Greater Yellowstone Ecosystem Climate Change Primer

Tony Chang [*+], Andrew J. Hansen [†+] and John Gross [‡*]

[+]Department of Ecology, Montana State University, Bozeman, Montana
[*]Inventory and Monitoring Program, US National Park Service, Fort Collins, Colorado

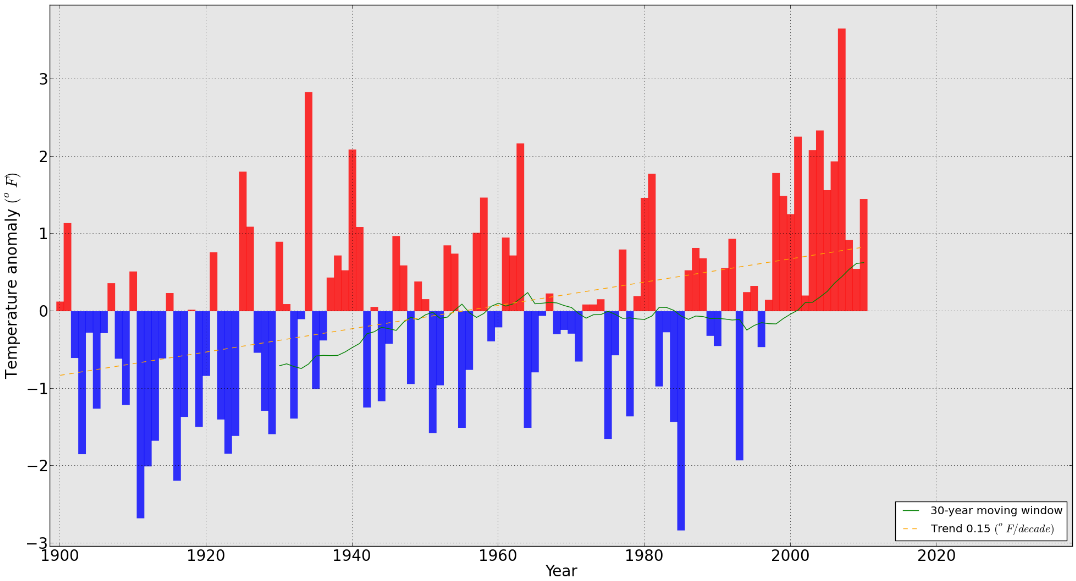
1 Introduction

Recent pre-Holocene temperature reconstructions from paleoclimatological proxies have suggested that the global warming of the past decades is uncharacteristic of the long term cooling trend that began approximately 5,000 years before present (Marcott et al. 2013). This recent uncharacteristic warming has been observed through numerous meteorological stations distributed across the globe and modelled extensively through physically based general circulation models, concluding an approximate 0.6-0.74^{o}C increase in global temperatures in the past century (Hansen et al. 2005; IPCC 2007). These findings have brought an increase of engagement from the political and land resource communities to respond to these climatic changes with appropriate mitigation and adaptation strategies. However, informed decision making at a local scale require the understanding of climatic changes at a resolution that is greater than those provided by global GCMs (horizontal resolution between 250 and 600 km) to maximize site specific responses. Robust high resolution mesoscale climate summaries are a key necessity for understanding the degree of current climate changes in local sites and appropriate planning for future climate impacts (GAO 2007).

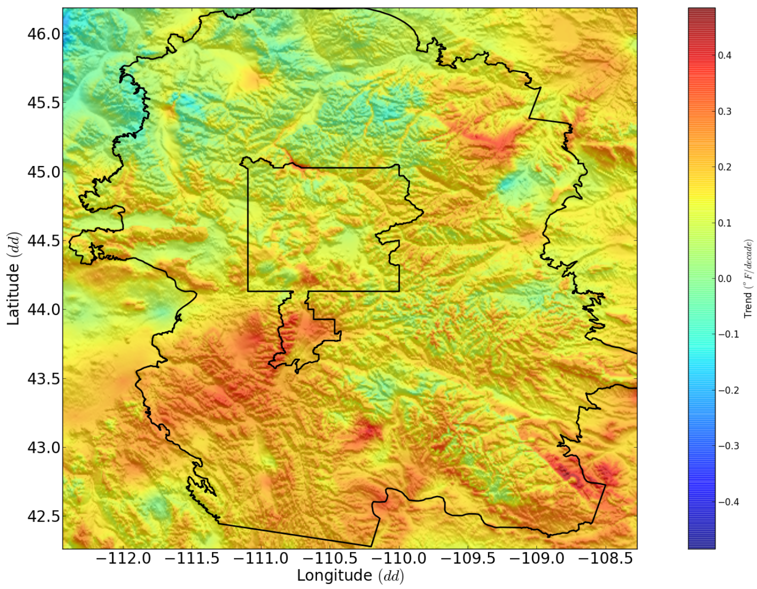
This primer presents a mesoscale summary of climate from the past century within the Greater Yellowstone Ecosystem (GYE). The GYE is a complex topographic mountain region with elevational gradients ranging from 500m to 3300m. As a high elevation region within the mid-high latitudes, it is expected that 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 GYE presents a unique region that contains one of the last few intact temperate ecosystems in the United States (Keiter and Boyce 1991). 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 (Schullery 2004). Given the depth of ecological resources, potential sensitivity to climatic change, and high human value suggested by the +3,000,000 annual visitors and tourists to the region (Duffield et al. 2008), the GYE is a distinct candidate region for climate change biological conservation planning and research. It is hoped that this primer will provide a summary of the current trends of the major climate factors within the GYE region to provide better insight for future adaptive management.

