



Climate Monitoring in Glacier National Park: *Annual Report for 2009*

Natural Resource Report NPS/ROMN/NRTR—2010/388



ON THE COVER

Red Eagle Lake, Glacier National Park September 2008
Photograph by: Kurt Chowanski

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Annual Report for 2009

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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. Moreover, climate is critical to park management and visitor experience, is a driver of change in other vital signs and park resources, and there is evidence that climate has changed in the past century and will continue to change. Here, the Rocky Mountain Inventory & Monitoring Network (ROMN) provides a summary and analysis of climate within and around Glacier National Park (GLAC) for the 2009 calendar and water year (Oct 1- Sept 30). We focus on temperature and precipitation, while providing supplemental information on snowpack, streamflow, and regional drought status. We found the following:

- Compared to the standard climatological reference period (currently 1971-2000), GLAC temperatures in 2009 were just slightly cooler at lower elevations and slightly warmer at high elevations. Locally and regionally, maximum and minimum temperatures were higher than normal during January, February, September and November. However, these were balanced by a particularly cool March, October, and December.
- Compared to the last 30-years, precipitation was below average. September was a particularly hot and dry month. The region to the east of GLAC, the Rocky Mountain Front, experienced relatively less precipitation than the rest of the region.
- Snow-water equivalents and river flow throughout the park during 2009 were lower than average. Glacier County, on the east side of the park had moderate drought conditions for most of the year but the drought conditions let up in November and December.

Acknowledgments

We thank the Rocky Mountain Climate Group for putting together the protocol used to produce this report. Mike Tercek's COOP data screener was invaluable by providing station based summary statistics. This report was modeled after the work of Steve Gray and Mike Tercek for the Greater Yellowstone Network. Comments from A. Ray (NOAA) and NPS staff including M. Britten, T. Carolin, J. Potter, B. Schweiger, and D. Divoky, improved the manuscript.

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 2009). 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 & Monitoring Network (ROMN) provides a summary and analysis of climate within and around Glacier National Park (GLAC) for the 2009 calendar and water year (October 2008 – September 2009). The water year is a standard used for reporting hydrologic data because it begins and ends at a relatively dry period. We base our report on the best available climate records in and around Glacier National Park.

The climate of GLAC is characterized by a cool season stretching through fall, winter and spring, and summers with warm days and cool nights (Pederson et al. 2010). The Rockies are oriented perpendicular to the prevailing westerly winds creating extreme east-west climate gradients in the park and large amounts of snow at high elevations (Davey et al. 2007). It is frequently 10 to 15 F degrees cooler at higher elevations (NPS 2006). Glacier's western valleys generally receive more rainfall than the east where strong winds and sunny days predominate (NPS 2006). Climate is changing rapidly in this region and over the past 100 years the number of extremely cold days has declined while the number of extremely hot days has increased (Pederson et al. 2010). A discussion of the long-term trends in climate and the ecological implications of this change are beyond the scope of this annual report, but can be found in a recent paper by Pederson and colleagues (2010).

The purpose of this annual climate report is twofold: First, we describe recent climatic events from both local (single weather stations) and park-level perspectives (based on climate zones within the park). Second, we place park 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). We see the value in this report as simply providing a broad perspective on the climate of the park for 2009. 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. The trends report will present rigorous analyses of inter-annual variability, long-term historical trends, and correlate local trends with hemispheric climate patterns, such as the Pacific Decadal Oscillation.

Those interested in additional climate-related information for GLAC and the surrounding areas may seek the following resources:

- Western Regional Climate Center (<http://www.wrcc.dri.edu/>) - Current weather, forecasts, and summaries of historic climate data
- Drought Monitor (<http://drought.unl.edu/dm/monitor.html>)-Drought information for the US, the West, and by state

- NOAA (National Oceanic Atmospheric Administration) National Weather Service Climate Prediction Center (<http://www.cpc.ncep.noaa.gov/>)-Current weather, forecasts, and summaries of historic climate data
- Natural Resources Conservation Service National Water and Climate Center (<http://www.wcc.nrcs.usda.gov/>)-Snow information including maps of accumulation and SWE
- USGS (U.S. Geological Survey) Water National Information System (<http://waterdata.usgs.gov/nwis>)-Streamflow information from the USGS
- Montana Climate Office (<http://climate.nts.g.umt.edu/>)-State climate resource
- USGS summary of Flattop Mountain SNOTEL station (http://www.nrm.sc.usgs.gov/research/ftm_snow.htm) – Annual and historic summary of Flattop Mountain snowpack
- NOAA current surface observation map for area surrounding Missoula, MT including GLAC <http://www.wrh.noaa.gov/mso/newlcl.php>
- NOAA online weather data for area surrounding Missoula, MT including GLAC <http://www.weather.gov/climate/xmacis.php?wfo=mso>
- NOAA annual summaries and graphics for stations near GLAC : http://www.wrh.noaa.gov/mso/climate/summary/2009_summary.php

Methods

Data sources and station selection

Given the relatively sparse network of climate stations and complex topography of GLAC, 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 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).

In addition to PRISM data, ROMN acquired long-term data from weather stations (Table 1) and stream gauges (Table 2) within 40 km of GLAC (Fig. 1). The 40 km buffer distance was selected as a standard by the NPS 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 four monitoring networks (National Weather Service Daily Coop Stations (COOP; National Weather Service Cooperative Network); Snowpack Telemetry (SNOTEL; Natural Resources Conservation Service); the USGS stream gauges, and Environment Canada. GLAC and the 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 detail elsewhere (Kittel et al. 2009). Generally the selection criteria were:

1. Networks and stations provide good spatial coverage within GLAC—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.

At this point, we did not include data from RAWs stations because of potential issues with instrumentation, site biases, and shorter period of records (Kittel et al. 2010). Instead, we focus on stations where the purpose of the instrumentation is climate monitoring.

Climate zones used as reporting units

Records from individual precipitation and temperature observing stations are included as a way to highlight intra-regional variability (Table 1). However, rather than report on individual stations, we report on climate zones that have consistent seasonal and temporal dynamics (individual station data for temperature and precipitation from 2009 can be found in Appendix 1). These zones have been derived statistically from long-term temperature and precipitation records (Tercek et al. in review). In other words, stations with similar seasonal patterns of rainfall and temperature dynamics were grouped together and these groups often, but not necessarily, included neighboring stations of similar elevation. This statistical process resulted in the creation of two major climate zones and 5 subzones in and around GLAC (Tercek 2010; Fig. 2, Table 3).

Climate zone 1 roughly corresponds to the mountainous and lower elevation regions in and around GLAC (Fig. 2). Climate zone 2 corresponds to the stations more distant from the park in the cities and regions to the east and west of the park boundaries which we refer to as the Rocky Mountain Front and the Flathead Valley, respectively. An important difference between the two major zones is that Zone 1 stations tend to have a greater proportion of annual precipitation in November through January compared to Zone 2 (Tercek 2010).

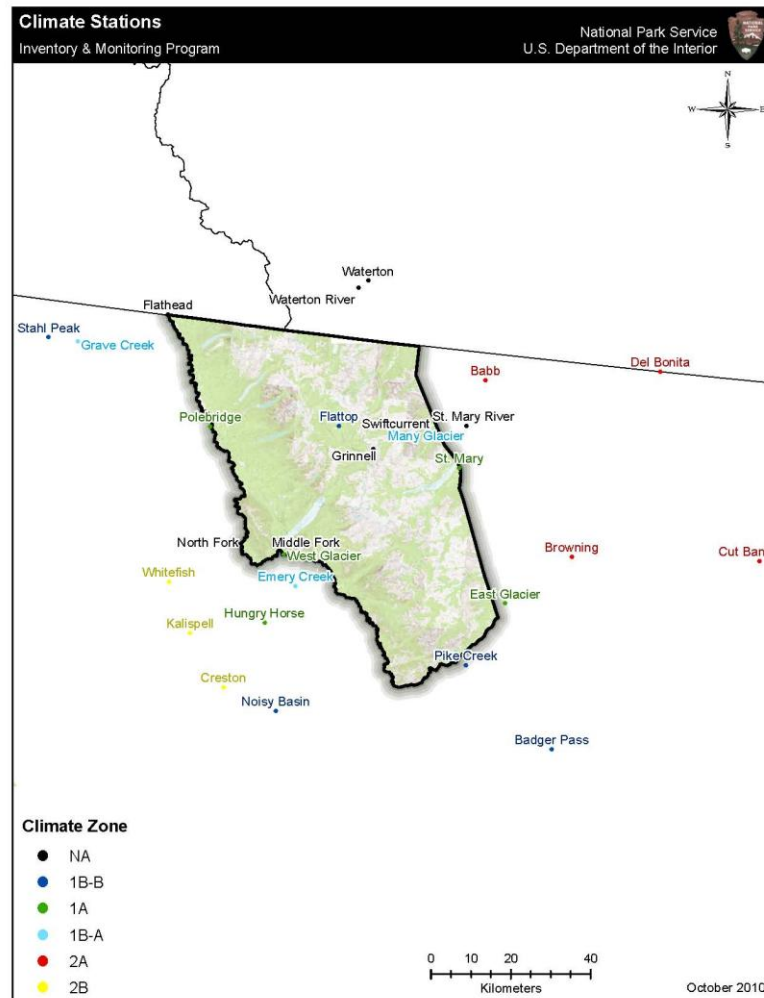


Figure 1. Map showing the locations and climate zone for weather stations included in this report. Colors indicate climate zones. Not all stations were include in the analysis of zones, these are indicated by black dots.

Table 1. Weather stations in and around Glacier National Park used for the 2009 climate status report. Recent data for Browning was not available

Station Name	Station ID	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Type	Start of record	Climat e Zone	Website
St. Mary	247292	48.738	-113.429	1390	COOP	5/1/1981	NA	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012829
West Glacier	248809	48.500	-113.985	961	COOP	7/1/1948	1A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012781
Babb 6 NE	240392	48.939	-113.372	1311	COOP	5/15/1906	2A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012861
Creston	242104	48.189	-114.134	896	COOP	2/1/1949	2B	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012715
East Glacier	242629	48.447	-113.224	1465	COOP	8/1/1949	1A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012768
Hungry Horse Dam	244328	48.343	-114.022	963	COOP	6/1/1947	1A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012750
Polebridge	246618	48.765	-114.284	1073	COOP	7/6/1933	1A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~30002969
Whitefish	248902	48.408	-114.359	945	COOP	11/1/1939	2B	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012769
Kalispell Airport	244558	48.3	-114.267	901	COOP	5/1/1899	2B	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012742
Cut Bank Municipal Airport	242173	48.6	-112.383	1170	COOP	1/1/1937	2A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012805
Del Bonita	242301	49.0	-112.783	1322	COOP	10/1/1960	2A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012878
Browning	241202	48.5667	-113.0167	1327	COOP	7/1/1948*	2A	http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwDI~StnSrch~StnID~20012800
Flattop Mountain	482	48.800	-113.850	1920	SNOTEL	1/1/1970	1B-B	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=482&state=mt
Many Glacier	613	48.800	-113.667	1494	SNOTEL	10/1/1976	1B-A	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=613&state=mt
Badger Pass	307	48.133	-113.017	2103	SNOTEL	10/1/1978	1B-B	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=307&state=mt
Emery Creek	469	48.433	-113.933	1326	SNOTEL	10/1/1976	1B-A	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=469&state=mt
Grave Creek	500	48.917	-114.767	1311	SNOTEL	10/1/1975	1B-A	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=500&state=mt
Noisy Basin	664	48.150	-113.950	1841	SNOTEL	10/1/1978	1B-B	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=664&state=mt
Pike Creek	693	48.300	-113.333	1807	SNOTEL	10/1/1979	1B-B	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=693&state=mt
Stahl Peak	787	48.917	-114.867	1838	SNOTEL	10/1/1975	1B-B	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=787&state=mt
Waterton	71154	49.131	-113.808	1289	Canada	10/1/1994	NA	http://www.climate.weatheroffice.gc.ca/climateData/dailyData_e.html?Prov=XX&timeframe=2&StationID=26850&Day=1&Month=10&Year=2010&cmdB1=Go

Table 2. Stream gauging stations in and around Glacier National Park used for the 2009 climate status report.

Station Name	Station ID	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Type	Start of record	Climate Zone	Website
Swiftcurrent creek	05014500	48.799	-113.656	1486	USGS	6/1/1912	NA	http://waterdata.usgs.gov/nwis/inventory/?site_no=05014500&agency_cd=USGS&agency_cd=USGS&
Middle Fork Flathead West Glacier	12357500	48.495	-114.009	954	USGS	10/1/1939	NA	http://waterdata.usgs.gov/nwis/inventory/?site_no=12358500&agency_cd=USGS&
Grinnell Glacier	05013900	48.758	-113.725	1927	USGS	7/1/1959	NA	http://waterdata.usgs.gov/nwis/inventory/?site_no=05013900&agency_cd=USGS&
North Fork Flathead Columbia Falls	12355500	48.495	-114.126	959	USGS	10/1/1910	NA	http://waterdata.usgs.gov/nwis/inventory/?site_no=12355500&agency_cd=USGS&
St. Mary River Babb	05017500	48.833	-113.419	1362	USGS	7/14/1901	NA	http://waterdata.usgs.gov/nwis/inventory/?site_no=05017500&agency_cd=USGS&
Flathead River British Columbia	12355000	49.002	-114.474	1209	USGS	4/1/1929	NA	http://waterdata.usgs.gov/nwis/inventory/?site_no=12355000&agency_cd=USGS&
Waterton River	05AD003	49.114	-113.839	-	Canada	6/1/1908	NA	http://www.wsc.ec.gc.ca/hydat/H2O/index_e.cfm?cname=graph.cfm&RequestTimeout=300

Zone 1 is divided into 3 subzones based on differences in the length of winter and mean annual temperature. While not all stations are within the boundary of the park, they are the best representatives of park climate and we therefore refer to these zones as the lower elevations of GLAC, mid elevations of GLAC, and high elevations of GLAC (Tercek 2010). For this report, station data were averaged within each zone.

