Climate and Climate Change in Montana

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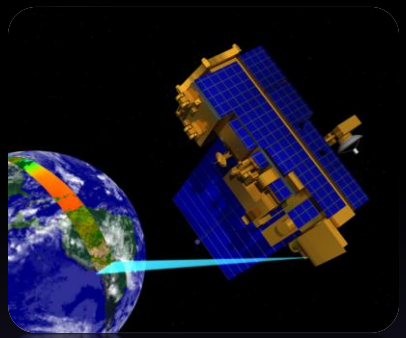
How do I spend my time?

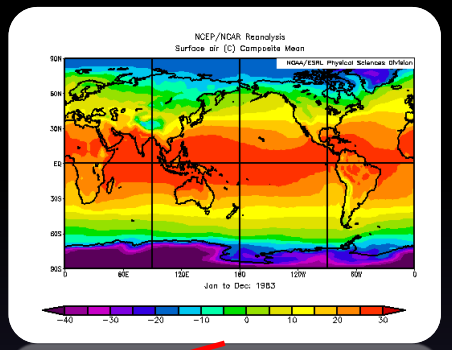
Weather Station Data

Topographic Data

Satellite Data



Large-scale Atmospheric Data



I wonder what the climate has been like up there?

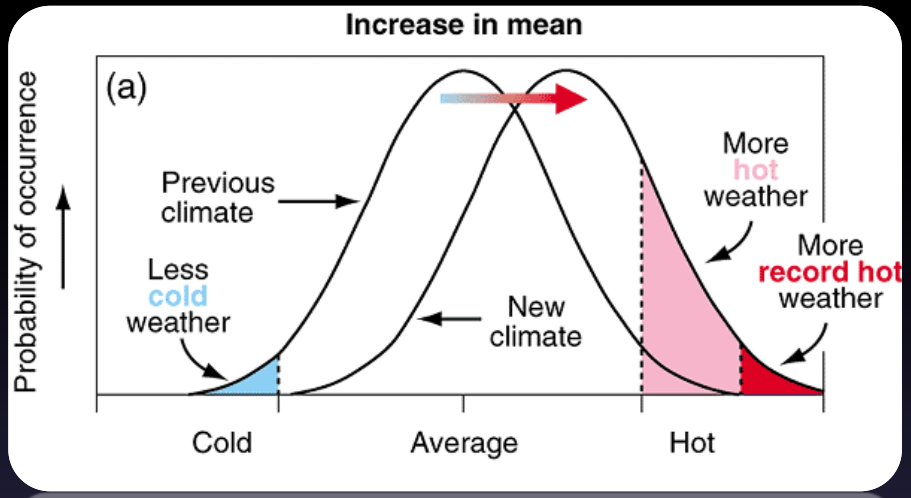
Outline

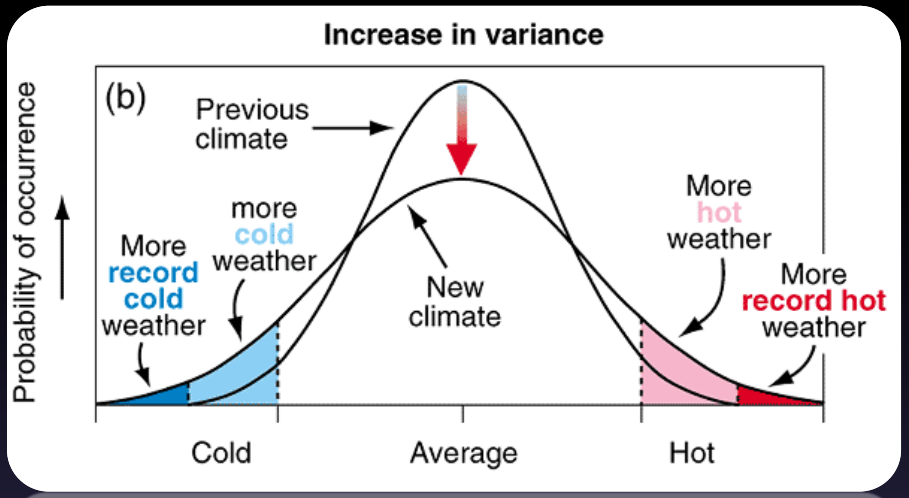
- Review of weather and climate basics
- General climate of Montana
- Large-scale natural climate variability
- Climate trends in Montana
- Snowpack trends
- Climate projections

