20TH CENTURY TEMPERATURE DATA INDICATE THAT THE "LAST BEST PLACE" IS HEATING UP

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INTRODUCTION

The people of Montana take a certain pride in enduring, and even enjoying, long, cold winters. That said, in the dead of winter the prospect of global warming is greeted by many with happy anticipation. While speculation about trends in Montana climate abounds, little scientific effort has been brought to bear on the topic. In this poster, we report on 20th-century trends in temperature extremes for nine Historical Climate Network stations with at least 100 years of record in the mountains of western Montana.

What are extreme climate events? Weather conditions are highly variable in Montana. In seeking to detect changes in extreme climate events, we defined "extreme climate events" as large areas experiencing unusual climate values over a long period of time. More specifically, we used daily weather records to determine number of days per year exceeding three key thresholds (-17.8ºC (0ºF), 0ºC (32ºF), and 32.2ºC (90ºF); following Easterling et al. 2000).

Why focus on temperature extremes? In Montana, episodes of extreme heat or cold are often associated with major impacts on human health, agricultural production, wildfire, and consumer energy demands (Easterling et al. 2000). Some of these impacts may be socially positive (e.g., reduction in the number of heating degree days). Some of these impacts have the potential to disrupt human livelihoods and local economies (e.g., large wildfires, Westerling et al. 2006).

What causes extreme temperature events? Episodes of extreme climate events are associated with long-term changes in drivers of regional climate change in the American West, particularly Pacific Ocean temperature patterns such as El Niño – Southern Oscillation (ENSO) variability. Trends towards extreme warmth in recent decades provide evidence that Montana's climate may be warming in synchrony with the overall climate of the Earth. Increasingly, scientific evidence indicates that approximately global temperature rise of 0.6ºC (1.1ºF) over the 20th century can be directly attributed to the accelerated accumulation of greenhouse gases in the atmosphere (Figure 1; IPCC 2001, Hansen et. al. 2005).

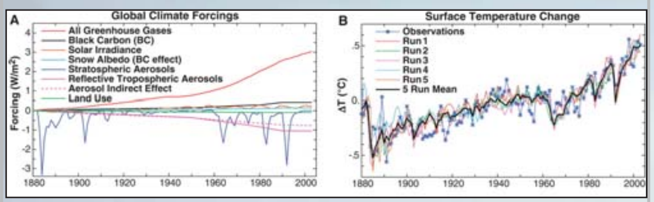


Fig. 1. (A) Forcings used to drive global climate simulations. (B) Simulated and observed temperature change. Before 1900, the observed curve is based on observations at meteorological stations and the model is sampled at the same points, whereas after 1900 the observations include sea surface temperatures for the ocean area, and the model is the true global mean. Five climate simulations are carried out that differ only in initial conditions. Figure adapted from Hansen et al. 2005.

DATA RESOURCES

A major goal of this project was to make the data resources and analysis available to other states, counties, and the general public. To meet this goal we sought to: 1) compile high-quality, freely available, daily and montly temperature data, 2) use freely available analysis software, and 3) keep analysis methods simple and provide well-documented, easy-to-use code for more difficult functions. These goals were accomplished. The long-term (1895-2002), corrected data used in the analysis presented here are provided by the U.S. Historic Climatology Network (http://cdiac.ornl.gov/epubs/ndp/ushcn/newushcn.html), and the recent updates (2002-present) from the Western Regional Climate Center (http://www.wrcc.dri.edu/). Northern Hemisphere and Global temperature data was obtained from the Global Historic Climatology Network (http://cdiac.ornl.gov/trends/temp/lugina/data.html). All statistics and daily data analysis were performed using the **R** project software environment (free download at http://www.r-project.org/). Code written for single station daily temperature analysis may be obtained from Greg Pederson (gpederson@montana.edu) and will soon be available on-line from the Big Sky Institute (http://bsi.montana.edu/).

REGIONAL TRENDS IN MAXIMUM AND MINIMUM TEMPERATURES

Globally, a major driver of change in average temperatures results from a decreasing Diurnal Temperature Range (DTR). The decrease in DTR is mainly attributed to a more rapid increase in minimum (nighttime) temperatures rather than in maximums, which is likely caused by a number of factors, such as increased cloudiness (Easterling et al. 1997). In a previous study the authors here along with several Canadian scientists found a strong decrease in DTR throughout the Canadian Rockies (Glacier National Park, MT to Jasper, AB). For western Montana, however, changes in maximum and minimum temperatures are different across seasons (Figure 2). Results may be summarized as follows:

- **Significant ($p<0.05$) increases in maximum and minimum temperatures.**
- **A decrease in DTR due to more rapid increase in minimum temperatures.**
- **Maximum temperatures exhibit greater variability than minimums.**
- **Over the last 20 years spring minimum temperatures were on average above freezing.**
- **Since the 1960s winter maximum temperatures have been trending above freezing.**