Certain areas of the park (white regions in Fig. 2), could not be classified in a specific zone. It is important to note that correlation maps (Fig 2) are merely a technique for illustrating the *approximate* geographic area associated with each group of weather stations. Climate zones are formally defined by weather station data, and they consist of groups of weather stations. In topographically complex areas like GLAC, different statistical techniques can produce maps with differing climate zone boundaries (Tercek et al. in review).

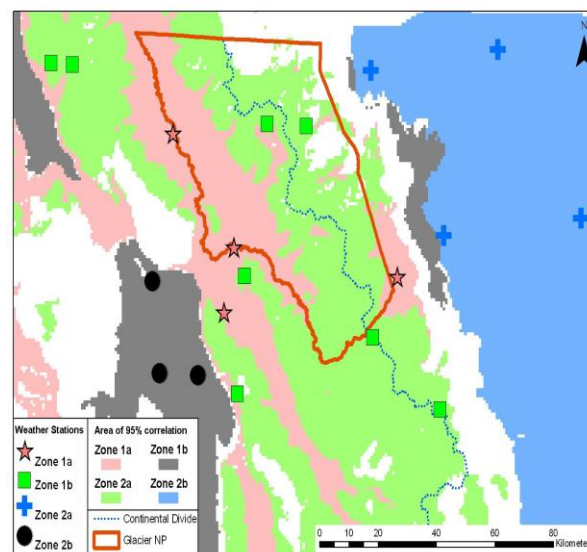


Figure 2. Map depicting climate zones showing areas that have 0.95 or greater correlation with weather stations in each climate zone. White areas had correlation below 0.95 for all zones. Map is from Tercek (2010).

Integrative measures of climate

Snowpack and streamflow measurements are presented as both integrators of multiple aspects of GLAC climate (e.g., temperature, precipitation, relative humidity) and as key drivers of ecosystem processes. Because there are relatively few stations, snowpack and streamflow data are presented from individual stations. We also present data on snowpack across the state of Montana that is made available by the Natural Resource Conservation Service. In the final section we present drought conditions as a “broad brush” overview of GLAC area climate throughout the year. These are based on data and maps made available through the USDA drought monitor (USDA 2010).

Data Quality Control and Analysis

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 all cases, 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.

With PRISM data, mean monthly maximum temperature, minimum temperature, and accumulated precipitation from 2009 were derived as percentiles of the period from 1971-2000. This 30 year period is the current standard used by climatologist as a reference or “normal period”. Normals are best used as a base against which climate during the following decade can be measured. The normal period changes at the end of each decade (e.g. the next change will be in 2011 where the standard normal period will shift to 1981-2010). We define the warmest and coldest or wettest and driest months as those in the top or bottom 20% of the 30 year reference period. In other words, those months are similar to the warmest or coolest 6 years on record. We present temperature and precipitation on a monthly basis for the region including GLAC at a scale of 4km. PRISM data are not available for Canada and therefore, these data end at the border. Maximum and minimum temperatures are reported because they are more reliable data than average temperatures.

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 GLAC area moisture status and hydrology. Temperature, precipitation, and snowpack observations for the reporting year are compared against the period of 1971–2000 where possible. There are no COOP stations, the preferred network for temperature measurements, at the mid and high elevations of GLAC and SNOTEL data were used instead. These data are not as reliable as COOP data and the length of record is often shorter. For these stations and zones temperatures were compared to the period of 1991-2000.

Table 3. Climate zones in and around Glacier National Park used for the 2009 climate status report. Zones are based on analyses in Tercek (2010).

Zone name	Zone number	Stations	Mean length of winter (days)	Mean elevation (m)
GLAC low-elevations	1A	West Glacier, East Glacier, Hungry Horse, Polebridge, St. Mary	153.2	1114
GLAC mid-elevations	1B-A	Many Glacier, Emery Creek, Grave Creek	180.7	1377
GLAC high elevations	1B-B	Flattop Mountain, Stahl Peak, Pike Creek, Badger Pass, Noisy Basin	244.8	1902
Flathead valley	2B	Kalispell, Creston, Whitefish	118.3	914
Rocky Mountain Front	2A	Babb, Cut Bank, Del Bonita	N/A	1285

Results

Temperature

Grid-based estimates of maximum and minimum average monthly temperatures generated via the PRISM approach were used to provide an overview of climatic conditions in the GLAC area. Average maximum and minimum temperatures in 2009 varied considerably from month to month compared to the reference period of 1971-2000 where some months were much warmer than average and others were cooler (Fig. 3, 4). For most of the region, January and February maximum and minimum temperatures were much warmer than January and February of past years. March, on the other hand was cooler. Maximum temperatures during April through August were spatially variable over the region, but generally temperatures were slightly warmer than those same months during the normal period (Fig. 3). Minimum temperatures for the same months showed a stronger tendency to be warmer than the reference period, particularly during July and August (Fig. 4). September and November 2009 were particularly warm across the region, and in most locations maximum and minimum temperatures were in the warmest 20% of the reference period (Fig. 3, 4). On average, October and December were cool months.

To highlight the intra-regional variability, records from individual precipitation and temperature observing stations were averaged across the five zones (Table 3). Mean monthly minimum temperatures varied from less than 0°F (-18°C) to approximately 50°F (10°C; Fig. 5). For the year, average minimum temperatures for all zones were close to 30°F (-1°C; Fig. 5). Mean monthly maximum temperatures ranged from 20°F (-7°C) to over 80°F (27°C), with the annual averages all close to 50°F (10°C; Fig. 5). The warmest temperatures of the year were found in the Flathead valley. The highest elevation stations showed the coolest maximum temperatures compared to the other regions, particularly in the summer months. Minimum temperatures at high elevations were also cooler across the year, except for the winter months when minimum temperatures were slightly warmer than other locations. The low elevations showed colder minimum temperatures than high elevations. This pattern was unexpected and primarily driven by very cold temperatures in Polebridge. This is a consistent pattern and from 1971-2000, annual mean minimum temperature at Polebridge (24°F; -4°C) averaged almost 8 F degrees colder than West Glacier (31.7°F; 0°C). Temperatures at the mid and low elevations were similar for most of the year, but maximum monthly temperatures were warmer at low elevations during the summer months.

A comparison of monthly temperature departures from the reference period (Fig. 6), showed a pattern consistent with the PRISM data. Temperatures were generally warmer than average in January, February, September and November, and cooler than average during March, October, and December (Fig. 6). September temperatures were about 10 F degrees warmer than average and December temperatures were 10 F degrees cooler. The summer months tended to be slightly warmer than the average summer temperatures from 1971-2000. Temperatures from stations in the low elevations of GLAC and the Rocky Mountain Front were cooler compared to the reference period than temperatures in other zones, particularly in December.

The most reliable temperature data comes from COOP stations in and around the park. For this reason, we present data on average season length, extreme temperatures, and average growing degree days based on these stations (Table 4). Most stations recorded extreme summer (>90°F;

32°C) and winter (<0°F;-18°C) temperatures. As defined by frost, the shortest growing season was found at Polebridge and lasted from late July to late August. Creston and Hungry horse had a much longer frost-free period lasting from May to October.

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 Glacier National Park during 2009. Stations highlighted in green, red, and yellow are within the low elevation zones of the park, the Rocky Mountain Front, and Flathead Valley, respectively.

Station Name	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 ≤ 0F	# days ≤ 32 F
West Glacier	2-May	6-Oct	10-Jun	28-Sep	3127.5	1543	69	2	14	194
East Glacier	9-Jun	27-Sep	10-Jun	21-Sep	2234	882.5	11	0	33	213
Hungry Horse	25-Apr	6-Oct	2-May	5-Oct	3459	1848	65	8	NA	NA
Polebridge	9-Jun	25-Aug	30-Jul	23-Aug	2266.5	890	59	5	49	277
Cut bank	2-Jun	5-Oct	9-Jun	21-Sep	3072	1468.5	56	14	34	NA
Del Bonita	8-Jun	27-Sep	9-Jun	27-Sep	2734	1231	30	1	39	205
Creston	2-May	6-Oct	2-May	6-Oct	3419.5	1787	74	11	9	184
Kalispell	21-May	21-Sep	9-Jun	9-Sep	3271.5	1585	74	7	13	187
Whitefish	2-May	5-Oct	7-Jun	21-Sep	3006.5	1522	61	3	12	208

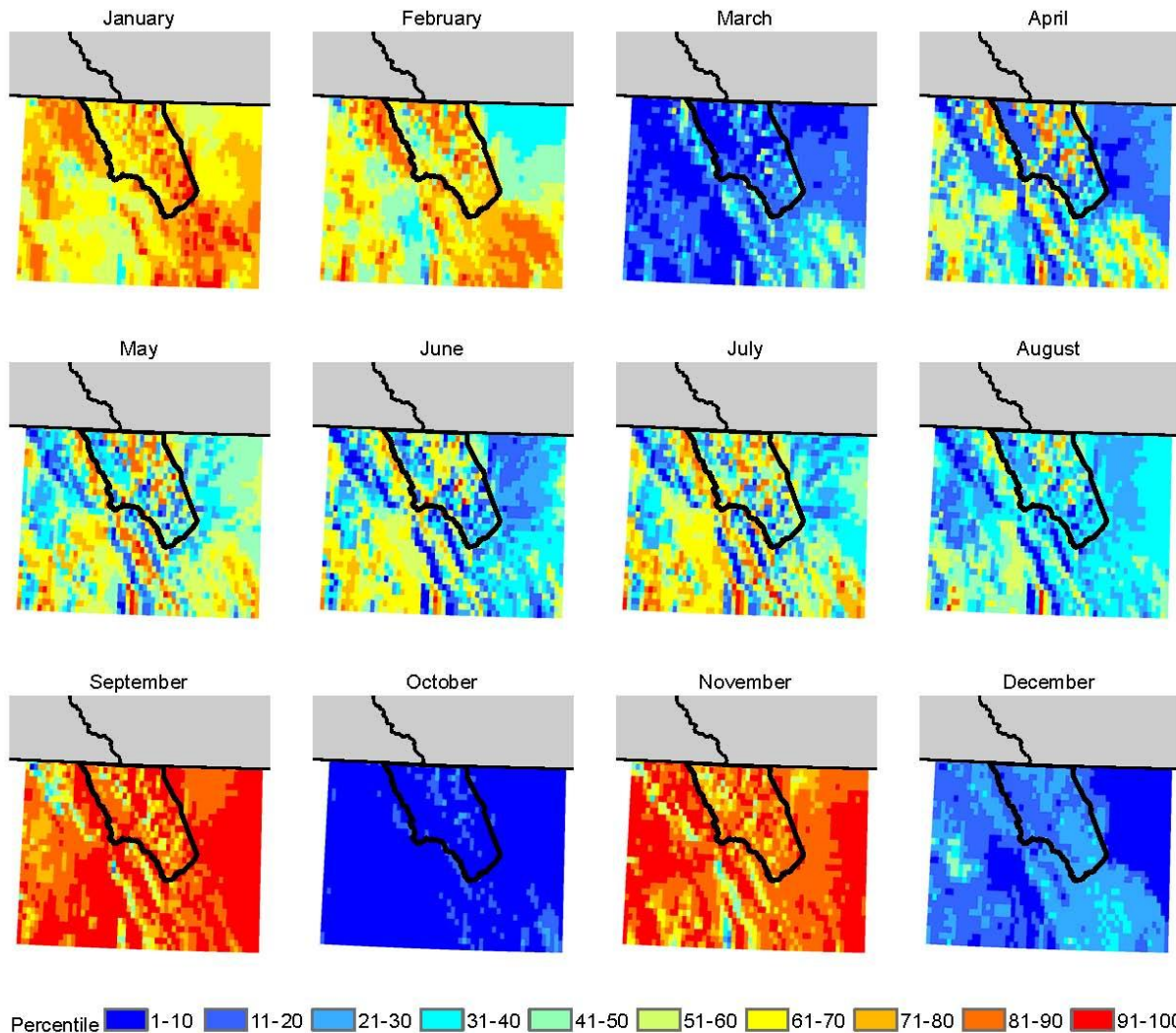


Figure 3. Maps showing departures from average maximum daily temperatures for each month in calendar year 2009 versus 1971–2000. Departure values are reported in degrees Fahrenheit. Maps were created using estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM interpolates 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/>.