[*]E-mail address: tony.chang@montana.msu.edu
[†]E-mail address: andrew.hansen@montana.msu.edu
[‡]E-mail address: john_gross@nps.gov

2 Observed trends in GYE temperature extremes and precipitation

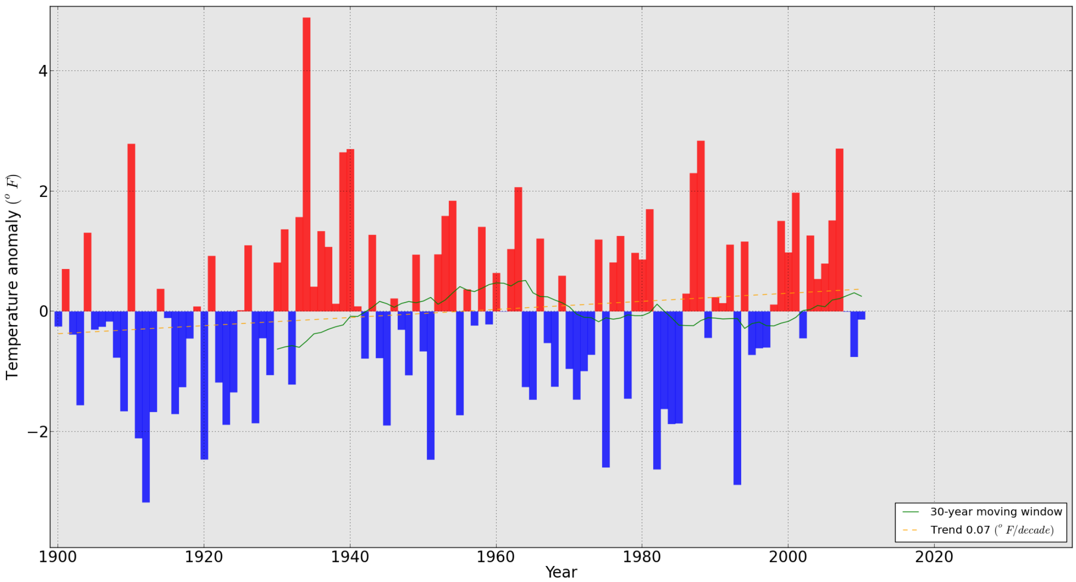


(a) Annual mean T_{min} for the entire GYE domain display a rise of 0.15^oF per decade (1.5^oF per century). The strongest warming signal can be observed in the last decade with minimum temperatures for the region exceeding that of the 1930 dust bowl era. Anomalies calculated on the 1900-2010 baseline to depict change.

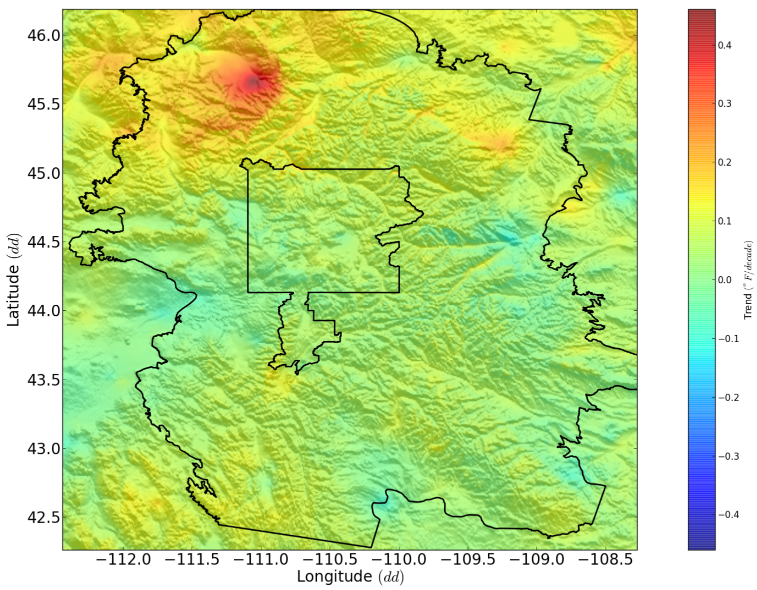


(b) The 0.15^oF per decade regional rate of change displays heterogeneous distribution within the GYE domain. The highest warming rates ($> 0.4^oF$ per decade) of minimum temperature have occured in the high elevation regions of the Northern Absaroka range, Teton range, and Wind River range.

