed examination of drought conditions on multiple time scales. An SPI of zero indicates historical median precipitation. The index is negative for drought, and positive for wet conditions.

In Yellowstone and Grand Teton, the Snake River and Yellowstone River drainages were in moderate to severe drought during most of 2007 (fig. 17). Due to near-average precipitation in 2008 (Gray et al. 2009), SPI improved to near-normal, during the winter (DJF) and spring (MAM) but remained dry during summer 2008 (JJA; fig. 17). Calendar-year 2009 saw normal to wet SPI for all months in the Snake and Yellowstone River drainages (fig. 17). The Bighorn River Drainage had similar patterns but was somewhat drier during 2009. The 12-month SPI, which is calculated for the water year (October–September) declined slightly toward drier conditions in Bighorn Canyon from 2008 to 2009.

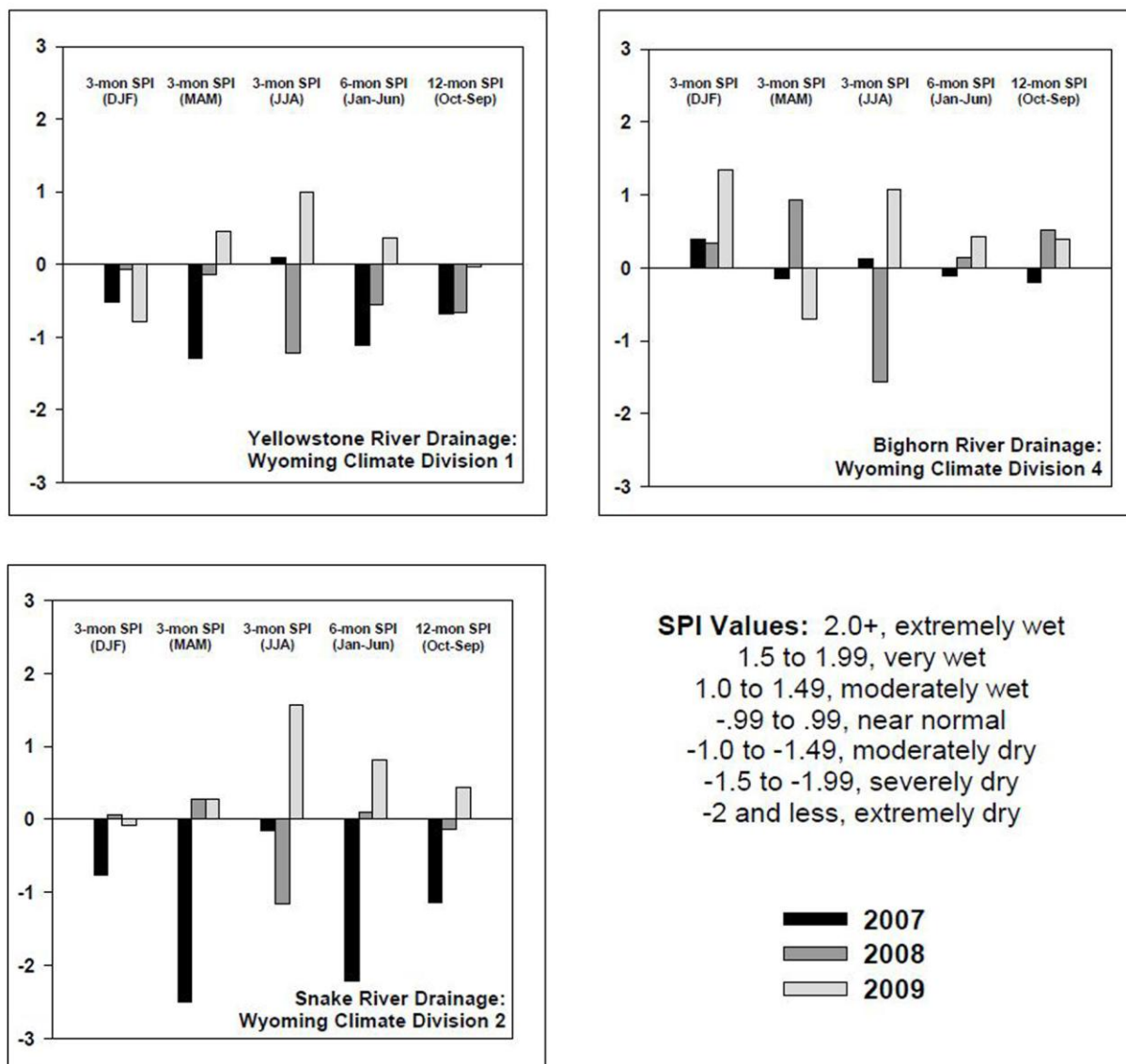


Figure 17. Standardized Precipitation Index (SPI) for three GRYN watersheds during 2007–2009. Data are organized by month. DJF = December, January, February. MAM = March, April, May. JJA = June, July, August. The Snake River drainage is located in Grand Teton National Park and southern Yellowstone National Park.