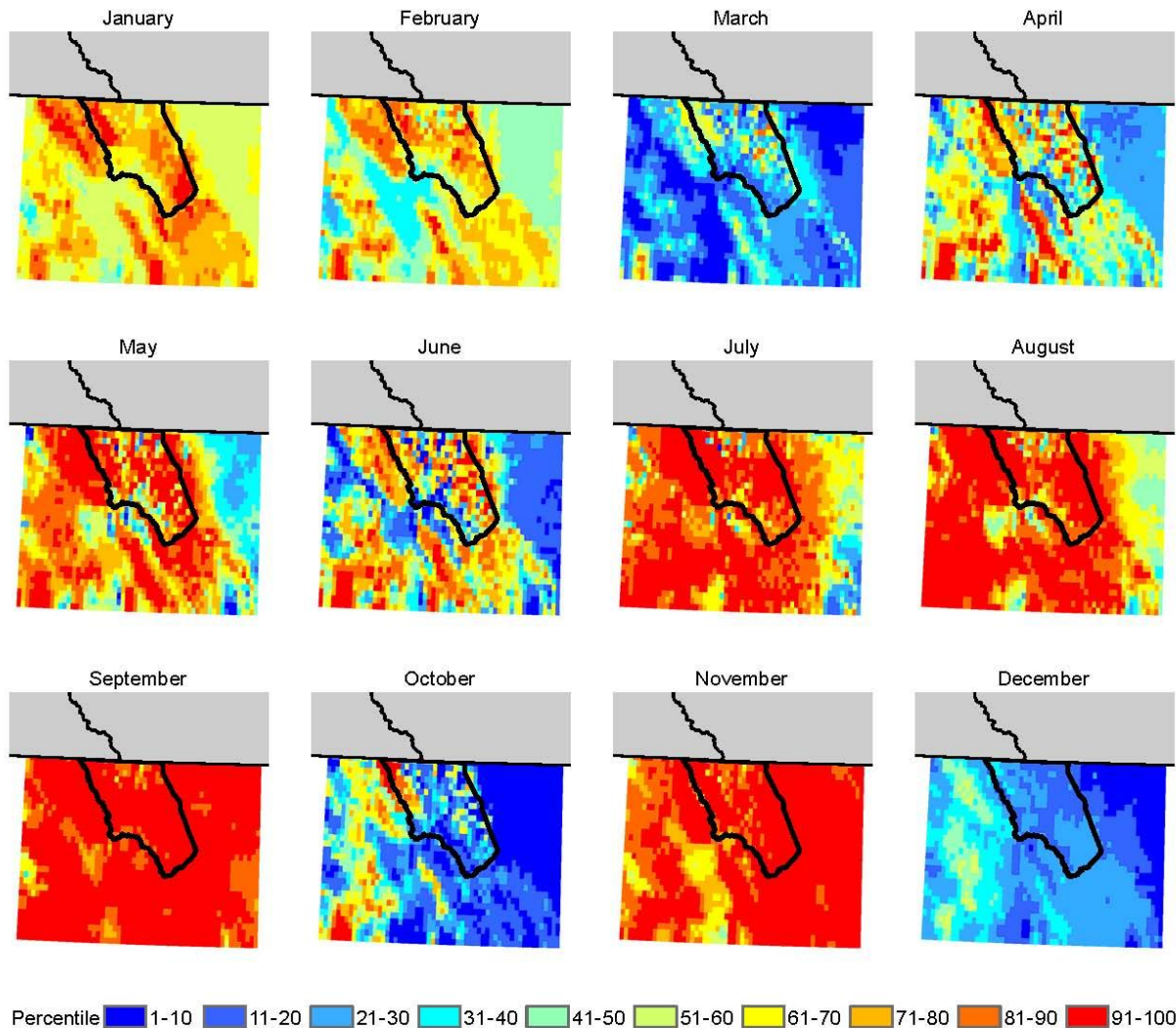


Figure 4. Maps showing departures from average minimum daily temperatures for each month in calendar year 2009 versus 1971–2000. Departure values are reported in degrees Fahrenheit. Maps were created using estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM interpolates 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/>.

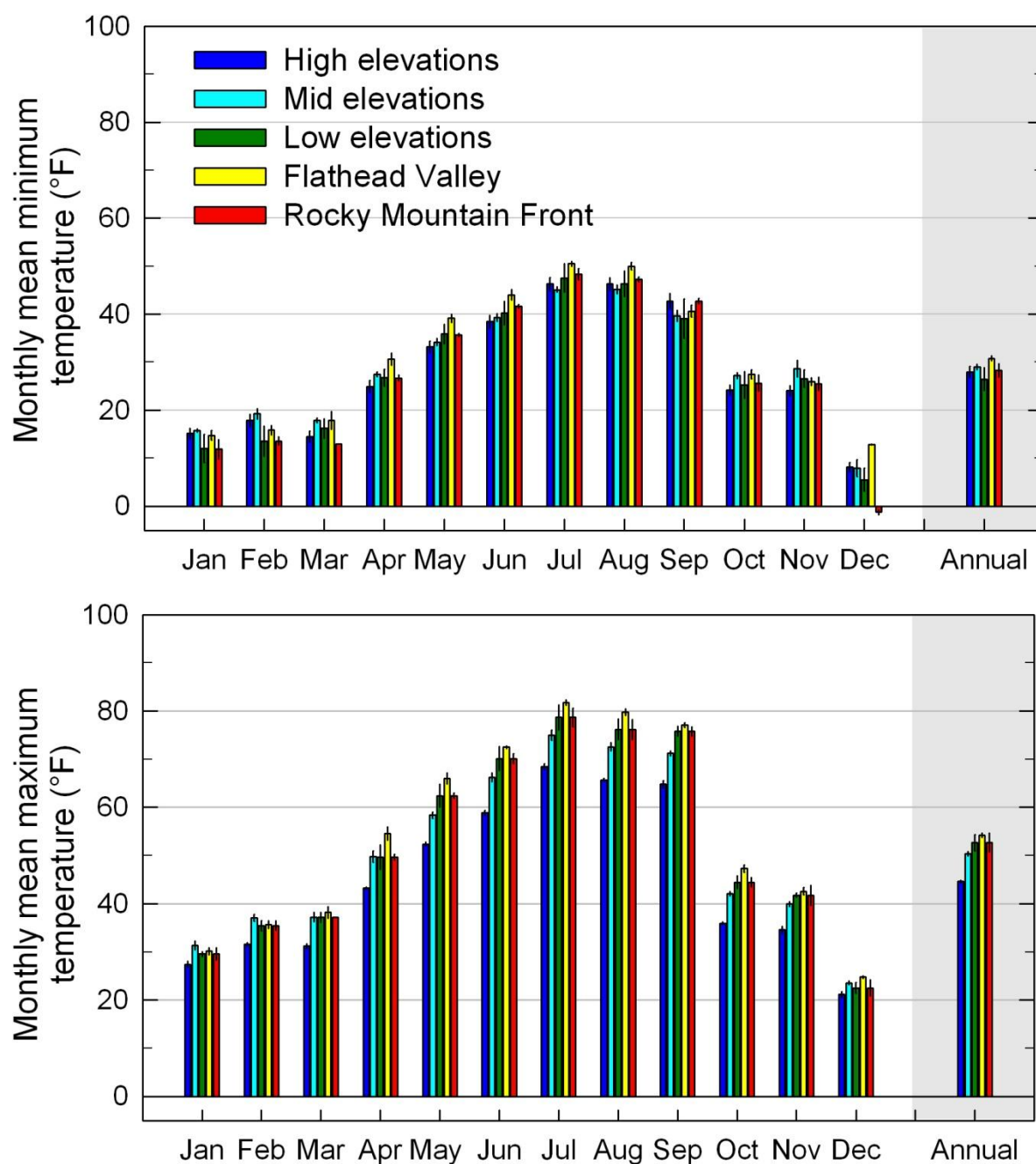


Figure 5. Monthly mean minimum and maximum temperatures during 2009 for five climate zones in and around Glacier National Park. Bars are mean values for climate stations in the corresponding zone, $n=2-5$, error bars represent ± 1 standard errors of the mean. High elevation and mid elevation zones are based on temperature from SNOTEL stations which are less reliable than data from the other zones.

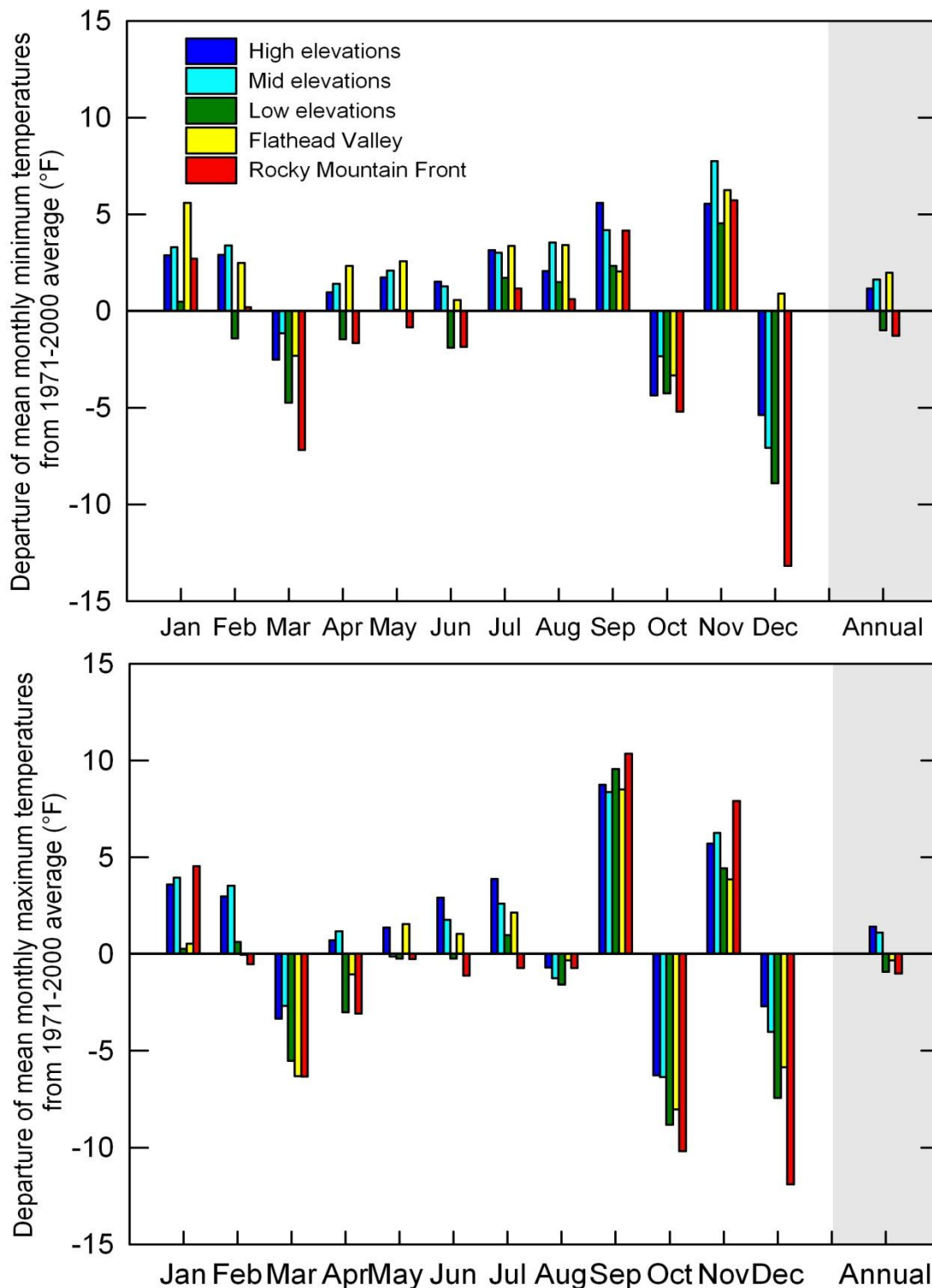


Figure 6. Departures of 2009 monthly mean minimum and maximum temperatures from mean temperatures for 1971-2000 for five climate zones in and around Glacier National Park. Bars are mean values for climate stations in the corresponding zone, $n=2-5$. High elevation and mid elevation zones are based on temperature from SNOTEL stations due to the length of the record and concerns of reliability the normals for these two zones are based on the period from 1991-2000 .

Precipitation

As with temperature, grid-based estimates of precipitation generated via the PRISM approach were used to provide an overview of climatic conditions in the GLAC area. Averaged across the year, precipitation was just slightly below average in 2009 compared to the normal period.

During January 2009, the eastern portion of GLAC was drier than average and the west was wetter (Fig. 7). In February, precipitation was highly variable throughout the park, but most regions saw close to average conditions. March was a wet month across the park and this was followed by fairly average precipitation in April, May, and June but there was a large amount of variation across the park. July, like March, was uniformly wetter than average. September was particularly dry and October was particularly wet across the region. The year closed with fairly average conditions in December, although as with the summer months, precipitation was spatially variable across the region.

The station based data were consistent with the PRISM data in 2009. Monthly precipitation totals in GLAC varied from 0 to 8 inches (0 to 203 mm; Fig. 8). Most precipitation fell in the winter months and the least fell in August and September. There is a clear gradient in annual accumulated precipitation across zones where the highest elevation stations recorded over 50 in (1270 mm) and the Rocky Mountain Front had less than 10 in (254 mm). With the exception of the Rocky Mountain Front, most zones ended up with just 20% less than average precipitation (Fig. 9). This was driven primarily by September precipitation where most areas experienced less than 25% of average. Mid and high elevations experienced conditions 150-200% wetter than average during January, November, and December (Fig. 9).