Figure 1: Minimum temperature time series and rates of change in the GYE, 1900-2010

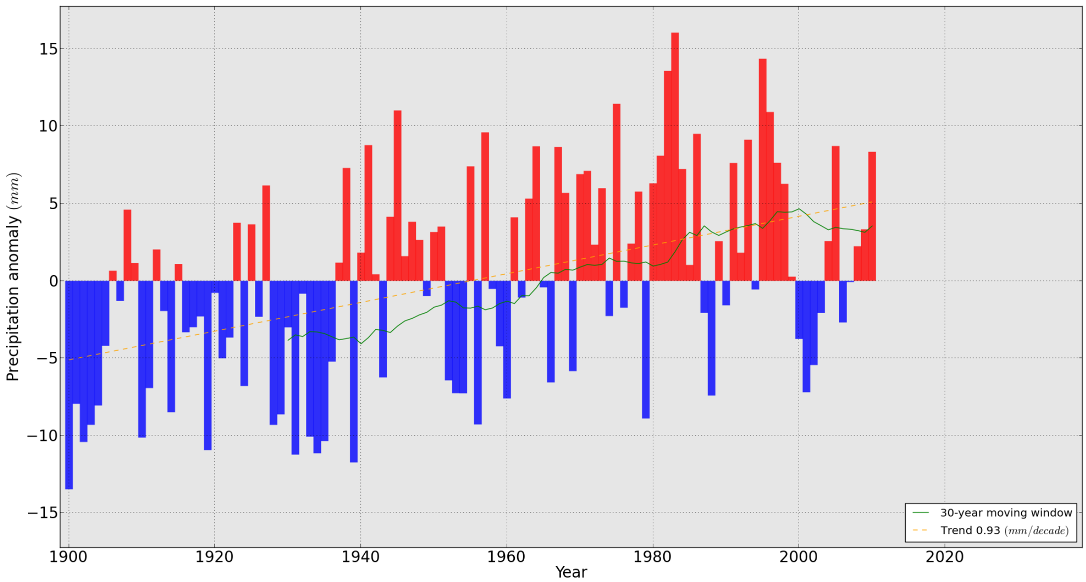


(a) Annual mean T_{max} of the GYE domain display a low increase at a rate 0.07^oF per decade (0.7^oF per century). Unlike minimum temperatures for the region, the range of observed maximum temperatures have not exceeded the historic records in the past two decades.

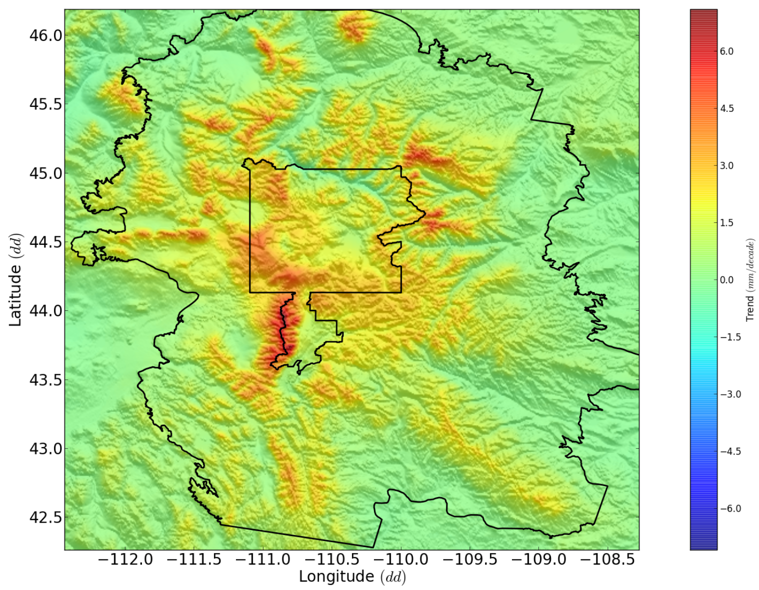


(b) The majority of this warming for maximum temperatures are observed within the Northwestern region of the GYE, centered in the Gallatin Range with rates as high as 0.47^oF per decade. The remainder th region has experience little change of T_{max} in the low elevation areas, with slight increases in the alpine areas.

Figure 2: Maximum temperature time series and rates of change in the GYE, 1900-2010



(a) GYE regional precipitation displays low rise of 0.93 mm [0.04 in] per decade. The past 30 years have been generally a wetter versus the 1900-2010 mean baseline, signaling an effect of the positive phase of the Pacific Decadal Oscillation.



(b) The overall low rate of change in precipitation within the GYE region can be contributed to slight decreasing precipitation rates in the lower elevations (minimum rate −0.4 mm [−0.2 in]/decade), and increasing precipitation rates within the high elevation alpine regions (maximum rate 7.1 mm [2.3 in]/decade). This suggests slight increases in the total regional runoff over the last century.

Figure 3: Precipitation time series and rates of change in the GYE, 1900-2010

2.1 Key Points

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

2. T_{max} and precipitation display a weak signal of increase over the century, and are localized again at high elevaitons.

3. Rates of change are consistent with the US historic climate network observed station trends within

the region (see CIG climate primer; http://www.greateryellowstonescience.org/download_product/3799/0).

