Greater Yellowstone Ecosystem

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LANDSCAPE CLIMATE CHANGE VULNERABILITY PROJECT

Over the next century, it is expeccted that most of the contiguous United States will experience climate changes associated with natural variability and increased concentrations of anthopogenic greenhouse gas emissions. These climatic changes will have differing regional effects that ecosystems will respond to through shifts in species distribution and composition. The Greater Yellowstone Ecosystem (GYE) is one of the few remaining intact ecosystems in the U.S., sustaining a wide range of habitat types and high biodiversity (Keiter and Boyce 1994). The mountainous landscapes of the GYE are defined by a complex topography that spans elevational gradients ranging from 500m to 3300m. As a high elevation region within the mid-high latitudes, it is expected that the regional warming signal may be proportionally greater than that of the global average (Trenberth et al. 2007, Serreze et al. 2000, Beniston et al. 1997). The importance of the natural resources within the region are accented by the residing federally protected lands that include, Yellowstone National Park, Grand Teton National Park, and ten distinct wilderness areas within the surrounding National Forests. Given the depth of ecological resources, potential sensitivity to climatic change, and high human value suggested by over three million annual visitors and tourists to the region (Duffield et al. 2008), the GYE is a vital region for climate change biological conservation planning and response.

This brief provides a summary of the current trends of the major climate factors within the GYE region to provide better insight for future adaptive management.

Historic Trends in Temperature and Precipitation

Regional climate in the GYE has shown an increasing rate of change in temperatures and precipitiaton, with strongest signals displayed within the most recent decades. Although heat waves have been frequent and widespread throughout the GYE range, since the 1990 period, an increased frequency of high minimum temperature have become more common (Fig. 1A). Furthermore, this minimum temperature heating event of the recent decade exceeds that of the 1930 dust bowl era, when heat waves were more prevalent (Fig. 1A). Based on trend analysis of the past 100 years in the GYE, annual mean minimum temperatures (T_{min}) for the entire domain display a slope of 0.15ºF/decade (1.5ºF/century). Records of maximum temperatures (T_{max}) have displayed a weaker warming signal of 0.07ºF/decade (0.7ºF/century). Within the past two decades, mean annual maximum temperatures have not exceeded the historicly recorded highs (Fig. 1B). This suggests that the major climate changes that

Key climate trends within the Greater Yellowstone Ecosystem in the past century

The analysis of historic temperature and precipitation records display two distinct messages.

► **Minimum temperature increases** – Strongest climate change signal within the GYE from the past century are related to T_{min} increases centered around high elevation ranges.

- **Little change in high temperatures and precipitation**– Mean annual maximum temperature and precipitation display a weak signal of increase over the century, and are localized again at high elevaitons.

► **Reduction of spring time snowpack** – Increased spring time minimum temperatures above the 0ºC isotherm have resulted in low April 1st snow water equivalents throughout the Northern Rockies.

- **Snowpack affects surface water flow**– Earlier spring snow melt reduces surface flowrates during the critical late summer season.