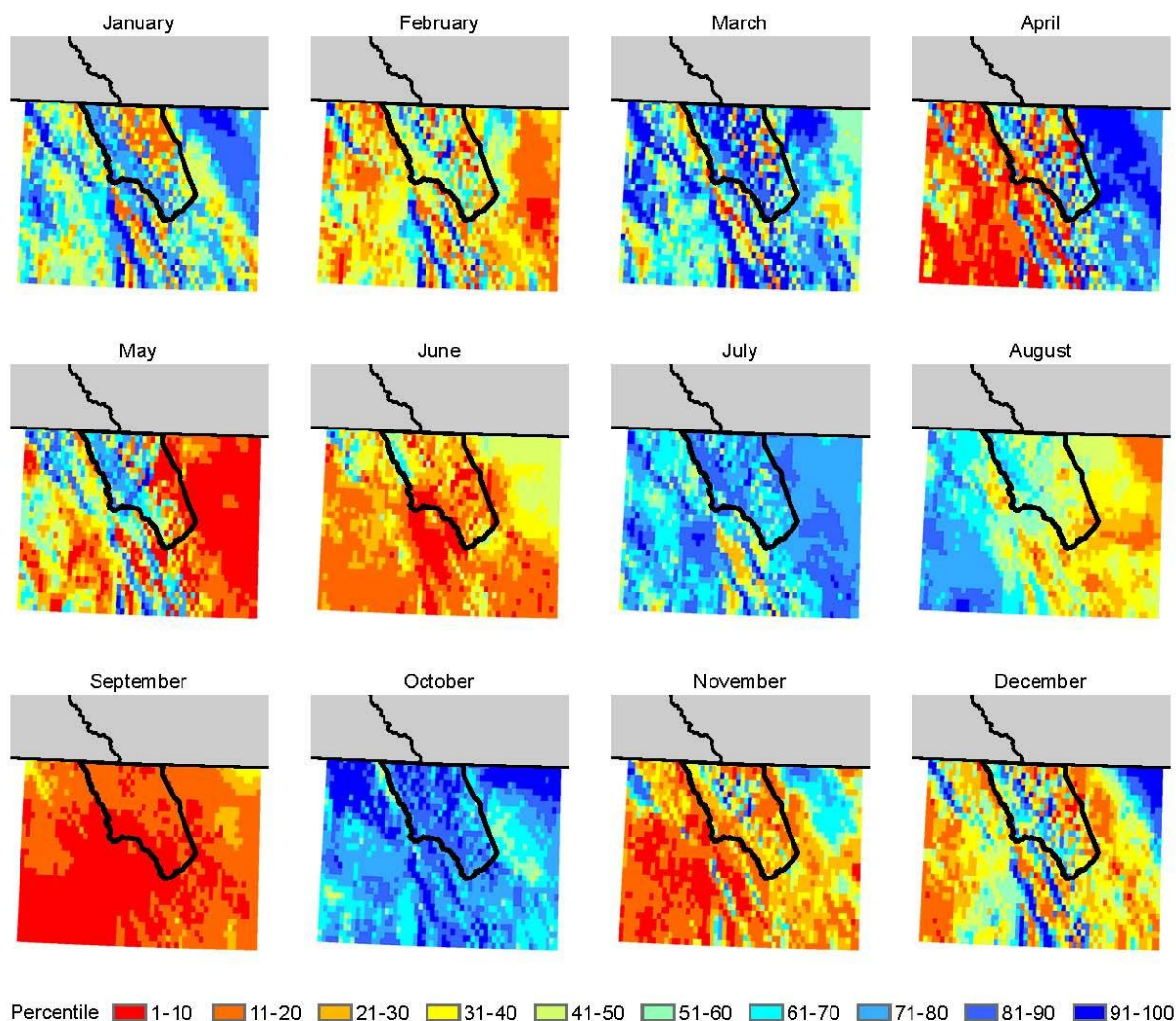


Figure 7. Maps showing percentiles of accumulated monthly precipitation versus 1971–2000 for each month in calendar year 2009. Colors show estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM interpolates precipitation values between actual observation stations, and corrects these interpolated estimates for changes in topography across the region. For more information, see <http://www.prism.oregonstate.edu/>. Red indicates that a given month was in the driest 20% of all months on records for 30 years. Blue indicates that a given month was in the wettest 20% for the 30 year period.

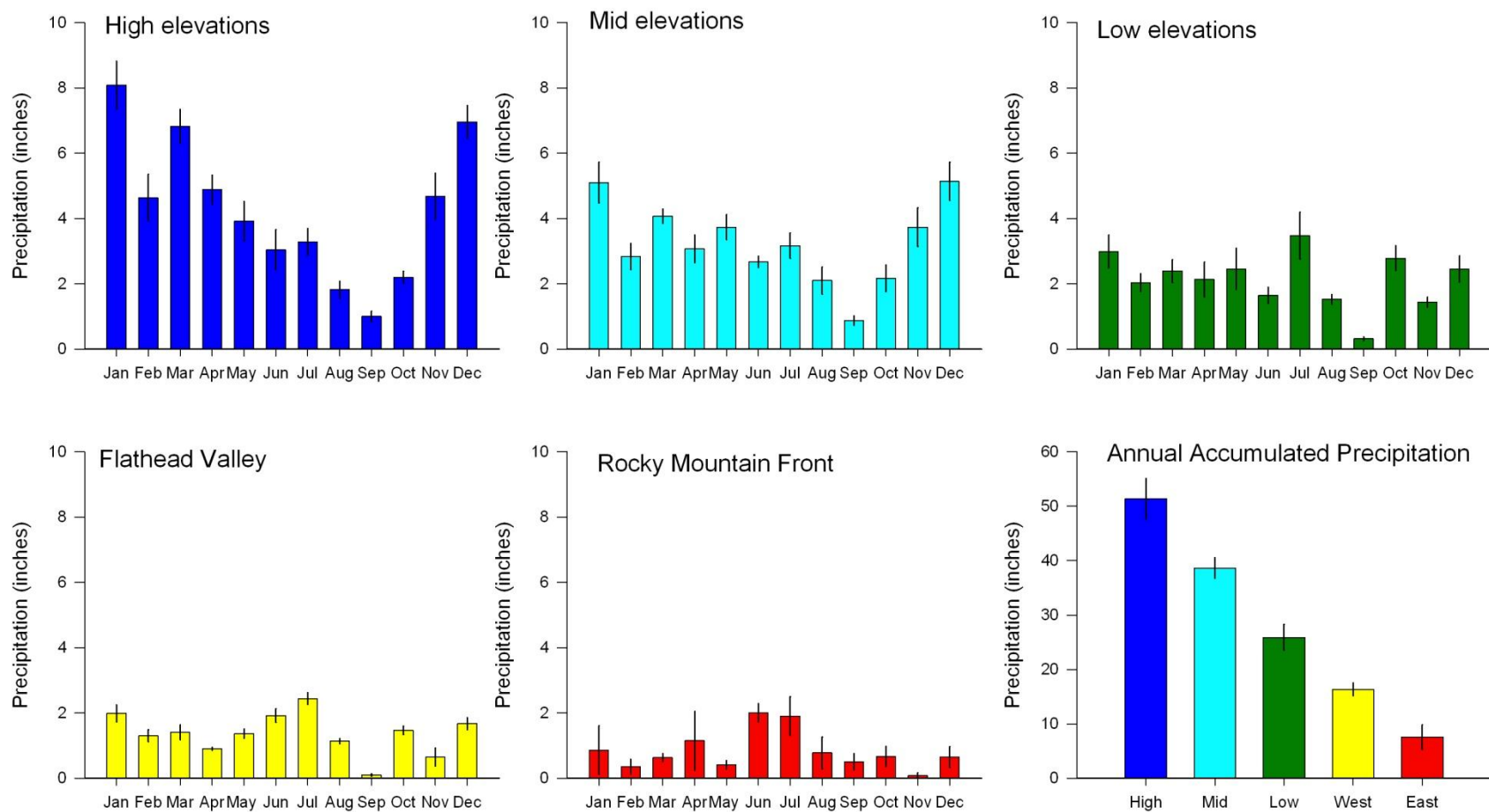


Figure 8. Monthly and annual accumulated precipitation in 2009 for five climate zones in and around Glacier National Park. Bars are mean values for climate stations in the corresponding zone, $n=2-5$. error bars represent ± 1 standard errors of the mean.

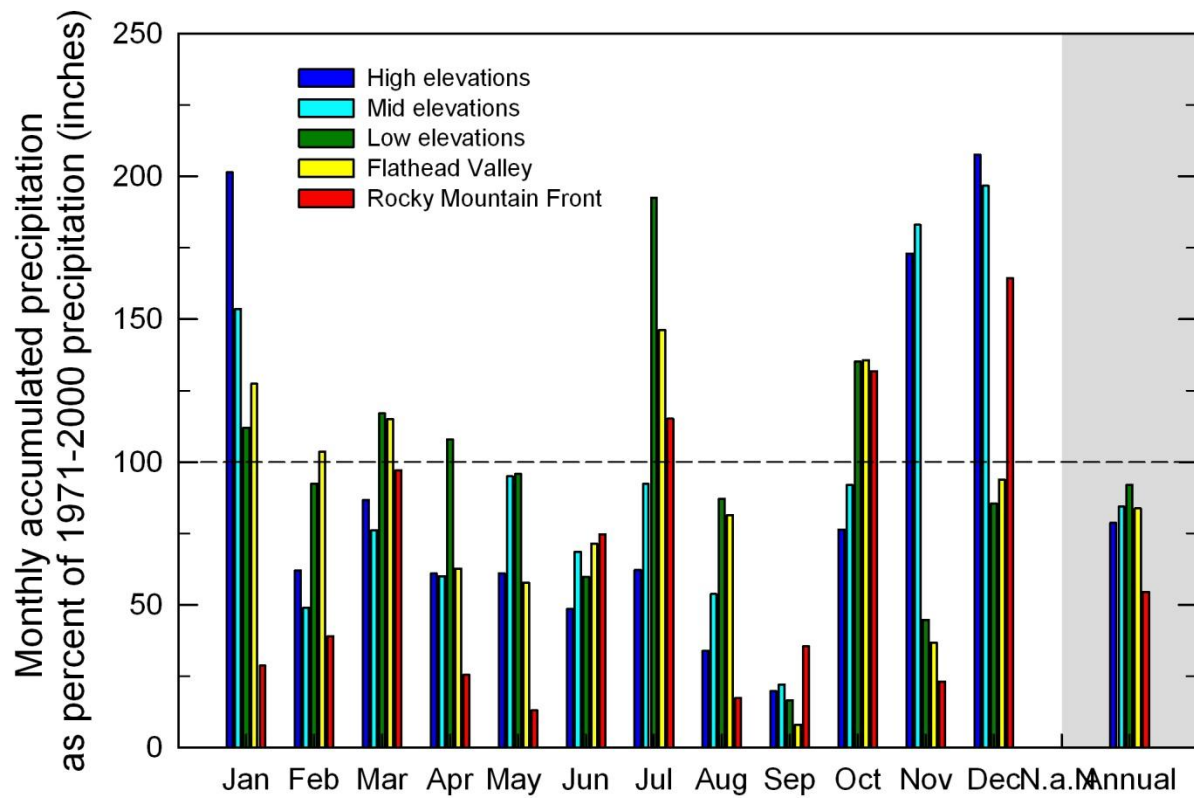


Figure 9. Monthly accumulated precipitation in 2009 as a percent of a normal period, 1971-2000, for five climate zones in and around Glacier National Park. Bars are mean values for climate stations in the corresponding zone, $n=2-5$. High elevation and mid elevation zones are based on precipitation data from SNOTEL stations and are compared to a normal period of 1971-2000 or from the initial recording year (mid 1970s) to 2000.

Winter Snowpack

The Natural Resources Conservation Service (NRCS) operates automated snow measurement (SNOTEL) stations throughout the region of GLAC. 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 was just below average during the 2009 water year (Fig. 10). Flattop Mountain, Many Glacier, and Pike Creek had the lowest snowpack compared the average snowpack for those locations from 1971-2000.

The maximum SWE for a given year is most often in April and the amount of SWE on April 1st is often used as an indicator of snowpack across years. In 2009, April 1 SWE varied from 15 in (381 mm) to 40 in (1016 mm), with the lower amount found at mid elevations (Fig. 11). Compared to the past 15 years, 2009 was well within the range of average snowpack (Fig. 11). In Figure 12, SWE on April 1 2009 is depicted as a percentage of average across sub-basins in Montana. The basins around GLAC are mostly below within 71-90% of average snow pack (Fig. 12).

Streamflow

Streamflow is monitored at numerous locations throughout the GLAC region. Following convention, we present data for the 2009 water year, which runs from October 2008 to September 2009. Total discharge on the Flathead River for all gauging locations, the Waterton River, the St. Mary River, and Swiftcurrent Creek (Fig. 13) was below the 1971 – 2000 average until late May and early June, when rapid snowmelt (Fig. 10) pushed the peak streamflow much above average. For example, at the North Fork of the Flathead River at Columbia Falls, peak flow was 459 cms on May 31 as compared to average historic flows of 334 cms at peak. Just a couple of weeks later, in mid June streamflows dropped to below average. Grinnell Creek is measured only during the summer months after ice melt. Grinnell Creek had average flows during 2009, but appears slightly lower than average in November.