3 Seasonal climate change within the GYE

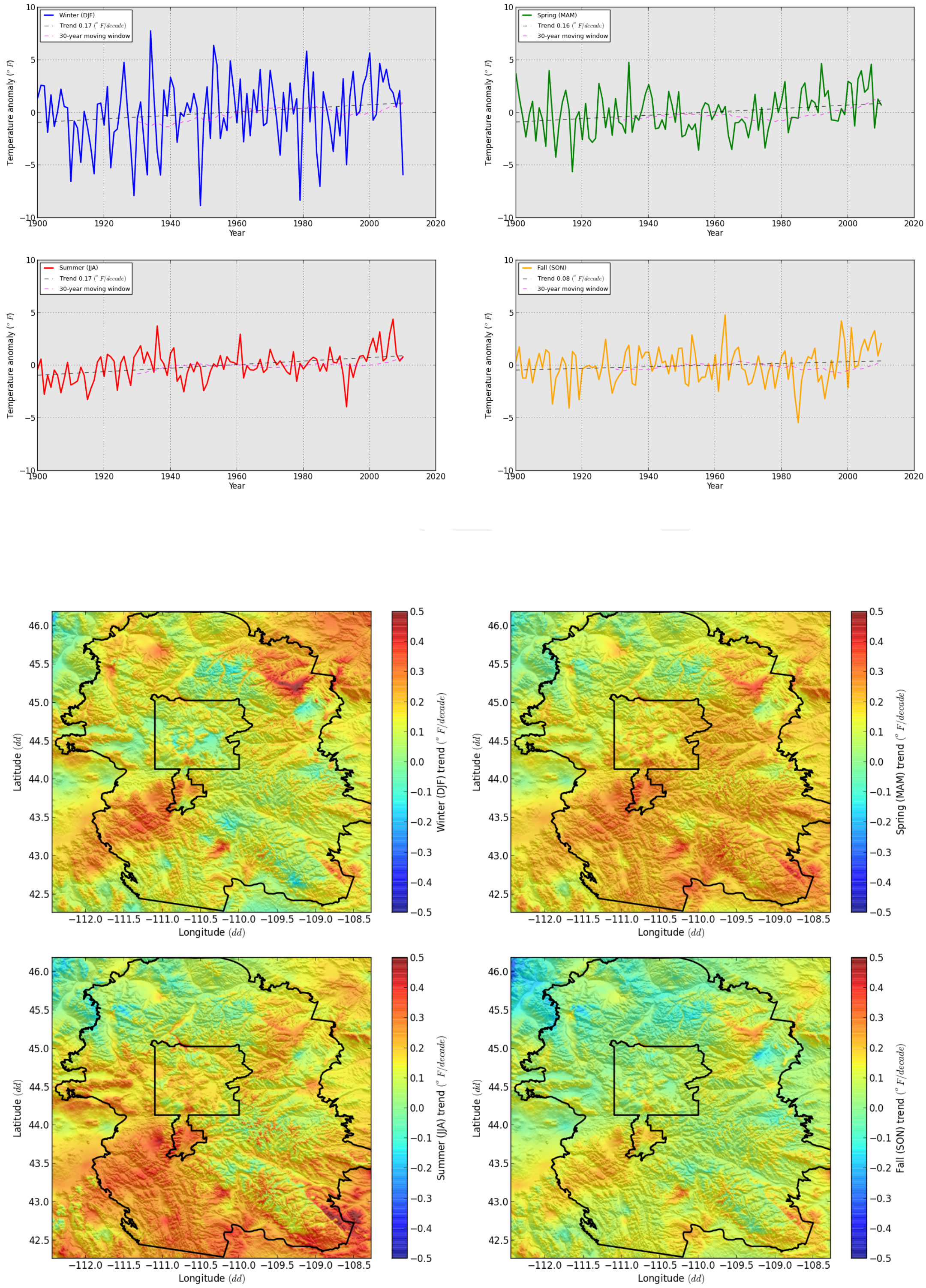


Figure 4: GYE seasonal means for T_{min} display a consistent warming rate compared annual means of $(0.15 - 0.17^oF$ per decade) for all seasons except for fall (SON).