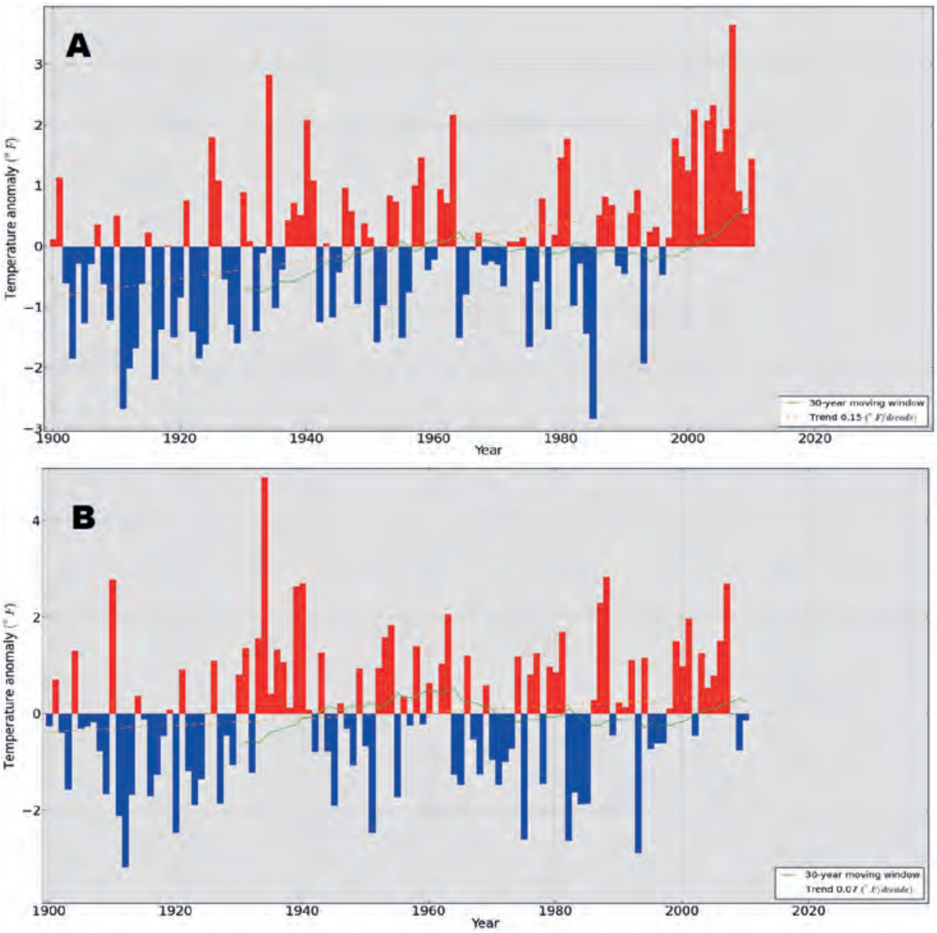
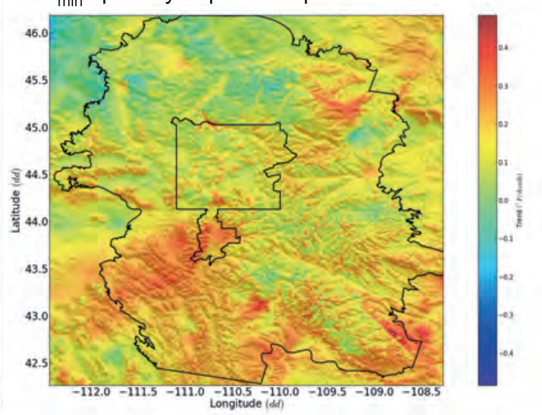
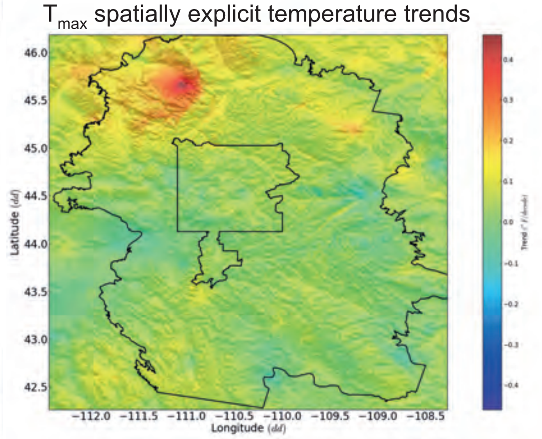


Figure 1 - Historic temperature anomalies within the GYE 1900-2010

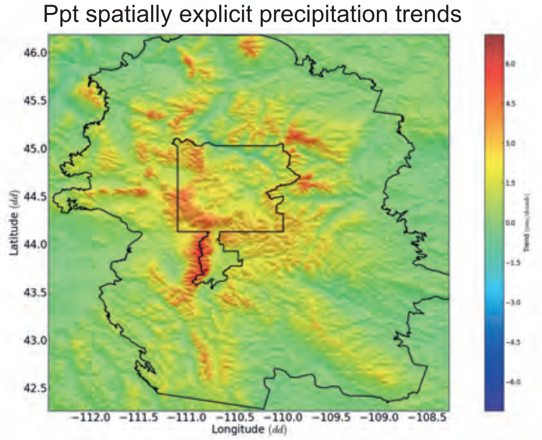
T_{min} spatially explicit temperature trends



T_{max} spatially explicit temperature trends



Ppt spatially explicit precipitation trends



have already occured within the GYE are primarily due to minimum temperature rises. This significant trend of increasing minimum temperatures in the recent decades has an observable impact on surface fresh water resources of the GYE. Increased frequency of minimum temperature above the 0°C isotherm has dramatic effects on the seasonal timing of spring snow melt. Recent analysis of April 1 surface snowpack have observed low snow water equivalents (SWE) throughtout the entire Northern Rocky Mountain region (Pederson et al. 2013). Such losses affect the summertime peak flow necessary for wildlife and recreation. Trends in precipitation have shown little change, with a 0.93 mm (0.04in)/decade increase, suggesting the system will not experience relief from increased temperatures and snow melt (Fig. 2). Spatial analysis suggests that high elevations may experience the greatest impact of temperature warming, while lower elevations are receiving no change or a slight reduction in precipitation. These conditions are analogous to the Medieval Climate Anomaly (~1143 to 1155 C.E), where warmer