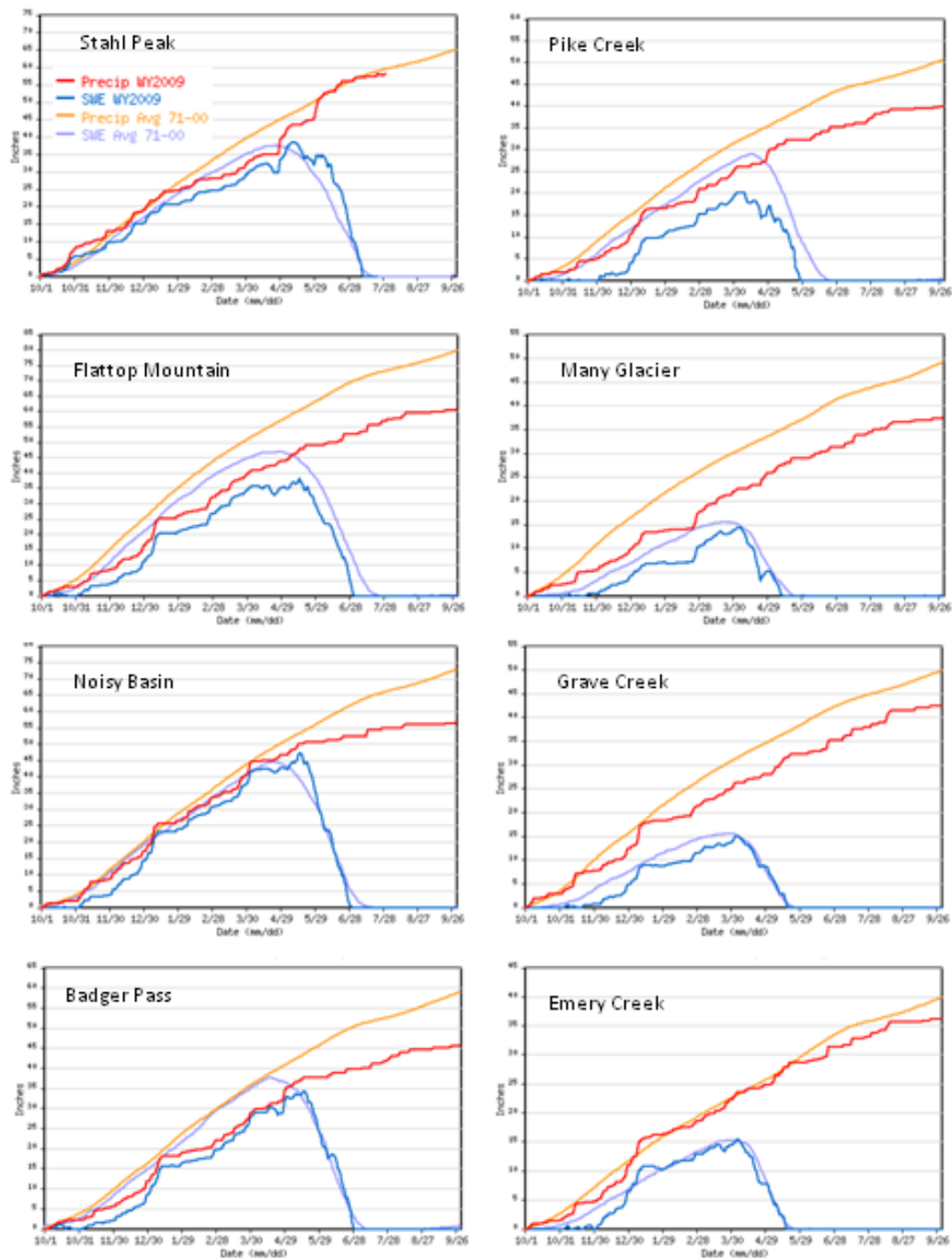


Figure 10. Daily measurements of snow water equivalent (SWE) and precipitation from representative sites in and near Glacier National Parks from October 2008 to September 2009. Values are compared to averages from the 1971–2000 period. Data courtesy of the Natural Resource Conservation Service. These provisional data are subject to change.

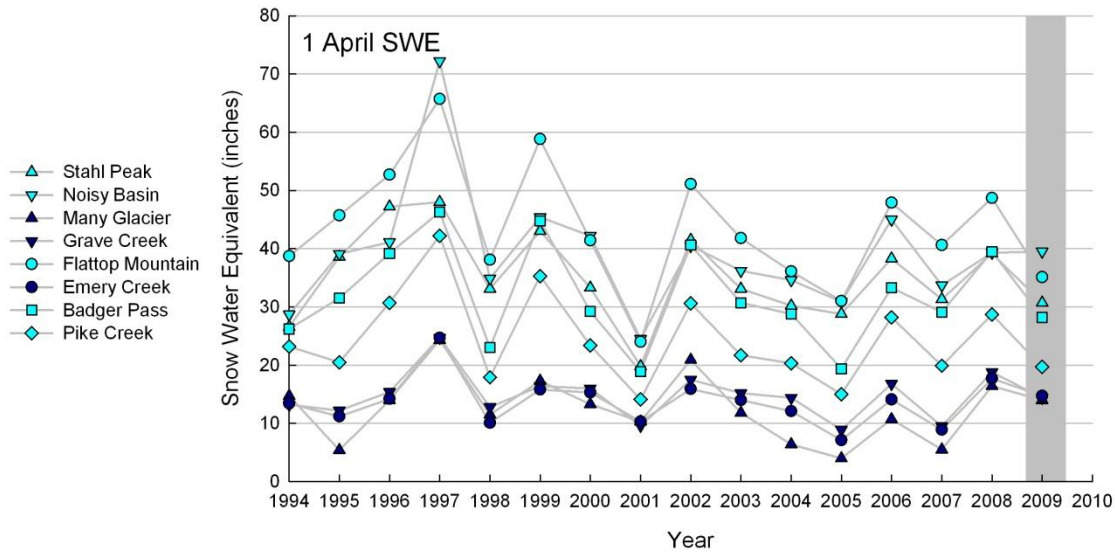


Figure 11. April 1 snow water equivalent (SWE) from SNOTEL sites in and near Glacier National Park for each year of a 15 year period from 1994-2009. 2009 is highlighted in gray. Data courtesy of the Natural Resource Conservation Service. These provisional data are subject to change.

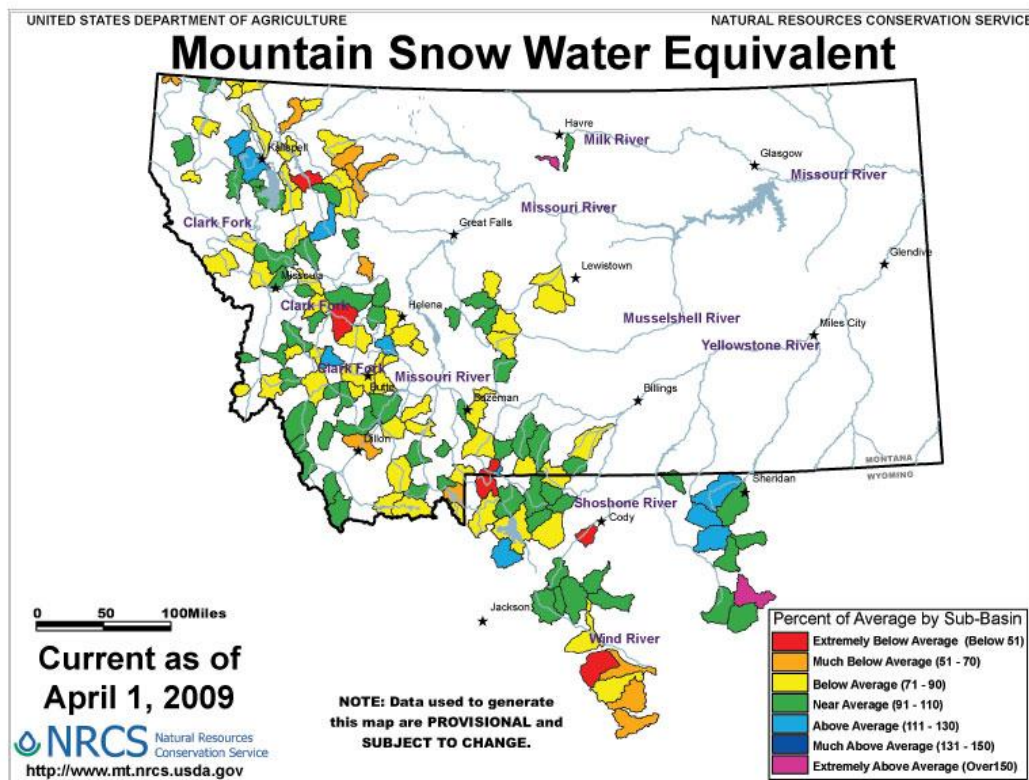


Figure 12. Snow water equivalent (SWE) from watersheds in Montana on April 1, 2009 as compared to April 1 averages from the 1971-2000 period. Data courtesy of the Natural Resource Conservation Service. These provisional data are subject to change.

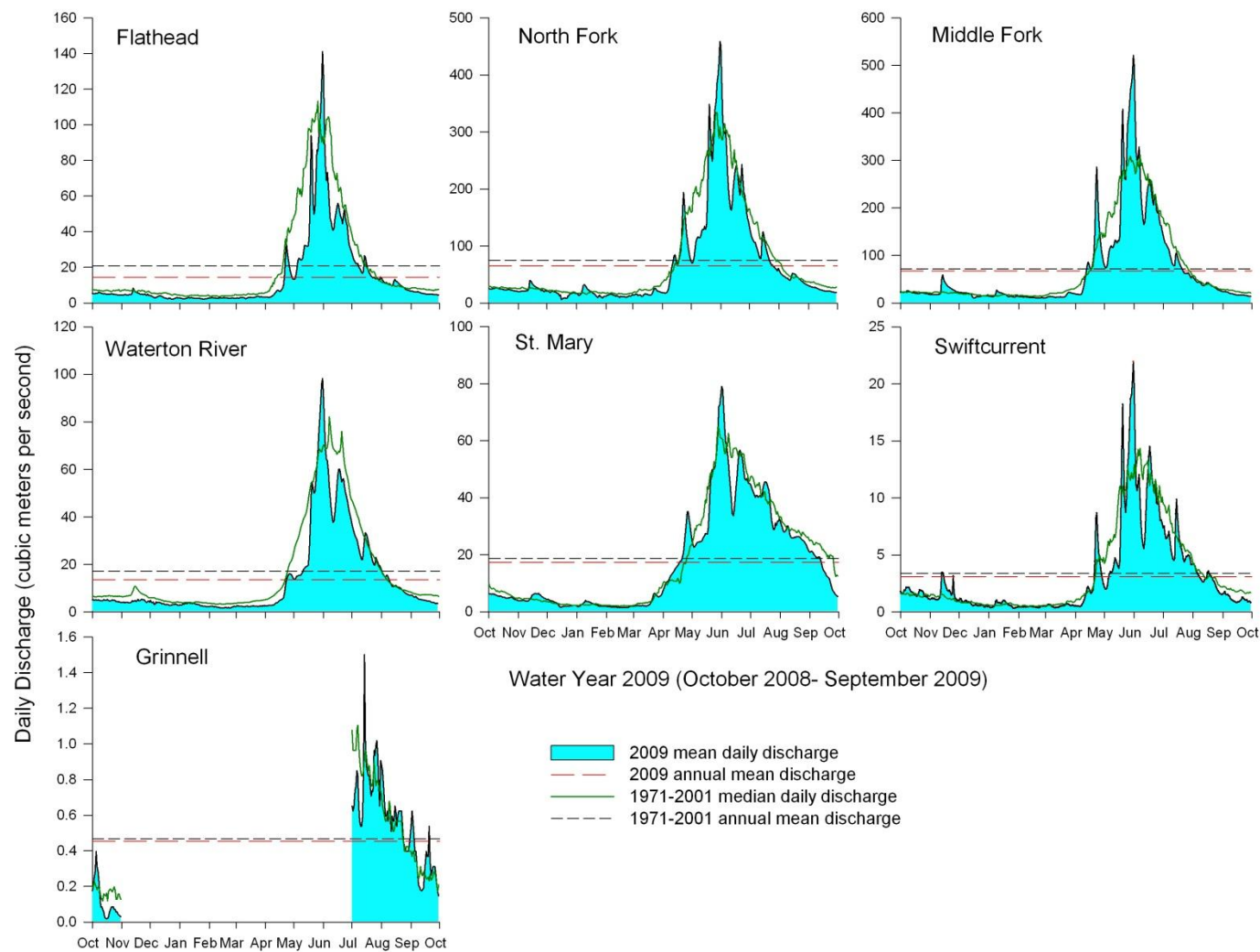


Figure 13. Mean daily and annual streamflow from gauges in and around Glacier National Park for the 2009 water year (October 2008 through September 2009) compared to median daily and annual mean flows from 1971-2000. Data courtesy the U.S. Geological Survey

Drought Status

The Drought Monitor, a collaborative effort among 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 GLAC and the 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 2009, Western Montana had conditions ranging from abnormally dry (D0) to moderate drought (D1; Fig. 14). During the spring of 2009 (April –June) most areas in the state improved to show no drought but the eastern portion of GLAC (Glacier county) remained in moderate drought conditions (D1; Fig. 14). Drought conditions returned to much of the state in July and August and became more severe on the east side of GLAC. An unusually dry September continued the drought in the east side, but a relatively wet October (Fig. 7) was able to offset conditions, so that by the end of the year, none of Montana was experiencing drought conditions but it remained dry (Fig. 14).