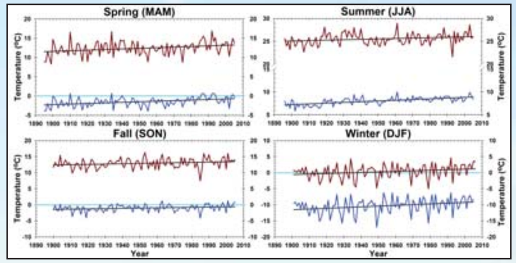
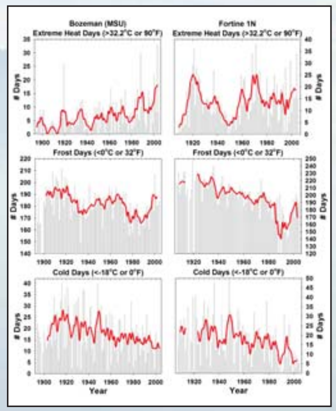


Fig. 2. Seasonal trends in maximum (red line) and minimum (blue line) temperatures for western Montana.

TRENDS IN EXTREME CLIMATE EVENTS

A major concern associated with changes in temperature is that an increase in frequency and duration of extreme events will occur. For western Montana we see two distinct patterns for changes in extreme events. These patterns are roughly representative of northwestern and southwestern Montana, here Fortine and Bozeman are presented as examples for each region (Figure 3). Results summarized as follows:



- **Southwestern Montana (especially Bozeman and Helena) has experienced a linear increase in the # of days > 32.2ºC.**
- **Northwestern Montana exhibits strong decadal variability in # of days > 32.2ºC. The early 20th-century spike in days >32.2ºC is associated with the "dust bowl" years.**
- **Extreme spikes in # days > 32.2ºC are associated with large regional fire activity.**
- **With few exceptions, western Montana has experienced a decrease in frost days (# days < 0ºC) and # of days below -18ºC.**
- **The trend in loss of cold days (i.e. # days <-18ºC) is generally greater then the apparent decrease in number of frost days, and is more consistent across records.**

Fig. 3. Trends in three key temperature thresholds (-18ºC (0ºF), 0ºC (32ºF), and 32.2ºC (90ºF) for Bozeman and Fortine, Montana.

GLOBAL CLIMATE CHANGE AND WESTERN MONTANA

The expression of global warming induced climate change may differ by region as well as across seasons. For western Montana we see temperature variability across seasons tracks global (not shown here) and Northern Hemisphere trends on short- (interannual) and long-term (multi-decadal) scales (Figure 4). Although this response is strong for the entire region, at the scale of an individual station the strength of the relationship may become quite variable (Figure 5). The decoupling of an individual station from regional or global trends may result from a variety of factors.

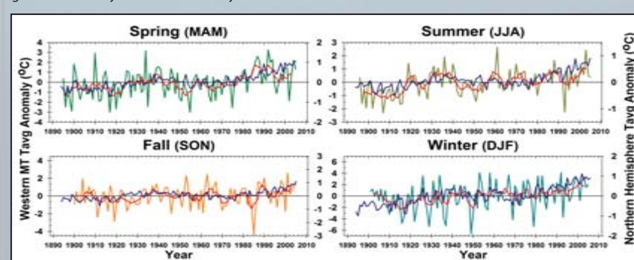


Fig. 4. Comparison between trends in western Montana (red lines) and Northern Hemisphere (blue lines) seasonal temperatures over the 20th century. Note, red line displays the 5-year running mean.

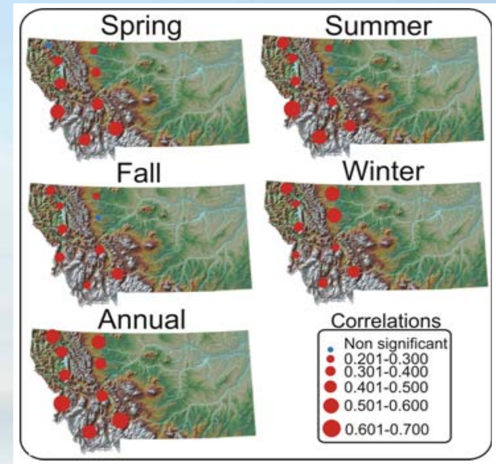


Fig. 5. Correlations between average annual and seasonal temperature records for the Northern Hemisphere and the nine individual Montana stations.

SUMMARY & IMPLICATIONS

KNOWN

- Reliable, long-term records of 20th century temperature can be readily accessed and analyzed in order to place current climate trends into context.
- 20th century warming trends over most seasons at the majority of western Montana climate stations are statistically significant.
- Extreme temperature events correspond with wildfires, phenology, and glacier mass balance.

LIKELY

- As greenhouse gas concentrations increase, temperatures in Montana are likely to rise.
- As temperatures cross critical thresholds (e.g., length of frost-free season), the potential for large changes in ecosystem services increase. Some of these changes are likely to be beneficial in Montana (e.g., crop yields), while some of the changes are likely to be seen as negative (e.g., wildfire frequency and extent).

IMPLICATIONS

- These results argue for continued resource allocation for monitoring climate, and integrating current observations with the rich archive of 20th century data.
- Further, it is imperative to devise robust strategies to monitor and anticipate changes in climate-sensitive resources in concert with stakeholder groups.

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