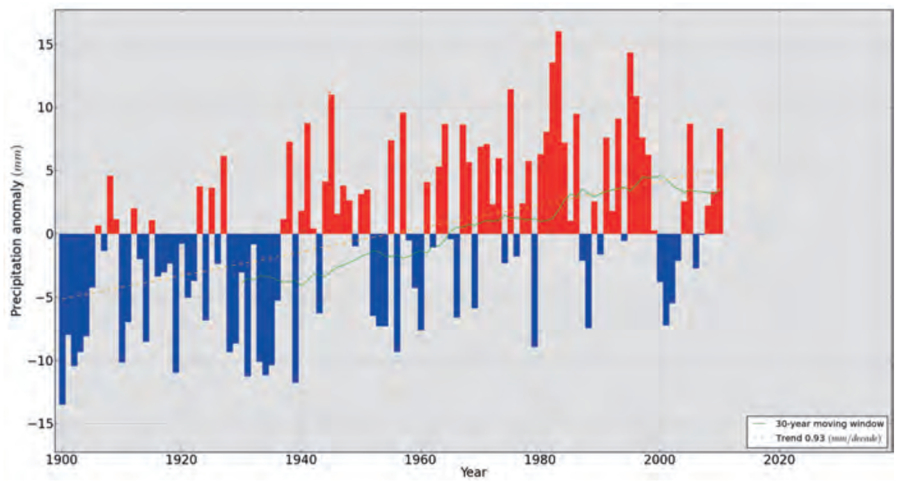


Figure 2 - Historic precipitation anomalies within the GYE 1900-2010

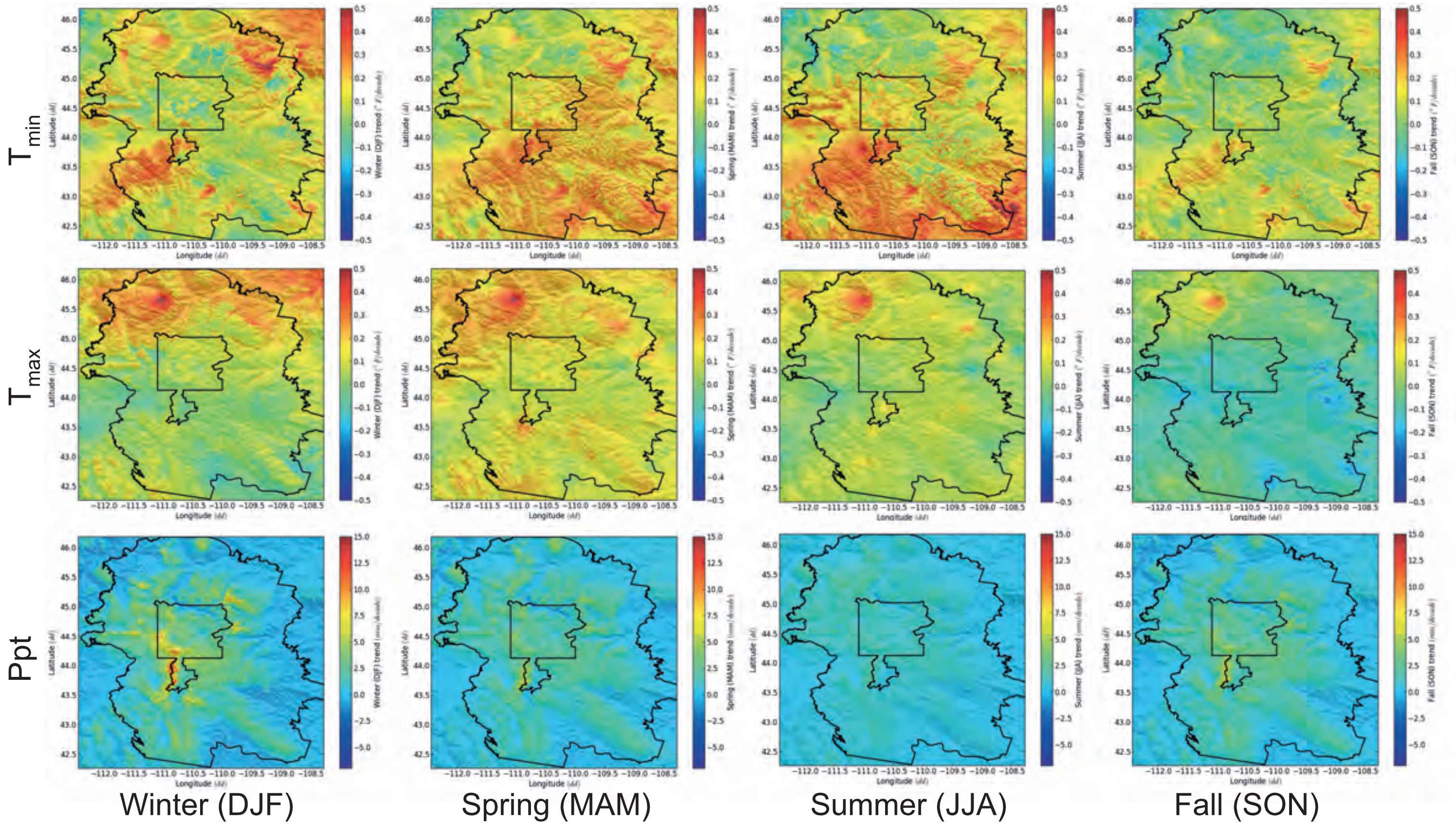


Figure 3 - Seasonal climate gradients from 1900-2010 within the Greater Yellowstone Ecosystem at 800m spatial resolution.

temperatures and severe decadal scale snowpack reductions in the mid-elevations have led to hydrologic droughts in the region (Pederson et al. 2011). Water supply shortages may effect attributes that are vital to vegetation stress resitance and resilience.

Seasonal Trends in Temperature and Precipitation

Seasonally stratified spatial analysis reveals major interannual periods of strong climate change. Analysis of suggest that the T_{min} increase is consistent with all seasons with the weakest warming rates in the fall (SON) and the strongest during summer (JJA), domain average of 0.17°F/decade (Fig. 3). Warming is variable across the landscape with a majority occuring in the Southern portion of the GYE. Seasonal T_{max} present a strong growth trend during the spring season (MAM) consistent with the mean annual T_{max} warming trend with a domain average of 0.13°F/decade. A strong isolated trend is in occurance within the Bozeman region, with the remainder of the region experiencing a generally homogenous warming across the landscape. One exception to this pattern is the (SON) season, where an overall regional cooling is measured (-0.05°F/decade). Seasonal stratification of precipitation shows taht the annual mean precipitation pattern is primarily driven by the winter (DJF), spring (MAM), and fall (SON) seasons. Winter precipitation means display the strongest increase for all seasons, but still remains minimal at 1.21 mm (0.05in.)/decade.

This seaonal warming in the winter and spring months change the climate exposure that ecosystems are accustomed to. Mild winter temperatures in alpine regions have

High elevation whitebark pine species experiencing severe mortality in the past decade. (photo credit: Jesse Logan)

been found to directly relate to the survivorship of overwintering broods of mountain pine beetle, the major disturbance agent acting on whitebark pine species (Logan et al. 2010, Logan and Powell 2009). This reduction in mortality of over wintering broods can result in an expansion of the dispersal and colonization effectiveness of insect pests. Since 1999, an eruption of mountain pine beetle events has been observed that exceeds the frequencies, impacts, and ranges documented during the last 125 years (Raffa et al. 2008, Macfarlane et al. 2013). Aerial assessment of whitebark pine species population within the GYE have indicated a 79% mortality rate. These dramatic changes maybe the first indicators of how sensitive the Greater Yellowstone systems are to shifts in climate patterns.