The Standardized Precipitation Index (SPI), a measure of drought based solely on precipitation, allows for a more detailed examination of drought conditions on multiple time scales. An SPI of zero indicates historical median or ‘near normal’ precipitation. The index is negative for drought, and positive for wet conditions. Figure 15 is a map developed by the National Climatic Data Center that depicts the SPI for climate divisions across the U.S for the 2008 and 2009 calendar year. In December 2008, western Montana varied from abnormally dry in some regions to abnormally wet in others. In December 2009, western Montana was abnormally dry. This is consistent with the Drought Monitor (Fig. 14) and shows that despite a couple of wet months during 2009, overall it was a dry year.

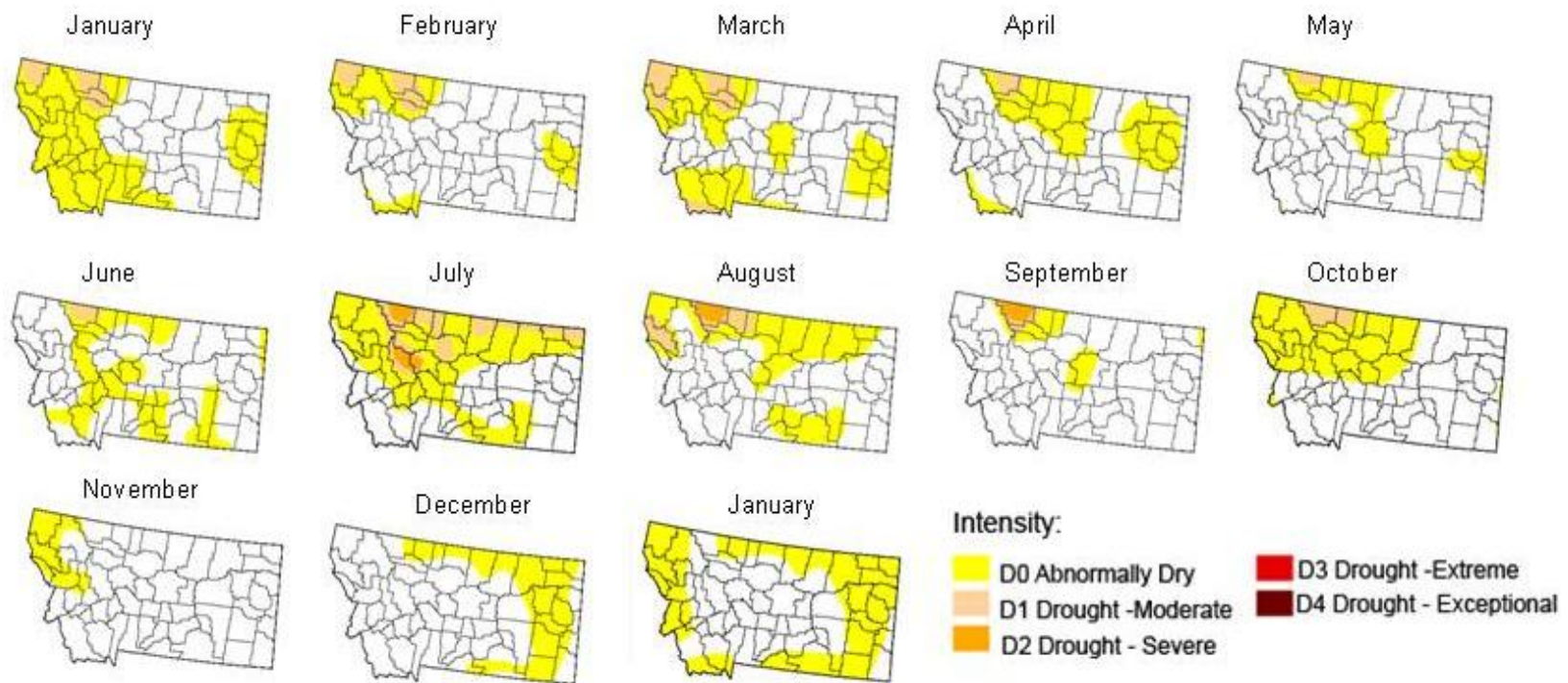


Figure 14. Monthly U.S. Drought Monitor maps for Montana over the course of calendar year 2009. Each month is represented by the drought status for first week of that month. Drought classifications range from “abnormally dry” (D0) to “exceptional drought” (D4). Maps courtesy of the USDA drought monitor.

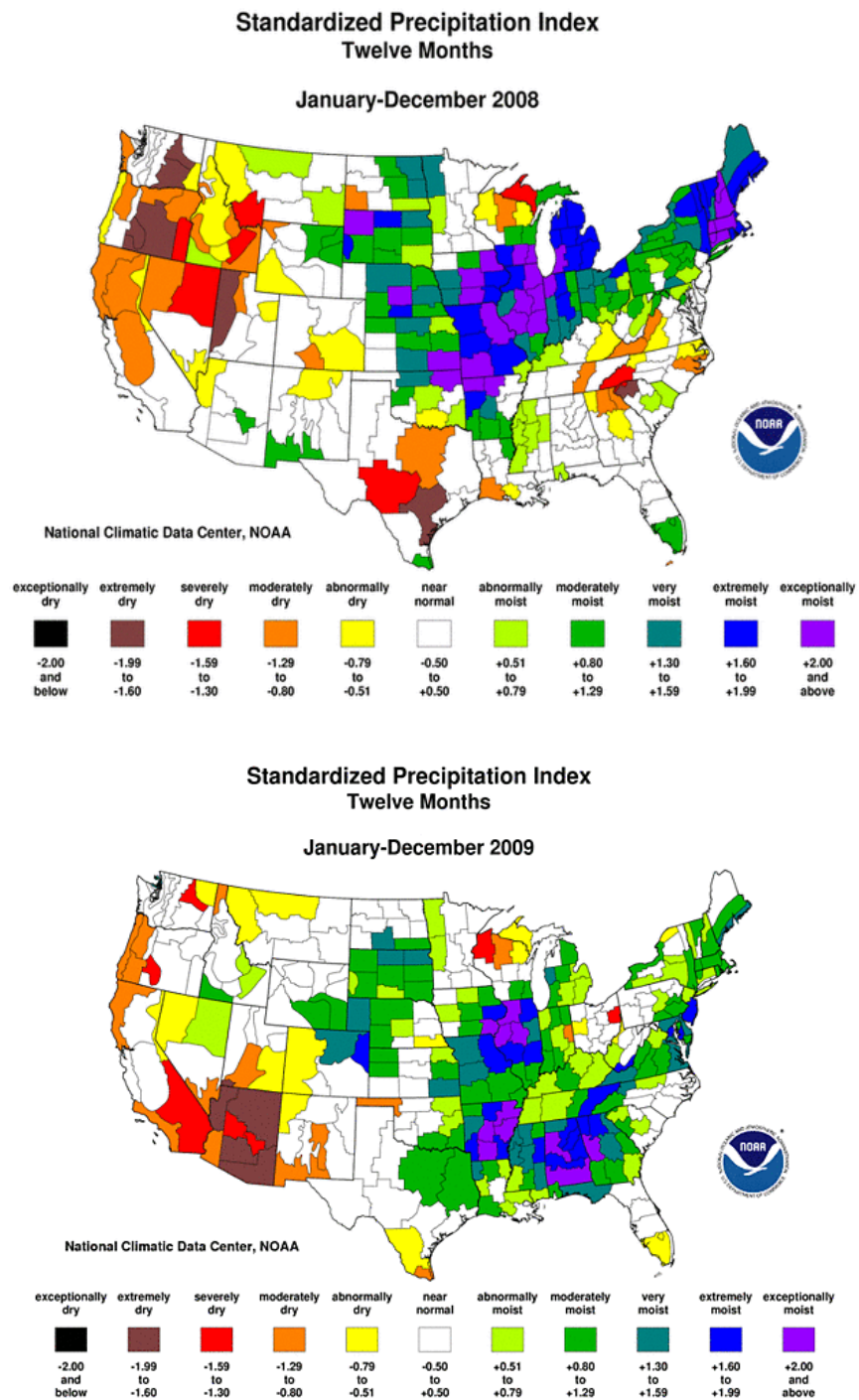


Figure 15. The Standardized Precipitation Index, a measure of drought based on precipitation, for the U.S. based on the 12 month period from January to December 2008 (top panel) and 2009 (bottom panel). Maps courtesy of the National Climatic Data Center From <http://www.ncdc.noaa.gov/sotc/?report=drought&year=2009&month=13>

Conclusions

- Maximum and minimum temperatures for GLAC were near normal when averaged across 2009. However, there was a large variation across months. The year began warmer than average but cooled off in the spring. Maximum temperatures then remained about average through August. Minimum temperatures were warmer than average during July and August. September and November were warmer than average, but these hot months were balanced by a cool October and December.
- Precipitation and snowpack in 2009 were average or just slightly below average. September was a particularly dry month compared to the historical average.
- Despite close to average precipitation and snowpack, average annual streamflow was below average in 2009. Rapid snowmelt lead to higher than average peak flows in mid-May but flow quickly dropped to below average in June and July.
- It was an abnormally dry year in 2009 with short periods of severe drought in the summer on the eastern side of GLAC.
- Trends in precipitation, and drought varied across the landscape, where the eastern portion of GLAC and the Rocky Mountain Front was drier than the west. This pattern is particularly apparent in January and May. High and mid elevations experienced a relatively warmer year than lower elevations

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Appendix

Below are tables and graphics for station based data.

Table A.1. Average maximum daily temperatures in degrees Fahrenheit for select Glacier National Park area stations during 2009 and departures from 1971 – 2000 averages.

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Creston	29.7	34.0	36.0	52.9	65.2	72.5	82.8	80.7	77.9	48.3	43.4	25.0	54.0
	-0.72	-2.10	-8.50	-2.07	1.39	1.73	4.27	1.34	9.73	-7.11	3.63	-6.50	-0.46
Cut bank	34.8	34.5	(-)	50.3	62.5	69.4	77.7	77.7	77.7	45.8	48.2	20.4	54.5
	6.41	0.80	(-)	-1.93	1.42	0.77	1.44	2.08	12.43	-8.16	10.23	-9.55	2.46
Del Bonita	32.2	32.6	35.1	49.1	61.5	67.4	73.9	73.5	75.8	43.9	44.1	16.9	50.5
	2.69	-1.83	-6.34	-4.23	-1.92	-3.00	-2.90	-3.52	8.27	-12.23	5.57	-14.30	-2.82
East Glacier	30.9	32.8	34.2	42.2	55.5	63.0	70.9	69.7	72.7	40.4	42.6	19.9	47.9
	1.10	-1.48	-7.17	-6.67	-3.95	-4.27	-2.70	-3.79	9.63	-12.15	5.13	-11.26	-3.09
Hungry Horse	28.5	35.1	38.6	50.4	63.7	71.9	81.8	78.6	77.1	45.9	41.4	(-)	55.7
	-0.98	0.57	-4.25	-3.27	-0.22	-0.07	1.67	-1.29	10.60	-6.26	4.13	(-)	2.14
Kalispell	31.5	36.1	40.2	57.4	68.4	73.0	81.8	80.0	77.1	47.6	43.3	25.1	55.1
	2.58	0.87	-4.71	1.37	3.65	1.13	1.57	-0.47	8.10	-7.65	4.67	-5.00	0.52
Polebridge	29.0	37.9	37.3	52.5	64.5	70.8	79.8	77.9	77.2	45.5	42.4	23.2	53.2
	0.50	2.23	-6.08	-1.40	1.65	0.50	1.64	-0.90	9.23	-9.52	4.87	-5.87	-0.23
St. Mary	(-)	(-)	(-)	46.4	(-)	(-)	(-)	77.2	(-)	43.1	41.3	23.0	(-)
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	
West Glacier	29.8	36.0	38.5	53.5	66.1	74.7	82.2	78.5	75.9	46.0	40.6	24.4	53.8
	0.51	1.16	-4.58	-0.67	1.60	2.87	3.26	-0.35	8.83	-7.40	3.63	-5.18	0.35
Whitefish	29.2	36.9	38.5	53.4	64.5	71.9	80.7	78.5	76.4	45.9	41.1	24.2	53.4
	-0.24	1.13	-5.75	-2.47	-0.38	0.23	0.58	-1.84	7.67	-9.33	3.30	-6.07	-1.07
Waterton	35.5	35.4	35.5	48.2	60.1	65.3	73.0	72.0	72.9	41.9	44.3	22.7	50.6

Note: 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.

Table A.2. Average minimum daily temperatures in degrees Fahrenheit for select Glacier National Park area stations during 2009 and departures from 1971 – 2000 averages.