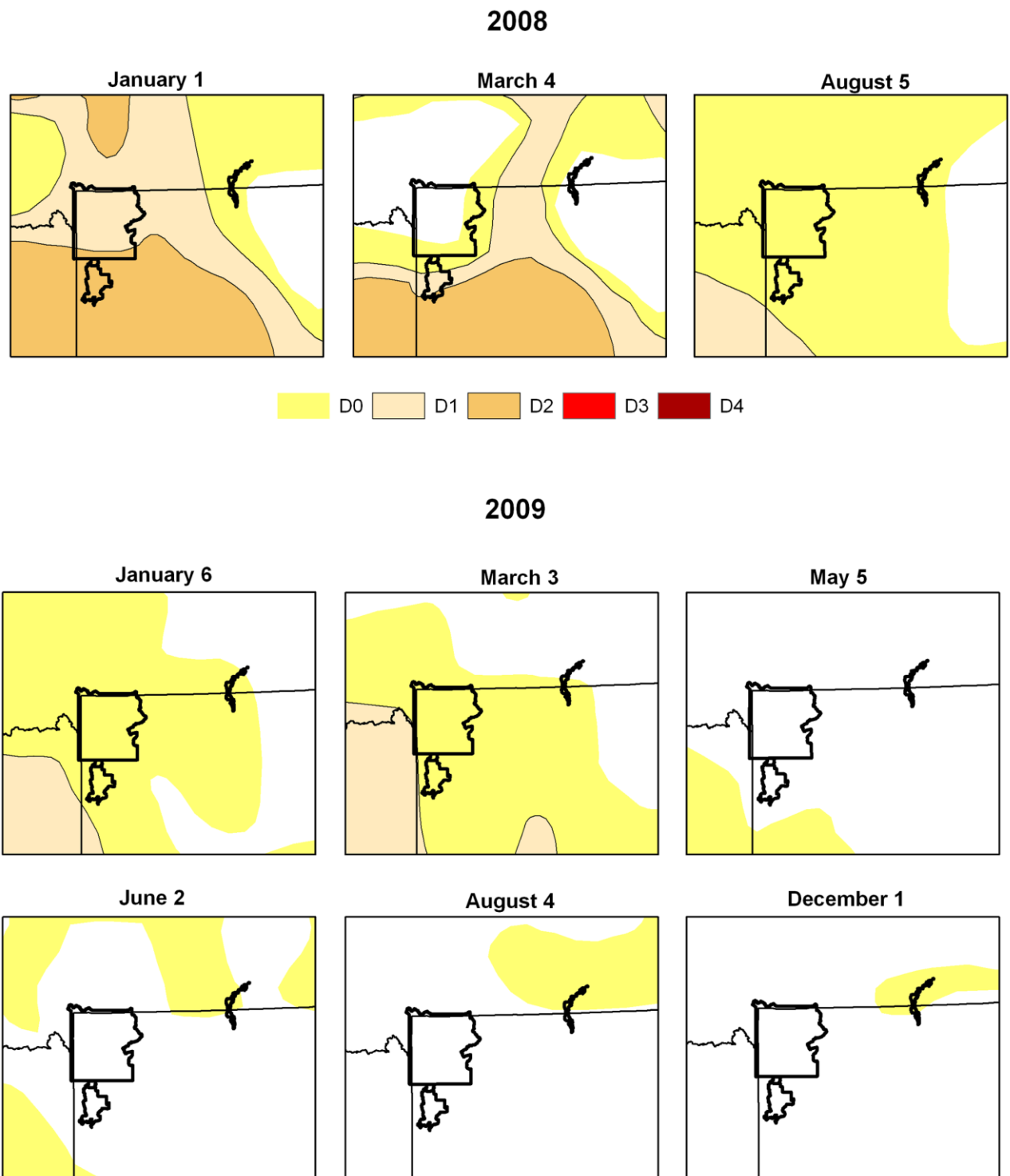


Figure 18. U.S. Drought Monitor maps for the Greater Yellowstone Network area over the course of calendar year 2009 and from selected months in 2008. Drought classifications range from “abnormally dry” (D0) to “exceptional drought” (D4).

7 Conclusions

Overall, 2009 was near normal in terms of total annual precipitation, average maximum temperatures, and average minimum temperatures, when compared to 1971–2000 averages. These annual statistics, however, do not reflect the large fluctuations that were seen from month to month. Indeed, if a single phrase were to be used to describe the year 2009, it would be “highly variable.” June, for example, saw precipitation in excess of 300% the 1971–2000 averages, while September had measurements that were 20–30% average. Similarly, September average daily maximum temperatures were in some locations six degrees above 1971–2000 averages, while October temperatures were roughly an equal amount below average. It was the balancing of these extremes—hot, dry months offering counterpoint to cold, wet months—that made 2009 an “average” year overall. In addition to the month to month variability, there was significant variability from place to place throughout the GRYN during 2009. For example, precipitation was near to slightly above the 1971–2000 average in Yellowstone and Grand Teton national parks, and somewhat below average in Bighorn Canyon National Recreation Area. Significantly, 2009 continued the recovery from drought that began in 2008. Even though 2009 had precipitation and snowpack that was similar to 1971–2000 averages, it was wetter than much of the previous decade.

8 References

- Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28(15): 2031–2064.
- Despain, D.G. 1990. Yellowstone vegetation, consequences of environment and natural history in a natural setting. Roberts Rinehart Publishers, Boulder, Colorado.
- Gray, S., C. Nicholson, T. Dietrich, and S. Laursen. 2009. Greater Yellowstone Network: Climate of 2008. Natural Resource Technical Report NPS/GRYN/NRR—2009/076. National Park Service, Fort Collins, Colorado.
- National Research Council. 2002. Ecological dynamics on Yellowstone's northern range. National Academy Press, Washington, D.C.
- Rocky Mountain Climate Working Group. 2010. Rocky Mountain climate protocol: Climate monitoring in the Greater Yellowstone and Rocky Mountain inventory and monitoring networks, Version 1.0. Natural Resource Report NPS/IMRO/NRR—2010/222. National Park Service, Fort Collins, Colorado.