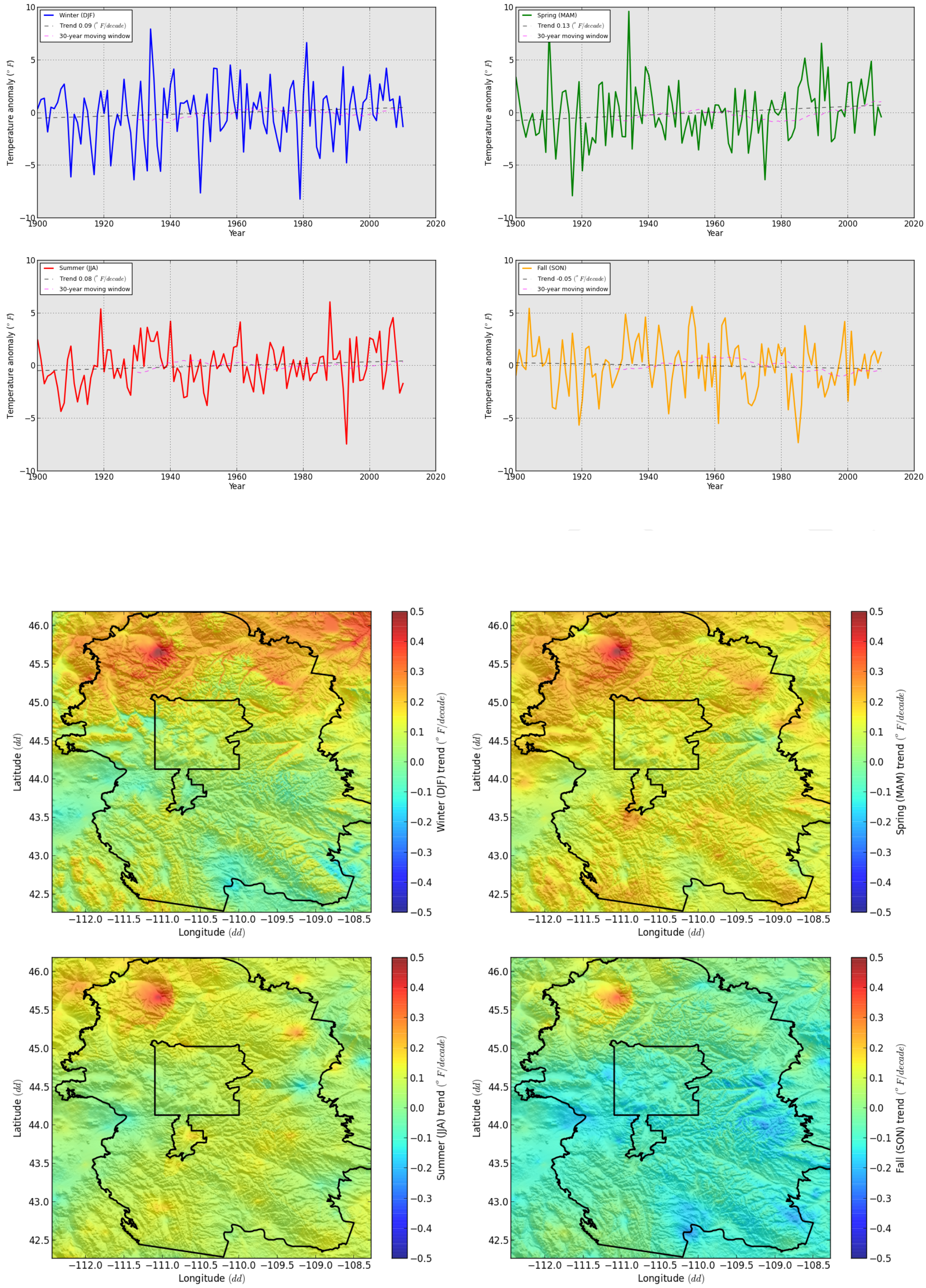


Figure 5: GYE seasonal means for T_{max} display a the strongest warming rates within the spring (MAM) seasons with a rate of (0.13^oF per decade). Reduction in the annual mean T_{max} signal derives from a slight decrease in fall (SON) T_{max} over the 1900-2010 time period.