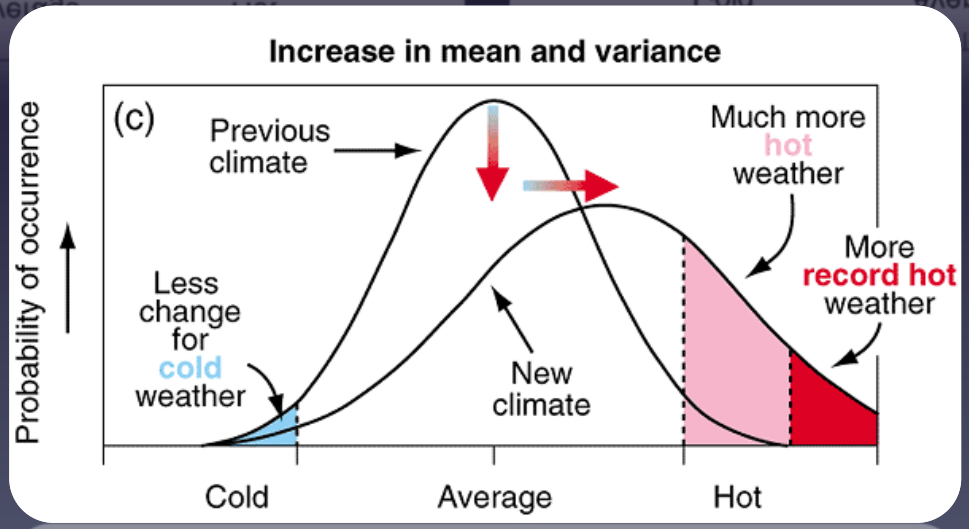
The Basics

- **Weather**: the condition of the atmosphere at any particular place and time
- **Meteorology**: scientific study of the atmosphere and the phenomena that we usually refer to as weather
- **Climate**: represents the long-term behavior of the atmosphere at a given region. A description of aggregate weather conditions; the sum of all statistical weather information that helps describe a place or region
- **Climatology**: scientific study of climate and climatic patterns and the consistent behavior of weather, including its variability and extremes, over time in one place or region; includes the effects of climate change on human society and culture

Climate Change







IPCC AR3 2001

Weather vs. Climate

Basic Elements

- **Basic elements** of both weather and climate:
  - Temperature
  - Humidity
  - Type/amount of cloudiness
  - Air pressure
  - Type/amount of precipitation
  - Wind speed/direction