- Tercek, M. T., S. T. Gray, and C. M. Nicholson. Forthcoming. Delineation of climate zones for the Greater Yellowstone Ecosystem, including Yellowstone and Grand Teton National Parks (Wyoming, Montana, Idaho). Submitted to the *Journal of Applied Meteorology and Climatology*.

Appendix A: National Weather Service COOP Stations

Table A1. National Weather Service Cooperative Observer (COOP) stations used in this report

Station	NWS_ID	Elev_ft	LatDMS	LongDMS	LatDD	LongDD	State	County	DataSource
ALTA 1 NNW	480140	6,434	43 46 22	-111 02 02	43.77278	-111.03389	WY	Teton	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy0140
Ashton	100470	5,212	44 02 33	-111 16 26	44.04250	-111.27389	ID	Fremont	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?id0470
Cody	481840	5,075	44 30 53	-109 02 42	44.51472	-109.04500	WY	Park	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy1840
Cooke City 2	241995	7,483	45 01 08	-109 57 18	45.01889	-109.95500	MT	Park	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt1995
Driggs	102676	6,120	43 43 50	-111 06 45	43.73056	-111.11250	ID	Teton	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?id2676
Lake Yellowstone	485345	7,870	44 33 43	-110 23 55	44.56194	-110.39861	WY	Park	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy5345
Lovell	485770	3,837	44 50 15	-108 24 15	44.83750	-108.40417	WY	Big Horn	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy5770
Yellowstone Park Mammoth	489905	6,230	44 58 36	-110 41 47	44.97667	-110.69639	WY	Park	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy9905
Moose	486428	6,444	43 39 13	-110 43 01	43.65361	-110.71694	WY	Teton	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy6428
Moran 5 WNW	486440	6,798	43 51 24	-110 35 20	43.85667	-110.58889	WY	Teton	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy6440
Old Faithful	486845	7,360	44 27 25	-110 49 58	44.45694	-110.83278	WY	Teton	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy6845
Pryor, 1S	246747	4,118	45 24 55	-108 33 18	45.41528	-108.55500	MT	Big Horn	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt6747
Shell 4 ENE	488124	4,393	44 34 00	-107 43 00	44.56667	-107.71667	WY	Big Horn	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy8124
Snake River	488315	6,882	44 08 00	-110 39 57	44.13333	-110.66583	WY	Teton	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy8315)
Yellowtail Dam	249240	3,305	45 18 46	-107 56 18	45.31278	-107.93833	MT	Big Horn	http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt9240)

