Rocky Mountain National Park
Climate Change Brief

LCC-VP
LANDSCAPE CLIMATE CHANGE VULNERABILITY PROJECT

What We've Seen: Observed Trends in Temperature and Preecipitation

Rocky Mountain National Park (RMNP) is characterized by dramatic mountain vistas, deep gorges, and clear mountain streams. In RMNP, interactions of complex topography and regional-scale air masses create dynamic short-term weather events and they are responsible for broader, landscape-scale climate patterns. Regular park visitors are acutely aware of the often very large differences in weather between the alpine environments and the much more moderate lower elevations.

Long-term trends in temperature and precipitation are largely determined by atmospheric dynamics at global to regional scales. Flows of regional-scale air masses and more local influences on RMNP climate have probably not changed much over the past century, but temperatures are increasing in RMNP, consistent wtih global patterns. Figure 1 illustrates observed increases in both minimum and maximum temperature in RMNP, leading to an averge rate of increase of about 1.9°C (3.4°F; PRISM data) per century. Minimum (nighttime) temperatures have been increasing much more rapidly than maximum temperatures.

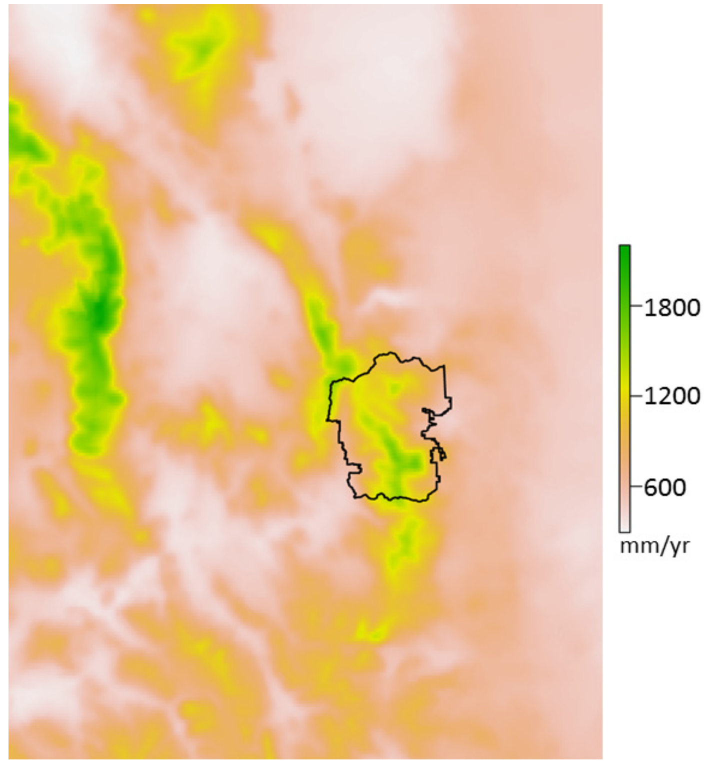

Figure 2. Annual precipitation in the region of RMNP (outlined in black). Steep gradients in precipitation are driven by elevation, and the higher elevations of RMNP (in green) receive about twice the precipitation of lower elevations (PRISM 800 m data).

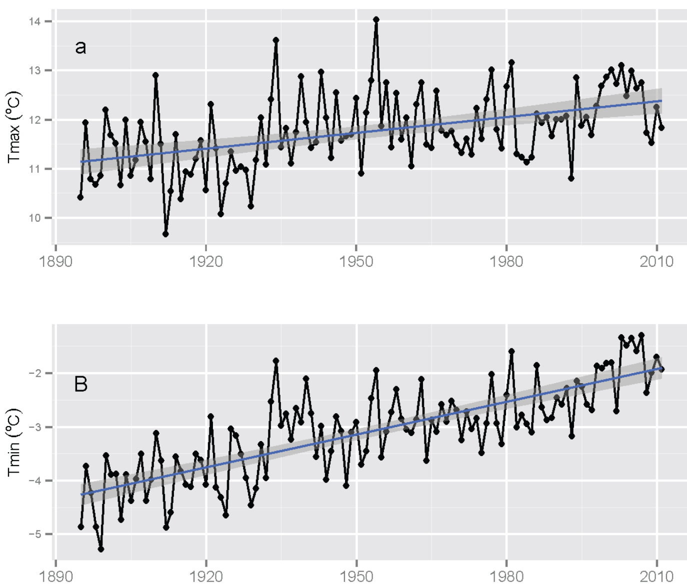

Figure 1. Temperatures have rapidly increased in RMNP over the last century, with maximum temperatures (A) increasing less rapidly than minumum temperatures (B).