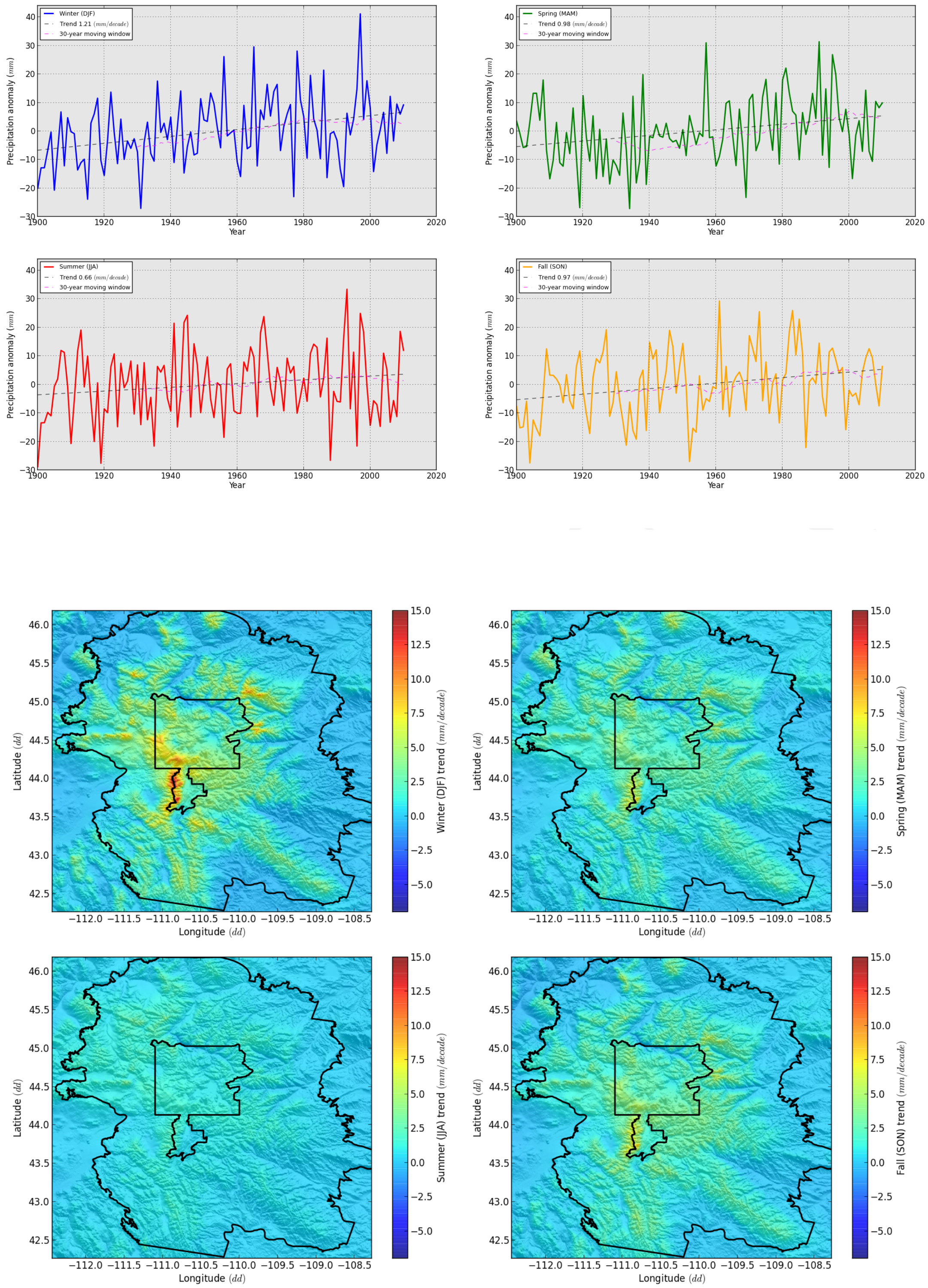


Figure 6: Rates of annual mean precipitation are primarily drive by winter (DJF), spring (MAM), and fall (SON) seasons. Winter precipitation means display the strongest increase for all seasons with a ($1.21mm$ [$0.05in$] per decade) rate of change for the 1900-2010 time period.

3.1 Key Points

1. Seasonal stratification of annual means within the GYE suggest that the T_{min} increase is consistent with all seasons, with the weakest warming rates in the fall (SON). This suggests a near ubiquitous T_{min} increase across the year.

2. Seasonal T_{max} presents a strong growth rate during the spring season (MAM), suggesting that warming rates in the annual mean T_{max} are driven by increasing spring time temperatures that result in earlier snow melt and reduced surface albedo

3. Regional precipitation may be slightly wetter in the winter seasons ($1.21mm$ [$0.05in$] per decade), however growth rate is negligible within the range of winter precipitation variability.

4 Projected 21^{st} century GYE climate changes

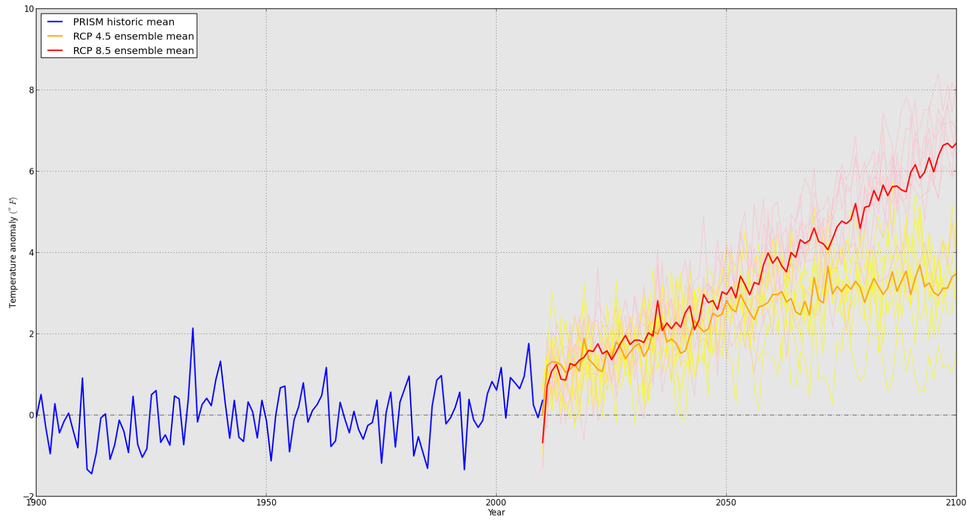


Figure 7: Ensemble means for RCP 4.5 and 8.5 scenarios display an annual mean temperature increase of $\sim 3.5^oF$ and $\sim 6.2^oF$ over the next century, above the 1900-2010 mean baseline respectively. Mean temperatures by 2050 are similarly projected for both RCP scenarios to $\sim 3^oF$ across the region.

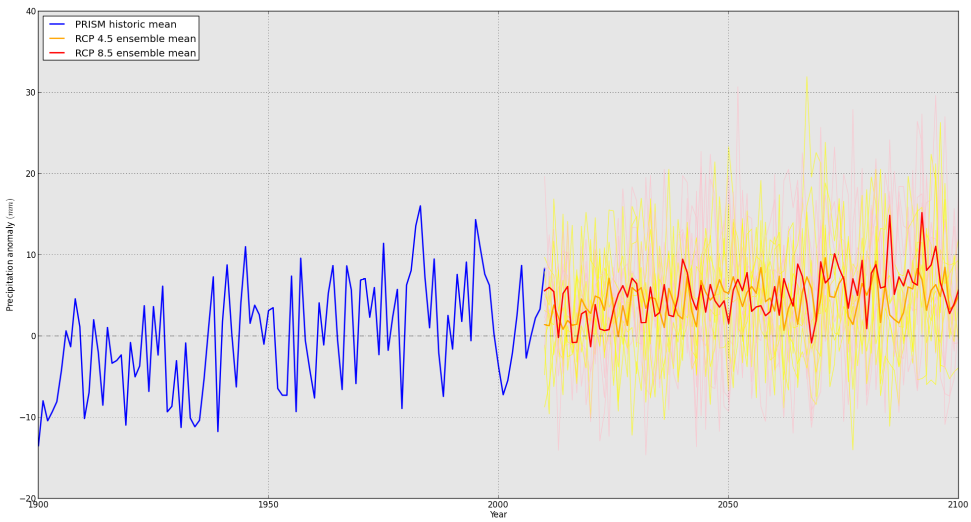


Figure 8: Ensemble means for RCP 4.5 and 8.5 scenarios project precipitation to increase of $\sim$ 4 mm (0.16 in) and $\sim$ 5 mm (0.2 in) over the next century, above the 1900-2010 mean baseline respectively. Both RCP scenarios suggest that increases of atmospheric CO_2 may not have a strong effect on the current rate of change of precipition until the year 2100, despite high interannual variability from individual GCMs.