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Creston	15.6	15.8	16.9	30.6	40.7	45.9	51.3	51.5	42.3	29.4	27.2	12.6	31.7
	0.55	-2.81	-8.40	-1.27	1.14	-0.07	2.02	3.88	3.73	-0.95	2.73	-4.99	-0.33
Cut bank	13.9	14.4	(-)	27.3	36.1	41.3	49.5	47.7	42.3	27.4	26.9	-0.8	29.6
	4.40	0.73	(-)	-2.37	-2.20	-4.53	-0.35	-1.59	1.77	-4.35	6.00	-13.37	-0.56
Del Bonita	9.8	12.7	13.0	26.0	35.4	42.0	47.1	46.8	43.3	23.9	24.0	-1.8	26.9
	0.84	-0.69	-6.90	-1.67	-0.95	-1.23	0.43	0.31	4.47	-6.66	5.13	-13.37	-1.74
East Glacier	12.9	14.2	16.1	25.3	34.6	38.7	45.5	45.6	40.7	23.6	27.7	4.0	27.4
	3.90	1.71	-1.87	-1.03	0.75	-1.70	1.45	2.28	4.70	-6.62	7.17	-8.77	0.11
Hungry Horse	15.0	16.5	18.2	30.9	40.4	46.2	54.2	52.5	47.7	30.3	29.5	(-)	(-)
	-1.00	-2.10	-6.11	-0.80	0.79	0.33	3.89	2.85	6.87	-2.51	4.23	(-)	(-)
Kalispell	15.8	17.6	21.5	32.9	39.0	42.1	49.5	48.7	38.2	26.8	24.6	12.8	30.8
	2.04	-0.79	-3.25	2.13	1.13	-1.37	2.82	2.88	1.10	-1.56	1.37	-3.29	0.31
Polebridge	3.6	4.4	10.5	22.8	30.8	34.5	40.3	39.3	27.9	17.9	21.2	1.6	21.2
	-2.19	-5.51	-6.75	-1.90	-1.19	-3.77	-0.41	0.19	-3.00	-5.46	3.93	-6.75	-2.76
St. Mary	(-)	(-)	(-)	23.2	34.0	(-)	(-)	(-)	(-)	(-)	28.7	3.4	(-)
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
West Glacier	16.7	19.0	20.0	28.3	37.6	41.7	50.1	48.1	39.9	29.3	27.8	10.9	30.8
	1.21	0.26	-4.20	-2.03	-0.12	-2.40	1.93	0.66	0.77	-2.44	2.77	-7.13	-0.94
Whitefish	12.8	14.1	15.1	28.5	37.6	44.1	50.8	50.0	41.4	26.4	26.1	13.0	30.0
	-0.06	-1.26	-7.17	-0.83	0.25	-0.33	2.07	2.16	3.30	-3.25	3.23	-2.80	-0.41
Waterton	15.5	15.3	16.2	28.6	37.0	40.4	46.2	45.5	41.1	25.9	31.5	4.7	29.0

Note: 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.

Table A.3. Total Monthly Precipitation in inches and percentage of average monthly precipitation versus 1971 – 2000 averages for select Glacier National Park area stations during 2009.

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Babb	2.34	0.81	(-)	2.94	0.63	(-)	(-)	1.69	(-)	(-)	0	0.7	(-)
	366	140	(-)	237	21	(-)	(-)	81	(-)	(-)	0	88	(-)
Creston	1.72	1.59	1.43	0.98	1.62	1.98	2.44	0.99	0.04	1.72	0.37	1.66	16.54
	130	134	109	57	64	69	136	67	3	138	24	104	82
Cutbank	0	0.13	0.48	0.34	0.43	1.66	1.18	0.04	0.2	0.29	0	0.06	4.81
	0	46	87	38	19	67	75	2	17	62	0	18	38
DelBonita	0.24	0.11	0.78	0.16	0.17	2.35	2.63	0.6	0.81	1.05	0.25	1.18	10.33
	57	31	107	13	7	82	156	32	54	202	46	311	71
East Glacier	2.94	2.39	3.41	3.71	0.98	1.47	5.88	1	0.36	2.25	1.63	2.35	28.37
	96	112	162	207	36	51	348	52	20	112	53	76	100
Hungry Horse	4.18	2.59	2.32	2.05	3.21	1.27	2.91	1.74	0.47	3.91	1.76	3.22	29.63
	124	101	94	86	102	36	130	91	18	138	44	85	85
Kalispell	1.73	0.96	1	0.82	1.12	1.53	2.76	1.16	0.14	1.29	0.37	1.35	14.23
	118	83	90	67	55	67	196	93	12	134	26	82	83
Polebridge	2.25	1.21	1.21	1	1.58	2.47	2.44	1.42	0.17	1.75	0.88	1.71	18.09
	101	68	83	83	93	110	155	108	15	131	37	72	87
St. Mary	1.55	(-)	2.65	2.9	(-)	(-)	(-)	1.82	(-)	2.69	1.53	1.46	(-)
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
West Glacier	4.01	1.95	2.35	0.99	4.04	1.36	2.68	1.63	0.26	3.31	1.38	3.5	27.46
	127	89	128	56	152	42	136	98	14	160	45	109	96
Whitefish	2.51	1.35	1.79	0.91	1.35	2.25	2.12	1.26	0.12	1.39	1.21	2	18.26
	134	94	146	64	54	78	108	85	10	135	61	95	86
Flattop Mountain	10.10	5.6	7.7	4.3	5.1	3.5	4.7	2.2	1.1	2.90	5.50	7.90	60.60
	192	57	75	42	64	49	77	35	18	83	194	217	77
Many Glacier	3.9	3.5	4.5	3.9	3	2.4	3.7	1.5	1.1	2.30	3.00	4.50	37.30
	91	54	79	74	73	60	109	40	27	96	135	140	76
Badger Pass	7.20	2.9	7	6.2	2.7	2	2.9	1.9	1.1	2.20	3.40	6.20	45.70
	186	48	104	80	47	33	59	37	25	98	111	194	77
EmeryCreek	5.40	2.1	3.8	2.5	3.9	2.6	2.4	1.9	0.6	1.40	3.30	6.30	36.20
	202	48	82	60	119	78	78	47	16	64	195	275	92
Grave Creek	6.00	2.9	3.9	2.8	4.3	3	3.4	2.9	0.9	2.80	4.90	4.60	42.40
	167	45	67	46	93	68	90	74	23	115	220	175	85
Noisy Basin	9.50	6.9	7.4	5.7	4.1	1.6	2.6	1.1	0.6	1.90	6.80	8.40	56.60
	251	88	83	66	60	21	41	19	11	47	233	215	78
Pike Creek	6.20	4	4.8	4.2	2.4	3	2.5	1.4	0.7	1.90	2.90	5.90	39.90
	198	67	76	66	47	62	65	33	18	89	129	211	79
Stahl Peak	7.4	3.8	7.2	4	5.3	5.1	3.7	2.5	1.5	2.1	4.8	6.4	53.80
	181	50	95	51	87	78	69	45	27	65	197	200	82
Waterton	1.43	1.88	2.16	2.14	1.38	2.31	3.98	1.86	0.50	2.43	0.55	1.54	22.16
	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: Percentages of average monthly precipitation versus 1971–2000 averages are given in the second line of data for each station. 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.

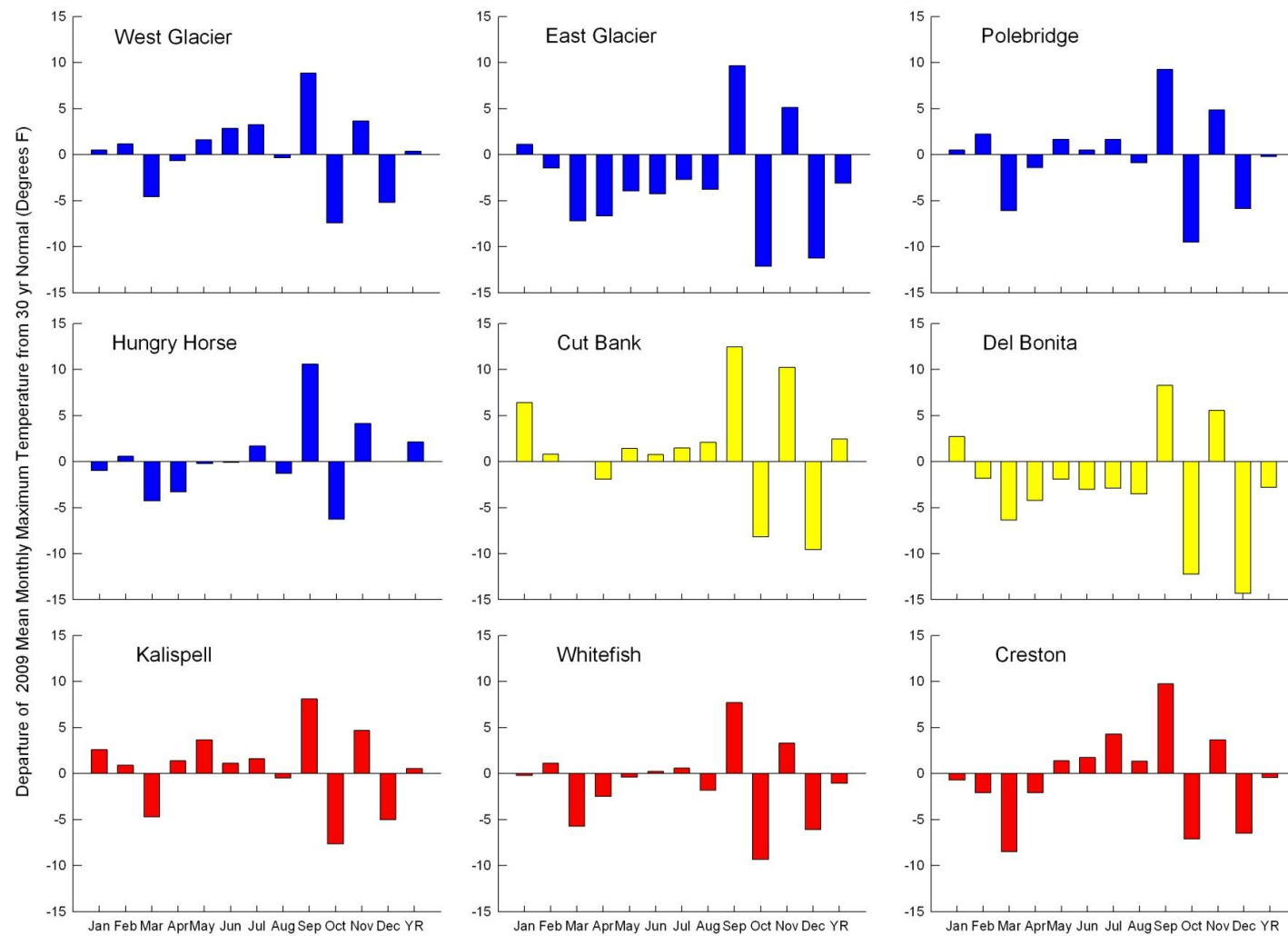


Figure A.1. Departure of average maximum daily temperatures from 1971 – 2000 average at key climate stations in and near Glacier National Park. Colors indicate the climate zone for each station. blue = zone 1a, yellow = zone 2a, red= zone 2b. Climate zone boundaries and stations locations are shown in Figure 2. SNOTEL stations (zone 1b) are not presented because of concerns about data reliability.

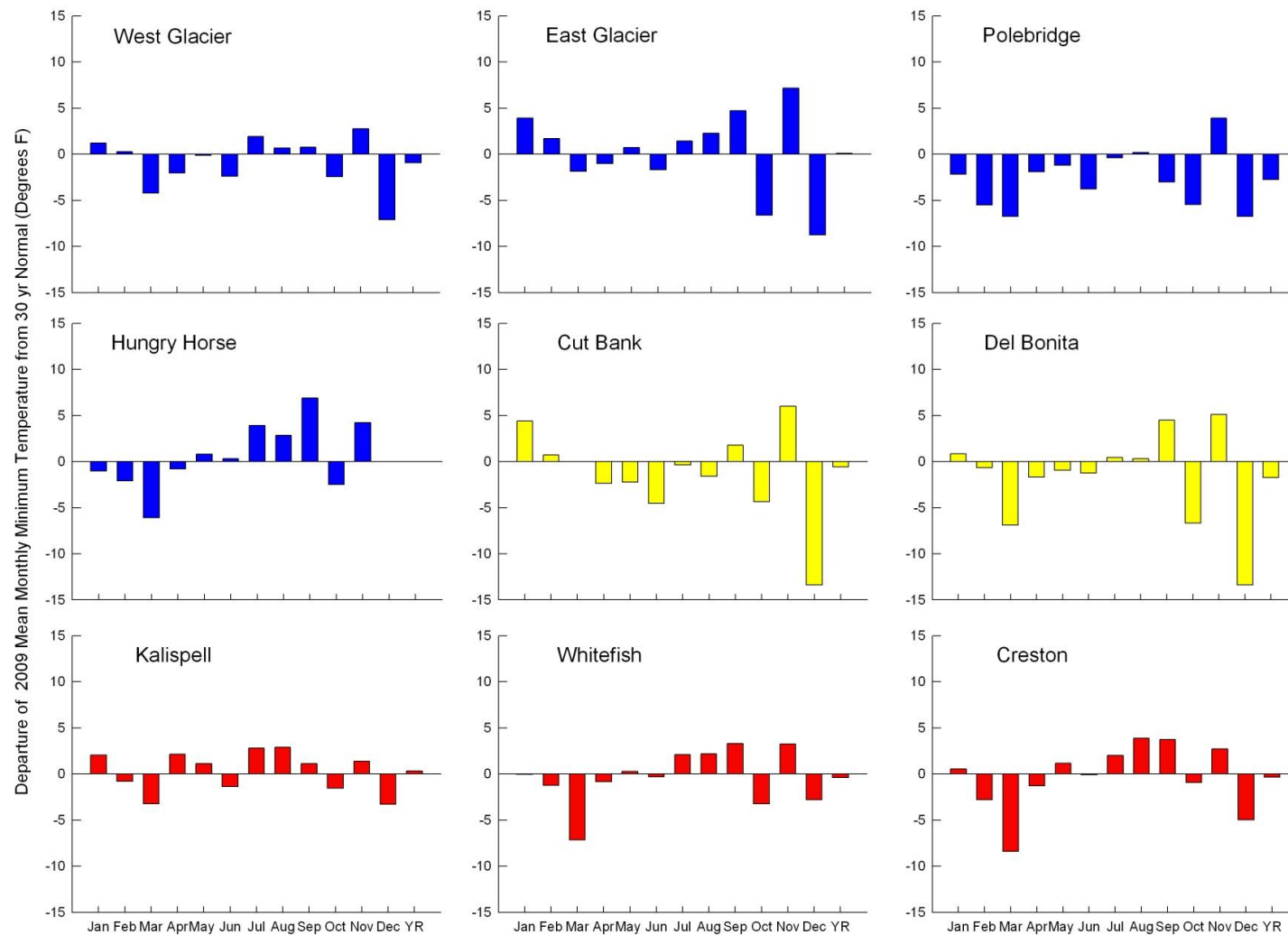


Figure A.2. Departure of average minimum daily temperatures from 1971 – 2000 average at key climate stations in and near Glacier National Park. Colors indicate the climate zone for each station. blue = zone 1a, yellow = zone 2a, red= zone 2b. Climate zone boundaries and stations locations are shown in Figure 2. SNOTEL stations (zone 1b) are not presented because of concerns about data reliability.