Elevation strongly influences both temperature and precipitation. As elevation increases, temperatures decrease and rates of precipitation increase. At higher elevations in RMNP, annual precipitation is more than twice that received at the lower elevations (Figures 1 and 3). Seasonality of precipitation also varies with elevation. Most high-elevation precipitation occurs as snow in winter, while at lower elevations most precipitation occurs as rain in summer. Interestingly, the climate at high elevations - greater than about 11,000 ft - appears to be largely disconnected and uncorrelated with that experienced at lower elevations (Losleben et al. 2010), presumably due to the exposure of high elevations to broader-scale jet streams and other atmospheric circulation phenomena.

NASA · Woods Hole Research Center · California State University Monterey Bay · Montana State University · Conservation Science Partners · Colorado State University · National Park Service

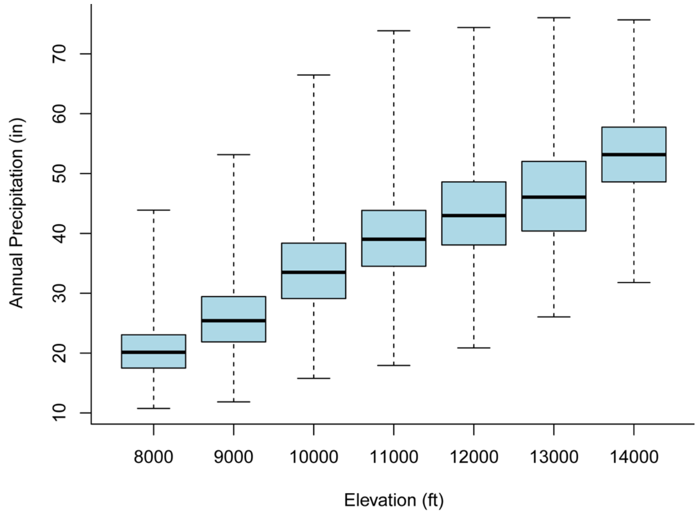

Figure 3. Annual precipitation in RMNP illustrating the sharp elevational gradient. The horizontal line is the median, boxes enclose 25th to 75th percentiles, and dashed lines show the range. Derived from 800m PRISM data,1980-2000.

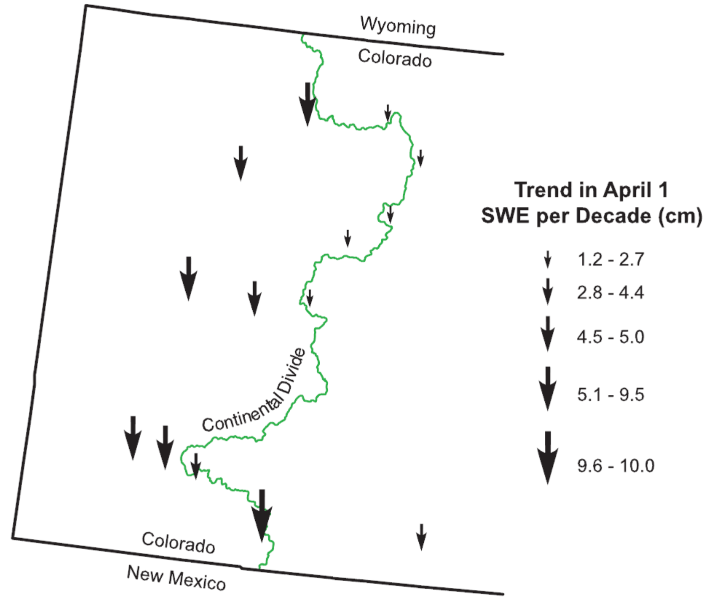

Figure 4. Since the late 1970s, winter precipitation has remained the same, but the snow pack, measured as Snow Water Equivalent (SWE, inches of water) has been declining in spring and peak of runoff has been occurring earlier (figure and results from Clow 2010).