Future climate projections expected earlier spring snow melt in critical alpine regions that reduces summer runoff (photo credit: NPS)

Future Projections of Climate within the GYE

Assessment of the possible future climate changes are critical in forecasting ecological response. Utilizing the phase 5 Coupled Model Intercomparison Project (CMIP5) down scaled climate models, experiments for the potential future of GYE can be explored. Climate forcings are quantified by Representative Concentration Pathways (RCP) that are designed to characterize feasible alternative futures of the climate considering physical, demographic, economic, and social changes to the environment/ atmosphere. An RCP value of 4.5 W/m^2 and 8.5 W/m^2 are considered in this brief to demonstrate the full range of potential future climates in the GYE. Current actual measured rates of greenhouse gas emissions since 2000, have been consistent with the RCP 8.5 scenario (Diffenbaugh and Field 2013, Rogelj et al 2012). Averaged GCM's trajectories of climate over the next century continue to display a strong warming direction. The conservative RCP 4.5 scenario expects a mean temperature increase of approximately 1.0-4.5^{o}F by the end of the century, while the RCP 8.5 scenario expects a mean temperature increase of approximately 6.0-8.0^{o}F by 2100. Projected precipitation patterns for both RCP scenarios show a slight increase from the 1900-2010 mean by the year 2100 (0-10mm increase) (Fig. 5). Interannual variability of precipitation are consistent for all GCMs, implying wet and dry years outside the historic range.

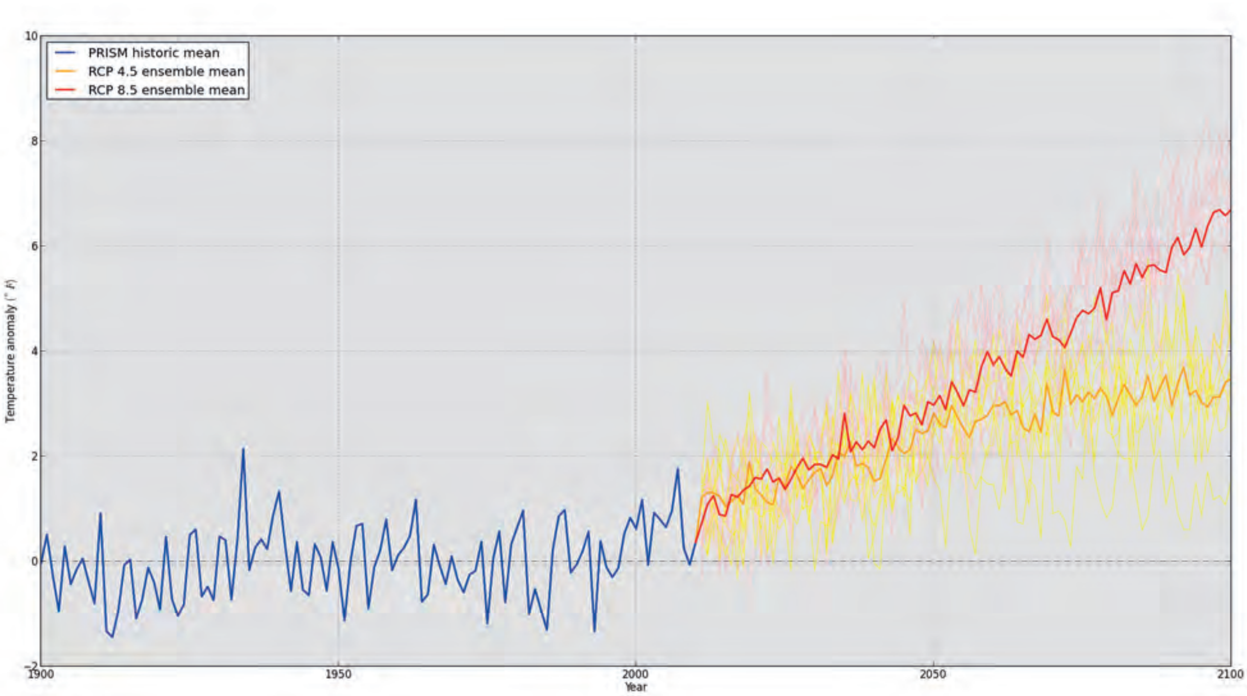


Figure 4 - Downscaled CMIP5 climate projections for mean temperatures within the GYE for the historic 1900-2010 period and 2010-2100 futures under the RCP 4.5 and 8.5 scenarios.

These projections will have major implications for the terrestrial and aquatic ecosystems in the GYE, requiring adaptation and mitigation for biological conservation. Given the inertia of the last 20 years of warming, future conditions may be completely novel from present conditions. It is expected that severe wildfires will become more common within the GYE, provided the projected temperature increases (Westerling et al. 2011). Observable landscape changes such as glacial retreat have already been documented within the GYE range. These glaciers are major freshwater reservoirs for alpine environments and are expected to be gone by 2050 (IPCC 2007, Zemp et al. 2006).