4.1 Key Points

1. Projection of ensemble means suggest future annual T_{mean} will increase radically and will be driven by T_{min} if current historic rates of change (1900-2010) continue.

2. Conservative interannual variability within GCMs suggest that future T_{mean} cold years will be as warm or warmer than record historic hot years.

3. Regional precipitation may be slightly wetter in upper alpine zones and drier in the lowlands, but subject to high interannual variability consistent to the historic record.

5 Potential impacts of climate change on the GYE

Regional climate in the GYE has shown an increases in temperatures and precipitiaton, with strongest signals displayed within the most recent decades. Spatial analysis suggests that high elevations look to experience the greatest impact of this warming and lower elevations primarily receiving a slight reduction in precipitation. This alpine zone warming trend may be described primarily as an effect of increased spring time minimum and maximum temperatures associated to the recent losses of mid-elevational snow pack (Pederson et al. 2013). This increase in spring time minimum and maximum temperatures in alpine regions directly relate to the physiology of mountain pine beetle life cycles, allowing multiple breeding cycles per active summer period and increasing disturbance potential for whitebark pine species. Climate projections suggest endemic alpine species habitat will reduce drastically within the region and become new novel climates, implying that conservation efforts utilizing historic ranges of climate variability may find no matching suitable habitat. Management of future ecosystems under continued warming must shift towards a more pluralistic and adaptive strategy that is directed towards ecological resilience and resistance.

6 Literature Cited

References

Beniston, M., Diaz, H. and Bradley, R. (1997), 'Climatic change at high elevation sites: an overview', *Climatic change* **36**(3-4), 233–251.

Duffield, J. W., Neher, C. J. and Patterson, D. A. (2008), 'Wolf recovery in yellowstone park: Visitor attitudes, expenditures, and economic impacts', *Yellowstone Science* **16**(1), 20–25.

GAO (2007), Agencies should develop guidance for addressing the effects on federal land and water resources, Government Open File Report GAO-07-863.
URL: *http://www.gao.gov/products/GAO-07-863*

Hansen, J., Nazarenko, L., Ruedy, R., Sato, M., Willis, J., Del Genio, A., Koch, D., Lacis, A., Lo, K., Menon, S., Novakov, T., Perlwitz, J., Russell, G., Schmidt, G. A. and Tausnev, N. (2005), 'Earth's energy imbalance: Confirmation and implications', **308**(5727), 1431–1435.

IPCC (2007), *Fourth Assessment Report: Climate Change 2007: The AR4 Synthesis Report*, Geneva: IPCC.

Keiter, R. and Boyce, M. (1991), *The greater Yellowstone ecosystem: redefining America's wilderness heritage*, Yale University Press, New Haven, CN.

Marcott, S. A., Shakun, J. D., Clark, P. U. and Mix, A. C. (2013), 'A reconstruction of regional and global temperature for the past 11,300 years', **339**(6124), 1198–1201.

Pederson, G. T., Betancourt, J. L. and McCabe, G. J. (2013), 'Regional patterns and proximal causes of the recent snowpack decline in the rocky mountains, usa', *Geophysical Research Letters* pp. n/a–n/a.
URL: *http://dx.doi.org/10.1002/grl.50424*

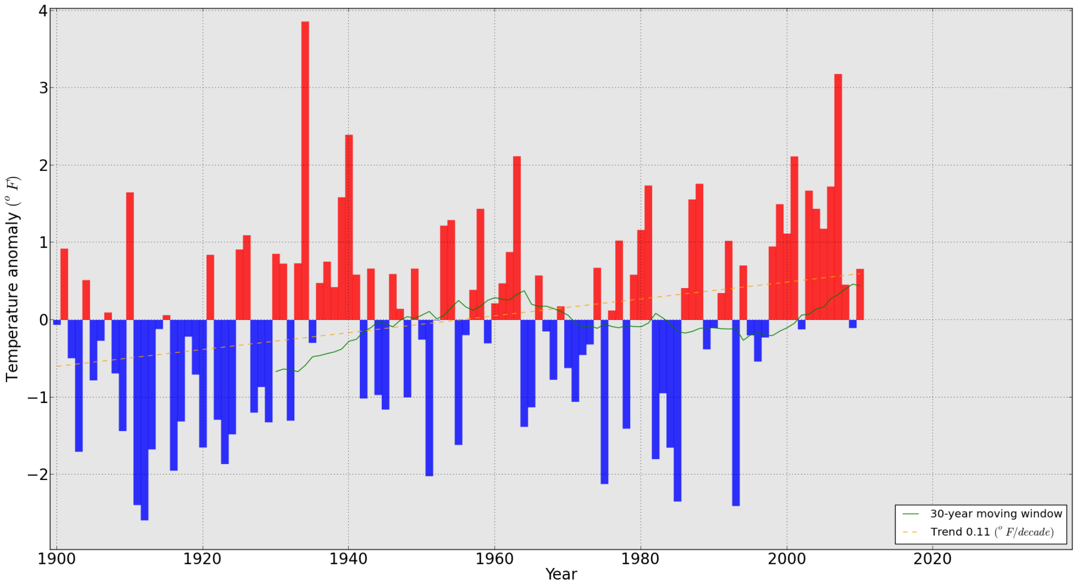
Schullery, P. (2004), *Searching for Yellowstone: ecology and wonder in the last wilderness*, Montana Historical Society.