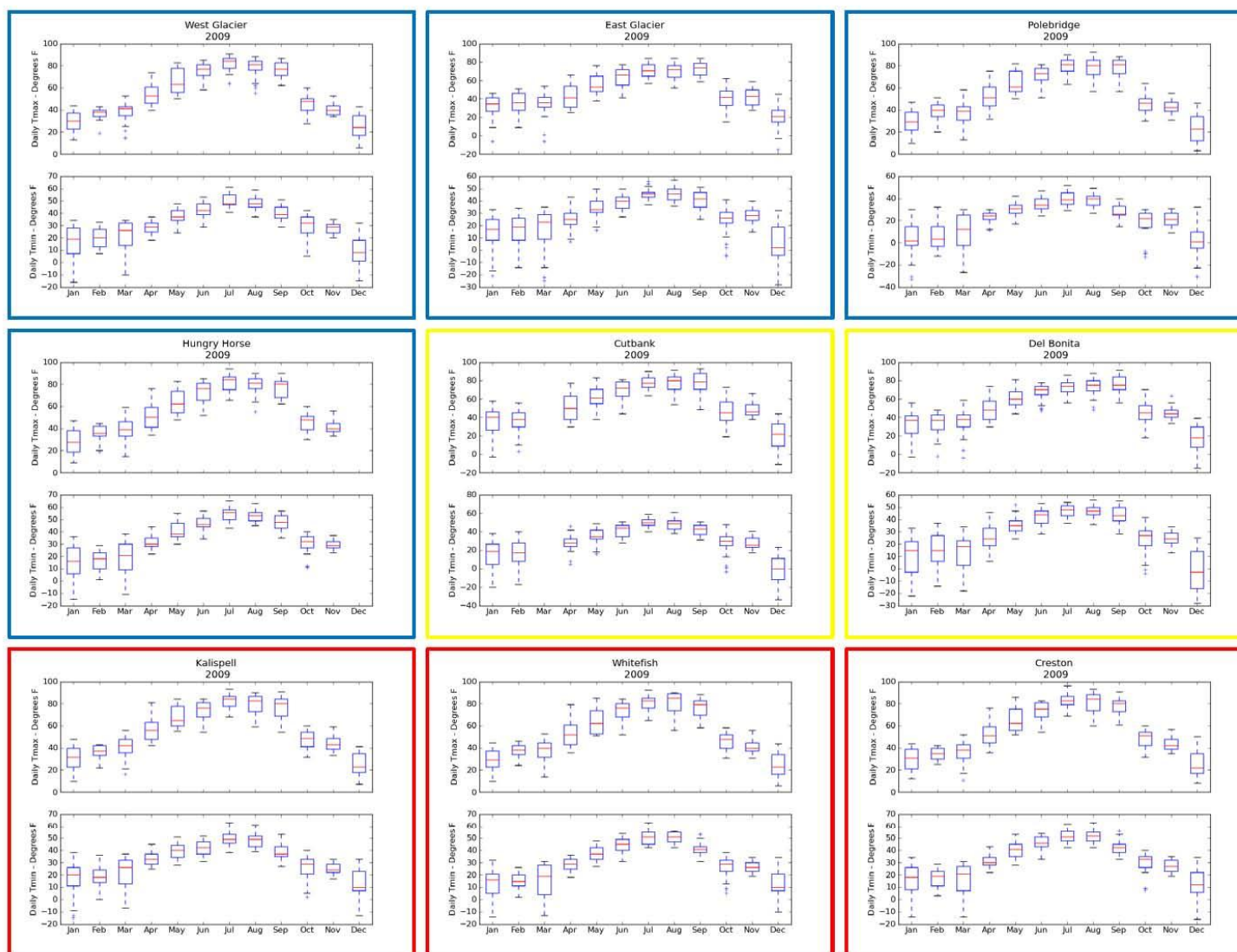


Figure A.3. Boxplots of average maximum and average minimum daily temperatures during 2009 at key climate stations in and near Glacier National Park. Colored borders indicate climate zone where blue = zone 1a, yellow = zone 2a, red= zone 2b.

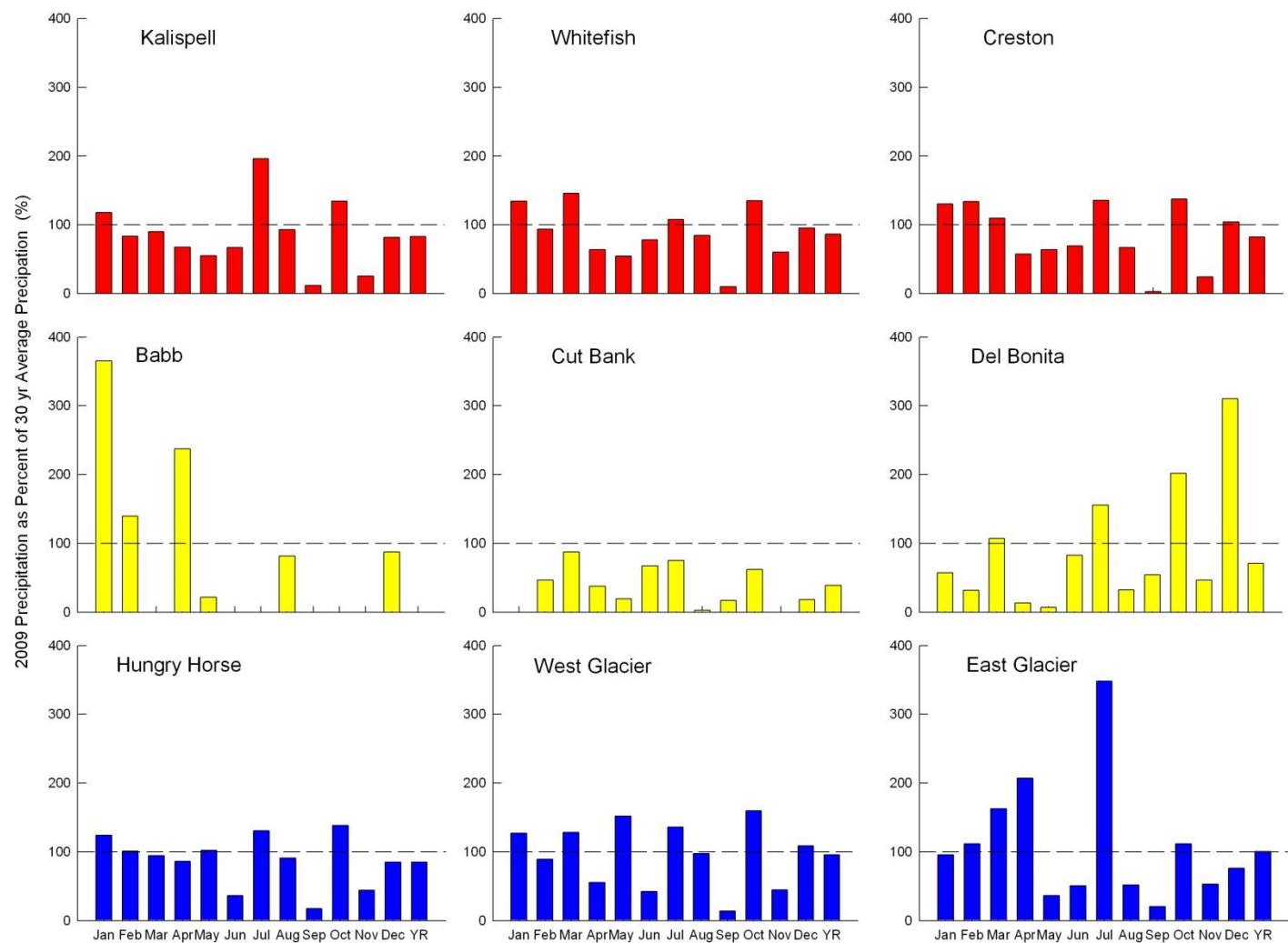


Figure A.4. Departure of 2009 precipitation from 1971 – 2000 average at key climate stations in and near Glacier National Park. Colors indicate the climate zone for each station. blue = zone 1a, yellow = zone 2a, red= zone 2b.

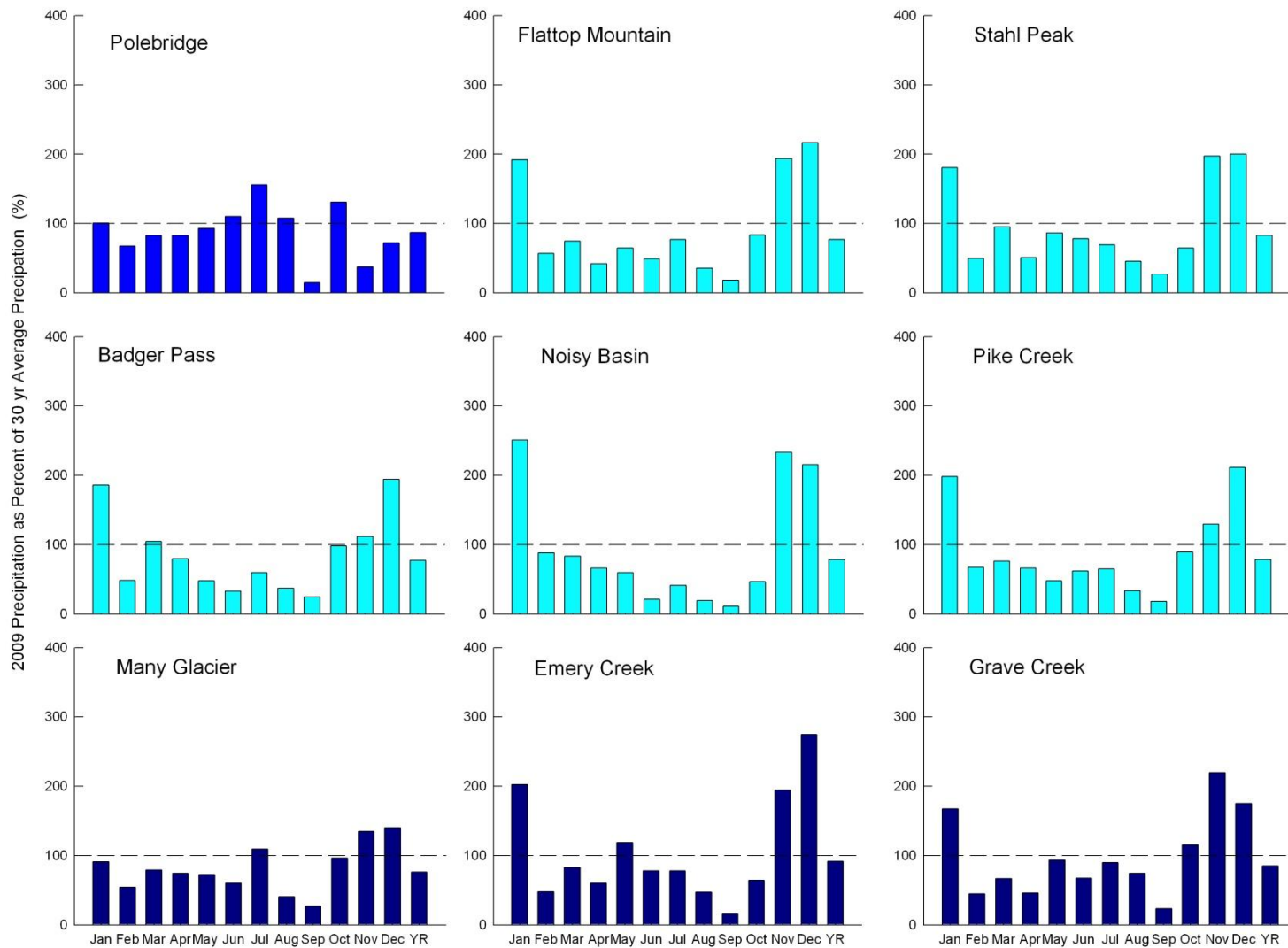


Figure A.5. Departure of 2009 precipitation from 1991 – 2000 average at key climate stations in and near Glacier National Park. Colors indicate the climate zone for each station. blue = zone 1a, cyan = zone 1b, high elevation, dark blue= zone 1b, low elevation.

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.

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