While there has been no significant change in annual precipitation over the past century, increased temperatures have led to changes in snow accumulation and melt. Water content of the spring snow pack has been diminishing earlier, and an analysis of runoff between 1978 and 2006 found that peak runoff is also occurring earlier (Clow 2010, Mote et al. 2005; Figure 4). Averaged across Colorado, the onset of snowmelt has been shifting at a rate of about 5 days per decade, for a change of about two weeks since 1978. Changes in snow melt are reflected in runoff, which has been shifting in a similar pattern. Rivers are rising and fallling earlier in the year. One consequence of earlier snow melt is a shift in soil water and an increasing summer water deficit, which is associated with fire seasons that begin earlier and end later. Throughout the west, higher temperatures are associated with a longer fire season, more large fires, and more total acres burned (Westerling et al. 2006, 2011).

Major weather events in RMNP and the Southern Rockies are caused by flows of air masses that can originate from any direction, and many notable weather events are the result of collision of air masses from more than one direction. The Front Range location of RMNP makes it particularly susceptible to heavy precipitation events. In the spring, moist air coming up from the Gulf can collide with colder arctic air and result is intense, very wet snowfalls with total snow depth measured in feet, containing inches of snow water equivalent. In the summer, moist upslope air masses can lead to intense orographic precipitation (e.g. microbursts) and violent thunder storms. Summer precipitation in the mountains is often a result of convection storm.

Warmer temperatures are likely already affecting all or RMNP's ecosystem. Native bark beetle populations , which historically existed at low densities, have exploded in RMNP and the surrounding area causing widespread mortality of conifers.

Current outbreaks of beetles are thought to be associated with drought and warming temperatures, especially the increase in winter minimum temperatures (Bentz et al. 2010). Very cold winter temperatures (below -20°F) cause high winter mortality, and previously-cool summers slowed development. Warmer winters have resulted in greater winter survival, and warm temperatures in spring, summer, and fall have factilitated rapid development of mature beetles. These very favorable conditions, in concert with drought in the 2000's, have led to widespread eruptions of mountain pine beetle and massive tree death.

Mountain pine beetles have caused extensive mortality of forest trees in RMNP.

Projected 21st Century Climate Changes

Global climate models (GCMs) consistently project substantial temperature increases, with rates of increase exceeding those experienced in the last century (Figure 5). Within a few decades, temperatures in "normal" years will likely exceed those observed during the dust bowl, the 1950s heat waves, and the record-setting summer of 2011. Increased temperatures will very likely be associated with greater frequency of hot spells that are now considered "abnormal", and with decreases in cold spells (IPCC 2012). RMNP will most likely experience a variety of other changes that are caused by regional to global scale atmospheric patterns (Table 1).

Projected trends in precipitation are uncertain. Annual and seasonal precipitation is naturally variable and projections of changes in precipitation are equally variable. However, it is almost certain that a higher proportion of precipitation will fall as rain rather than snow, especially at lower elevations where temperatures are closer to freezing (Mahoney et al. 2012).

Projected changes in climate drivers are summarized in Table 1. Overall, the future climate in RMNP will be warmer, snow will melt earlier, runoff and peak runoff will occur earlier, and the ecosystems will generally be drier. Annual precipitation may remain unchanged, but increased temperatures and longer snow-free seasons will lead to great surface evaporation, and greater water use by vegetation.

Climate-caused droughts have already increased mortality rates of forest trees in the western U.S. and other parts of the world (Anderegg et al. 2013, Allen et al. 2010). As the thermal and hydric environments change, there may be significant changes in rates of disturbance and in the regeneration of vegetation communities. Models of tree species distribution have projected dramatic, climate-driven changes in the suitability of RMNP habitats for currently-dominant tree species, including aspen, Ponderosa pine, lodgepole pine, subalpine fir, and Engelmann spruce (Rehfeldt et al. 2006; Hargrove 2013).

A warmer atmosphere has more energy in it (i.e., heat), and warmer air can hold more moisture. These relationships are, in general, the physical basis for more frequent storms, of higher intensity. At a continental to global scale, warming will lead to overall increases in precipitation. In RMNP and the surrounding region, the combination of climate trends may increase the frequency of extreme weather events and the likelihood of floods. Along the Colorado Front Range, floods can result from very localized microbursts, rain on snow events, and a combination of unusually warm weather and a very large snow pack. In the past century, RMNP has experienced floods from all three of these causes, and projected climate trends are consistent with an increased risk of floods (Mahoney et al. 2012).