Serreze, M., Walsh, J., Chapin, F. S., Osterkamp, T., Dyurgerov, M., Romanovsky, V., Oechel, W., Morison, J., Zhang, T. and Barry, R. (2000), 'Observational evidence of recent change in the northern high-latitude environment', *Climatic Change* **46**(1), 159–207.

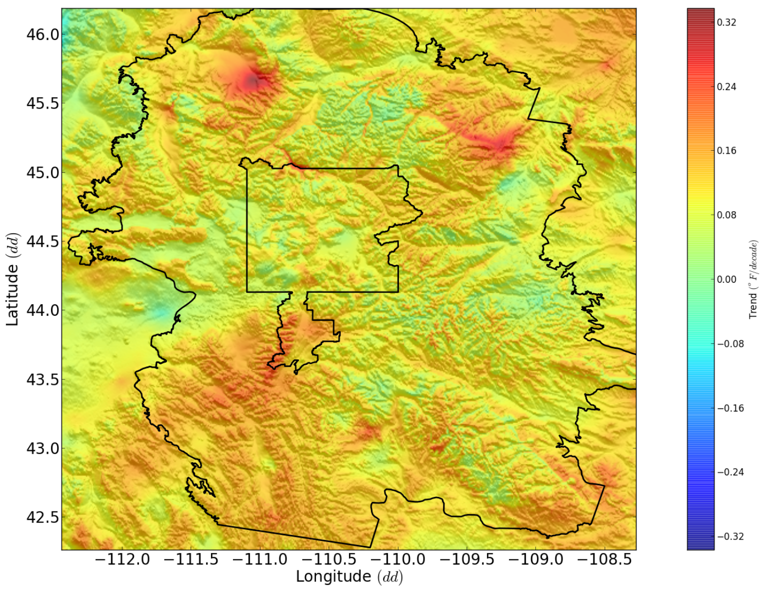
Trenberth, K. E., Smith, L., Qian, T., Dai, A. and Fasullo, J. (2007), 'Estimates of the global water budget and its annual cycle using observational and model data', *Journal of Hydrometeorology* **8**(4), 758–769.

7 Appendix

7.1 Additional Figures



(a) T_{mean} time series displays a 0.11 ^oF per decade increase for the 1900-2010 time period, that is consistant with the national rate of change (lower 48 states) of 0.13^oF per decade (EPA 2012; http://www.epa.gov/climatechange/science/indicators/weather-climate/temperature.html).



(b) T_{mean} spatial warming rates consistent as a combination of the T_{min} and T_{max} warming trends.

Figure 9: T_{mean} time series and rate of change from 1900-2010 within GYE.

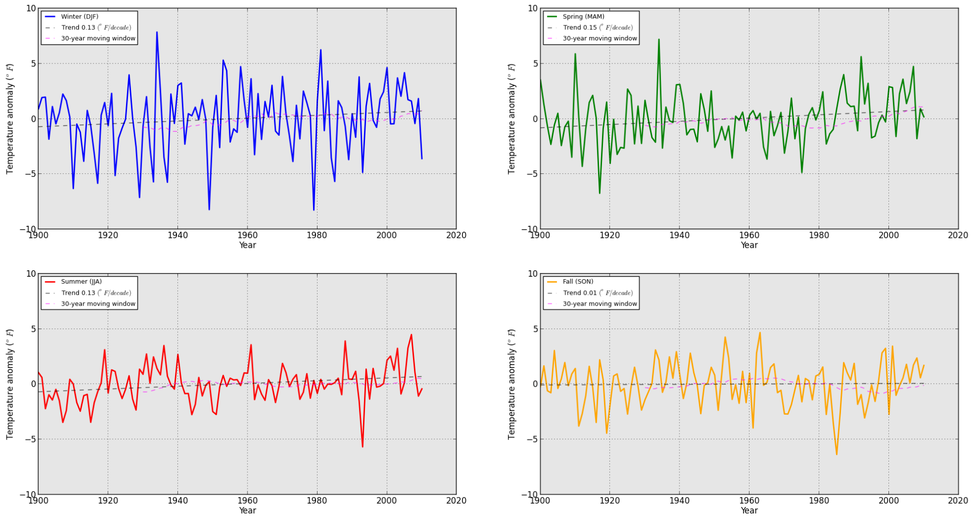


Figure 10: Ensemble means for RCP 4.5 and 8.5 scenarios display an annual mean temperature increase of $\sim 3.5^{o}F$ and $\sim 6.2^{o}F$ over the next century, above the 1900-2010 mean baseline respectively. Mean temperatures by 2050 are similarly projected for both RCP scenarios to $\sim 3^{o}F$ across the region.