This climate brief illustrates a post 1980's era turning point for nonstationarity of local temperatures in the Greater Yellowstone Ecosystem. These patterns are expected to continue throughout the next century for all projected RCP scenarios if current anthropogenic carbon emission rates proceed unchanged. Strategizing for adaptation and mitigation in natural resource management must be considered given the magnitude of potential future ecosystem impacts.

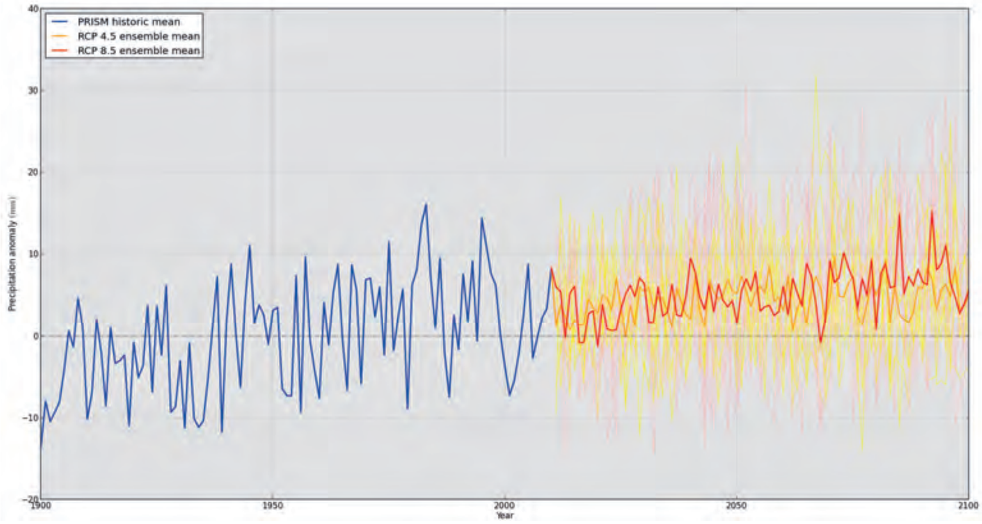
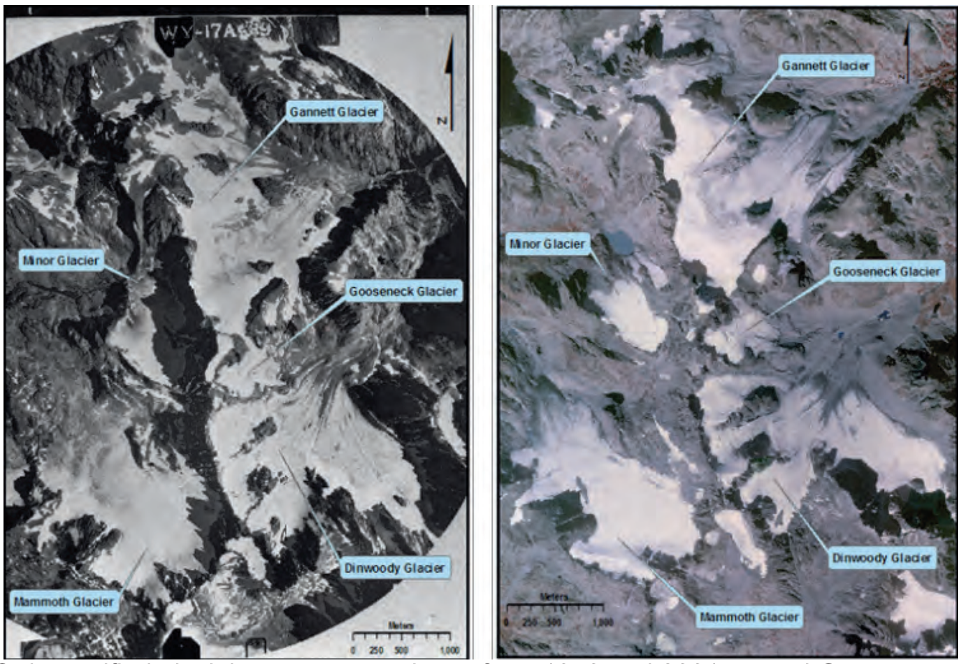


Figure 5 - Downscaled CMIP5 climate projections for precipitation with the GYE suggests little change to a slight increase over the 21st century.



Orthorectified glacial extent comparisons from 1950 and 2001 around Gannett peak (1950 Aerial photo: Mark F. Meier; 2001 Aerial photo: Sanborn Colorado LLC)

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Acknowledgements