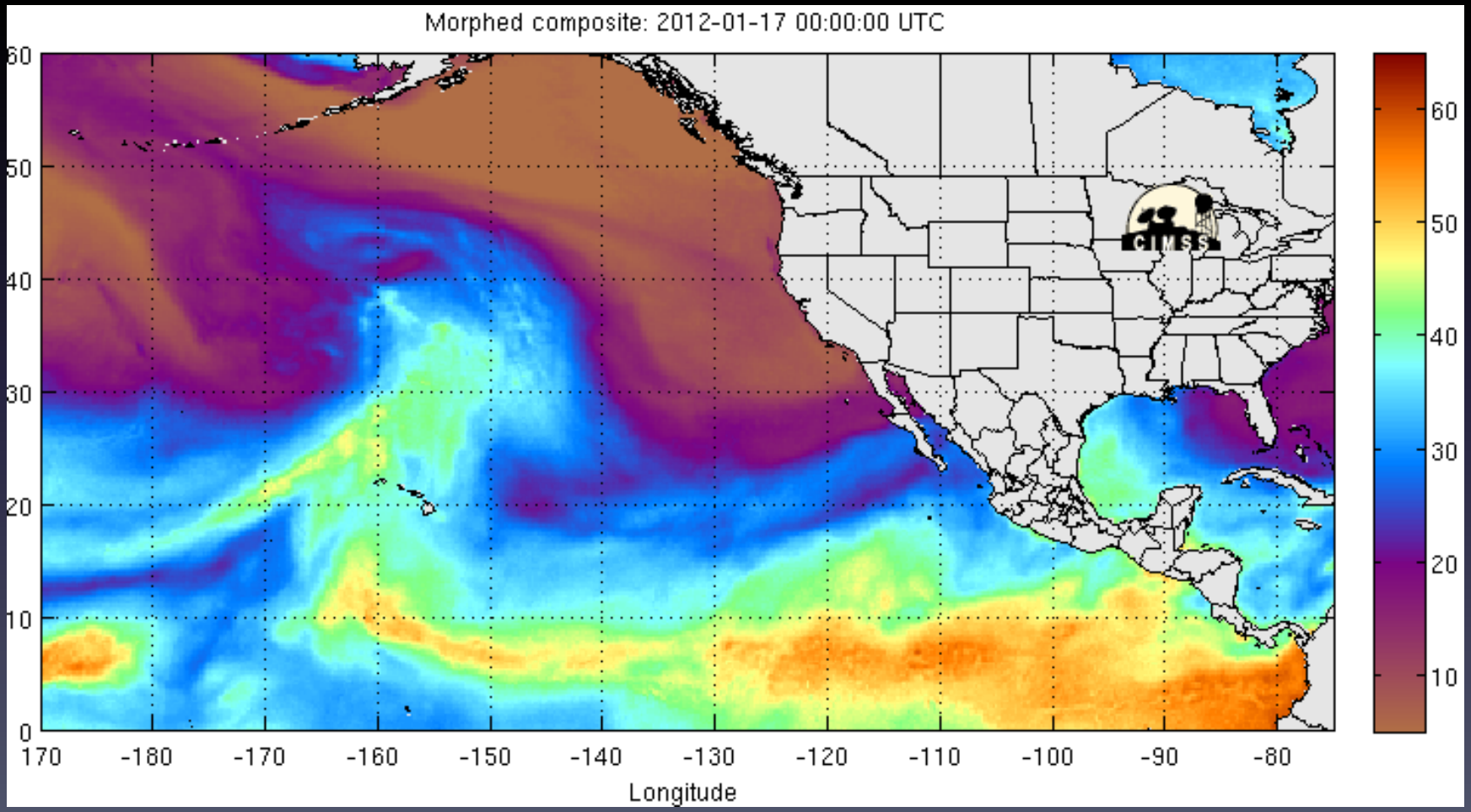
Climate of Montana

Climate of Montana

- East of the continental divide, mainly a **continental climate**
  - Large annual temperature range
  - Cold winters and hot, dry summers
- The continental divide forms a transition zone between **maritime** and **continental climates**
  - Maritime air masses bring storms during the winter with increased precipitation at many higher elevations
  - More moderate winter temperatures in the valleys
  - More stability in July/August with clear and dry conditions