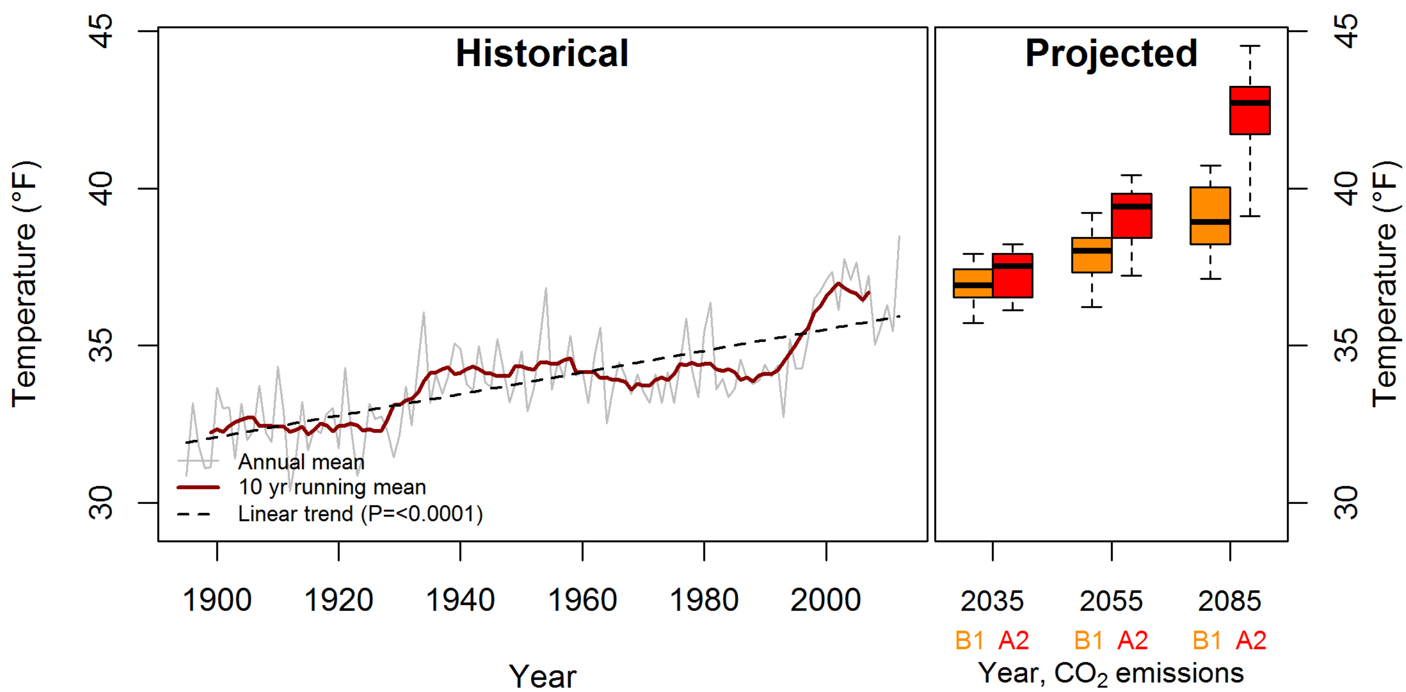

Figure 5. Observed (historical) and projected trends in average temperatures for a moderate (B1) and high (A2) emissions scenario. Historical data from RRISM, projections are a CMIP3 ensemble used for the National Climate Assessment (Kunkel et al. 2013).

Projected 21st Century Climate Changes

Table 1. Summay of projected trends in selected climate and hydrology drivers for Rocky Mountain Park and the surrounding area, with an evaluation of confidence it the the projections. These attributes are important determinants of the timing and intensity of many ecological, social, and economic activities.