Note: Station name, elevation, and location coordinates are from https://mi3.ncdc.noaa.gov/mi3_reports.shtml 6/28/2010

Appendix B: Natural Resources Conservation Service SNOTEL Stations

Table B1. Natural Resources Conservation Service SNOTEL stations used in this report

Station	Elevation (ft)	Latitude	Longitude	Latitude DD	Longitude DD	State	County	DataSource
Bald Mountain, WY	9,380	44 48	-107 51	44.8000	-107.8500	WY	Big Horn	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=309&state=wy
Canyon, WY	7,870	44 43	-110 31	44.72	-110.52	WY	Park	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=384&state=wy
Fisher Creek, MT	9,100	45 04	-109 57	45.07	-109.95	MT	Park	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=480&state=mt
Parker Peak, WY	9,400	44 44	-109 55	44.73	-109.92	WY	Park	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=683&state=wy
Sylvan Lake, WY	8,420	44 29	-110 09	44.48	-110.15	WY	Park	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=806&state=wy
Sylvan Road, WY	7,120	44 29	-110 02	44.48	-110.03	WY	Park	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=807&state=wy
Shell Creek, WY	9,580	44 30	-107 26	44.5	-107.433	WY	Bighorn	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=751&state=wy

Note: DD = Decimal Degrees

Appendix C: U.S. Geological Survey Stream Gauging Stations

Table C1. U.S. Geological Survey stream gauging stations used in this report

Station	USGSID	Latitude	Longitude	Latitude DD	Longitude DD	State	County	DataSource
Madison River near West Yellowstone, MT	6037500	44 39	-111 04	44.6569	-111.0675	MT	Gallatin	http://waterdata.usgs.gov/nwis/uv?06037500
Yellowstone River at Yellowstone Lake Outlet, YNP	6186500	44 34	-110 23	44.5675	-110.3800	WY	Teton	http://waterdata.usgs.gov/nwis/uv?06186500
Yellowstone River at Corwin Springs, MT	6191500	45 07	-110 48	45.1119	-110.7936	MT	Park	http://waterdata.usgs.gov/nwis/uv?06191500
Bighorn River at Kane, WY	6279500	44 45	-108 11	45.7556	-108.1685	WY	Big Horn	http://waterdata.usgs.gov/nwis/uv?06279500
Bighorn River near St. Xavier, MT	6287000	45 19	-107 55	45.3167	-107.9167	MT	Big Horn	http://waterdata.usgs.gov/nwis/uv?06287000
Shell Creek near Shell, WY	6278500	44 34	-107 43	44.5650	-107.7122	WY	Big Horn	http://waterdata.usgs.gov/nwis/uv?06278500
South Fork Shoshone River near Valley, WY	6280300	44 13	-109 33	44.2083	-109.5542	WY	Park	http://waterdata.usgs.gov/nwis/uv?06280300
Snake River above Jackson Lake at Flagg Ranch, WY	13010065	44 06	-110 40	44.0989	-110.6675	WY	Teton	http://waterdata.usgs.gov/nwis/uv?13010065
Snake River at Moose, WY	13013650	43 39	-110 43	43.6525	-110.7092	WY	Teton	http://waterdata.usgs.gov/nwis/uv?13013650

Note: Station URL is given in parentheses. DD = decimal degrees.

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NPS 101/105996, November 2010

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