Climate Variable	Trend	Relative Change by 2050	Projections for 2050s	Confidence	Source / Comments
Temperature (change from 1960-1990; ± SD)	↑	Large	2.7 ± 0.7 C (4.9 ± 1.3 F) Warming greater in summer	Very likely	CMIP3 ensemble for 1 degree cell including RMNP*
Extreme high temperatures	↑	Large	1-in-20 year mean maximum temperature Likely to increases by 2-3 C (3.6 -5.4 F). 1-in-20 year maximum temperature events Likely to occur 1-in-2 to 1-in-4 years.	Likely	IPCC 2012
Mean precipitation (% change from 1960-1990; + 1 sd)	↔	Small	1 ± 7.2 %	About as likely as not	CMIP3 ensemble for 1 degree cell including RMNP*
Evaporation	↑	Moderate	Increase due to temperature; difficult to quantify	Likely	Evapotranspiration may increase 20-30% at higher elevations (BOR 2012)
Intense precipitation events	↑	Moderate	"Marked" increase in 24-hr precipitaton for 2040-2070 period. 50-70% increase in event maxima.	Likely	IPCC 2012; Mahoney et al. 2012
Snowfall (April 1 SWE)	↓	Moderate	2050: -15 to -30%	Likely	Christensen & Lettenmaier 2006; BOR 2012; Gangopadhyay & Pruitt. 2011
Streamflow (total quantity)	↔	Small	No change to slight decrease.	About as likely as not	BOR 2012; Evapotranspiration may increase 20-30% at higher elevations (BOR 2012: B57ff)
Streamflow (timing)	↓	Moderate to large	Peak flows earlier; summer base flows lower	Very likely	Clow 2010; BOR 2012; Christensen & Lettmaier 2006
Drought	↑	Moderate	Difficult to quantify. Likely result of higher temperatures, increased evaporation, and increased variation in precipitation.	Likely	IPCC 2012
Hail	↓	Large	Almost complete elimination of surface hail	Likely	Mahoney et al. 2012

* The CMIP3 ensemble includes 15 Bias-Corrected and Spatially Downscaled (BCSD) GCMs, at 1/8 degree resolution.

References

Allen, C. D., A. K. Macalady, H. Chenchouni, D. Bachelet, N. Mcdowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, E. H. Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J. H. Lim, G. Allard, S. W. Running, A. Semerci, and N. Cobb. 2010. A Global Overview of Drought and Heat-Induced Tree Mortality Reveals Emerging Climate Change Risks for Forests. Forest Ecology and Management 259:660-684.

Anderegg, W. R. L., J. M. Kane, and L. D. L. Anderegg. 2013. Consequences of widespread tree mortality triggered by drought and temperature stress. Nature Clim. Change 3:30-36.

BOR (U.S. Department of the Interior, Bureau of Reclamation). 2012. Colorado River Basin Water Supply and Demand Study. Technical Report B – Water Supply Assessment. U.S. Department of the Interior, Bureau of Reclamation

Christensen, N., and D. P. Lettenmaier. 2006. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin. Hydrol. Earth Syst. Sci. Discuss. 3:3727-3770.

Clow, D. W. 2010. Changes in the timing of snowmelt and streamflow in Colorado: A response to recent warming. J. Climate 23:2293-2306.

Gangopadhyay, S., and T. Pruitt. 2011. West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections. U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Technical Memorandum No. 86-68210–2011-01, Denver, Colorado.

Hargrove, W.A. 2013. FORECASTS: climate change tree atlas. http://www.geobabble.org/~hnw/global/treeranges3/climate_change/atlas.html

IPCC, C. B. (Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, P. M. Midgley, and eds.). 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional climate trends and scenarios for the U.S. National Climate Assessment. Part5. Climate of the Southwest U.S., National Ocean and Atmospheric Administration, Asheville, NC.

Losleben, M., N. Pepin, and S. Pedrick. 2000. Relationships of precipitation chemistry, atmospheric circulation, and elevation at two sites on the Colorado front range. Atmospheric Environment 34:1723-1737.

Mahoney, K., M. A. Alexander, G. Thompson, J. J. Barsugli, and J. D. Scott. 2012. Changes in hail and flood risk in high-resolution simulations over Colorado's mountains. Nature Climate Change 2:125-131.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western north America. Bulletin of the American Meteorological Society 86:39-49.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences 167:1123-1150.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring Increase Western US forest wildfire activity. Science 313:940-943.

Acknowledgments

Support for this work was provided by the National Park Service, and by the NASA Applied Sciences Program, through award number 10-BIOCLIM10-0034.

More Information

John Gross, Ecologist, National Park Service, Ft Collins, CO. John_Gross@NPS.gov

Landscape Climate Change Vulnerability Project http://www.montana.edu/lccvp/index.html

NASA Ames Ecological Forecasting Lab http://ecocast.arc.nasa.gov/