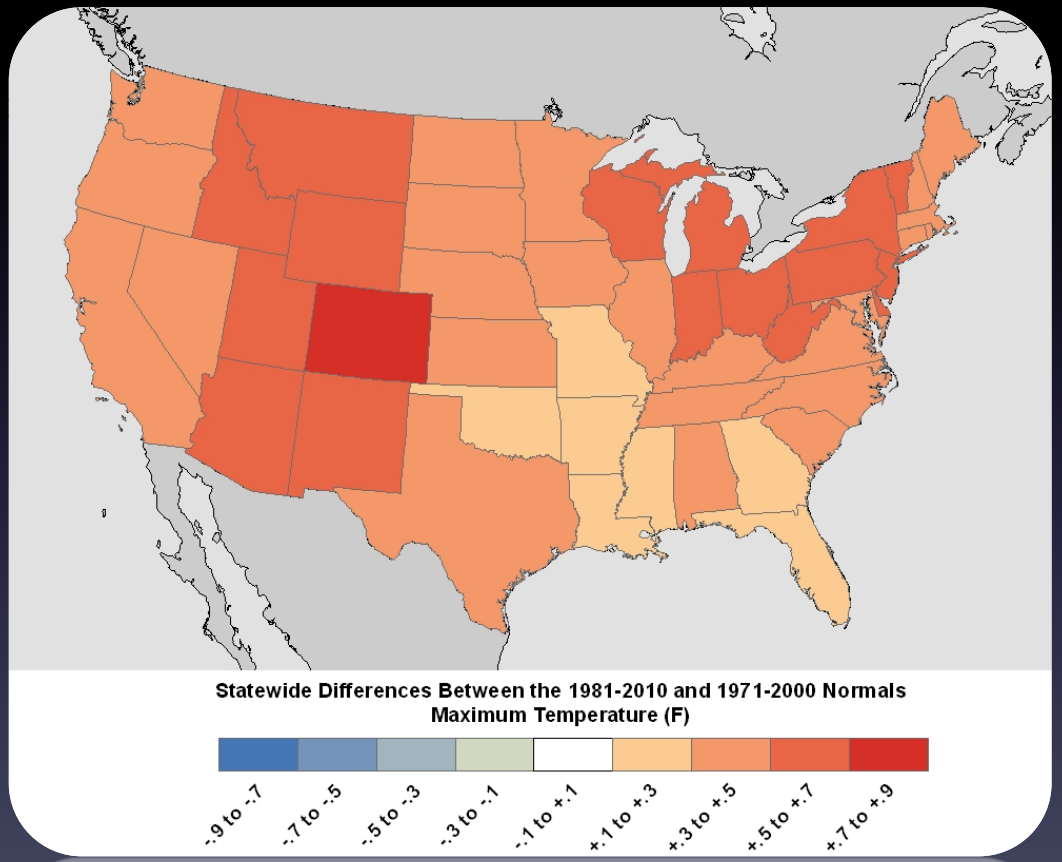
Climate of Montana

Example Pacific storm in winter



Climate Normals

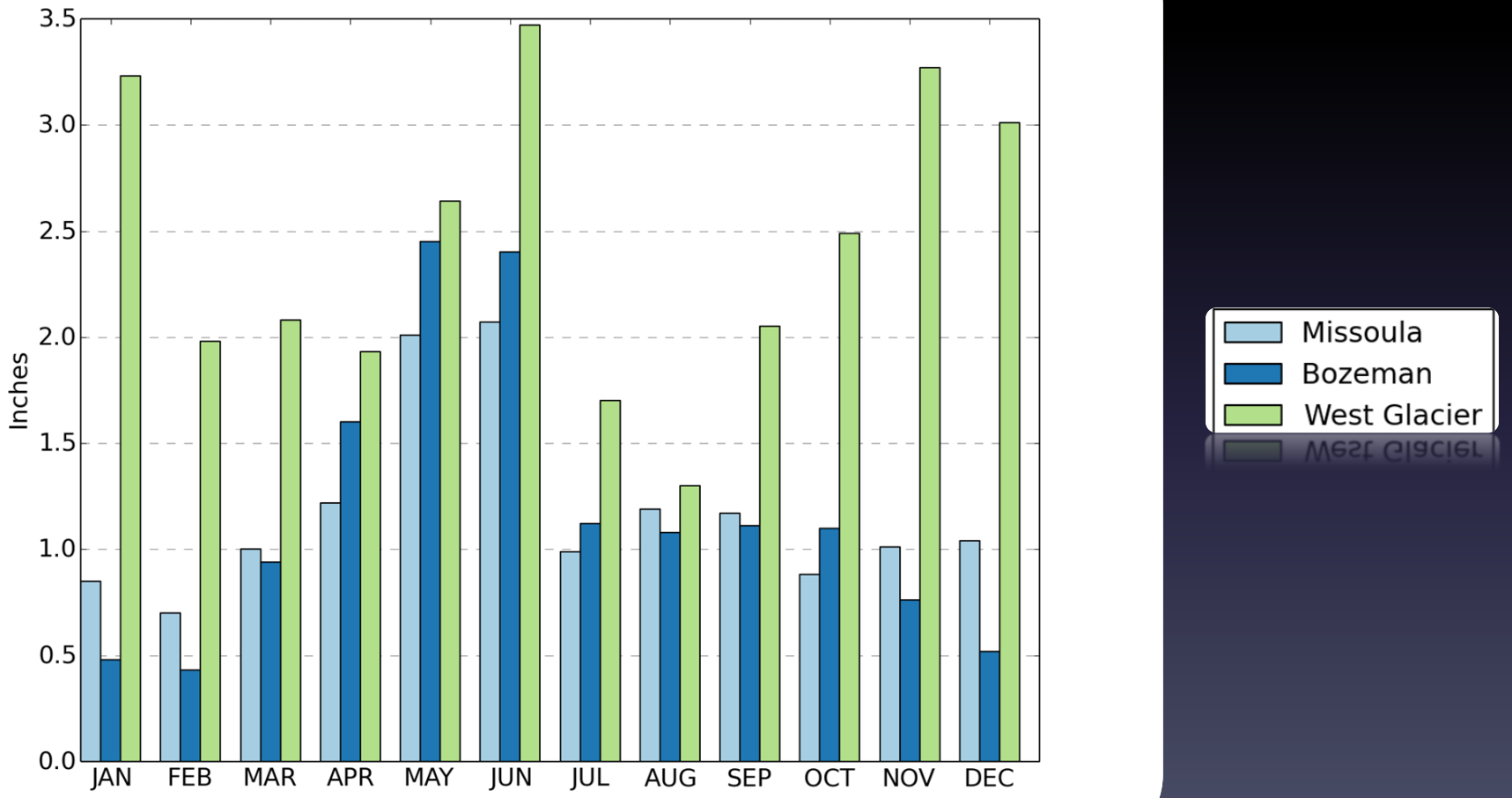
- **Climate Normal**: a 30-year average of a weather/climate variable (e.g.—temperature). Also includes degree days, probabilities, standard deviations, etc.
- The latest climate normals are for 1981 – 2010. Updated on a decadal basis.



http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data

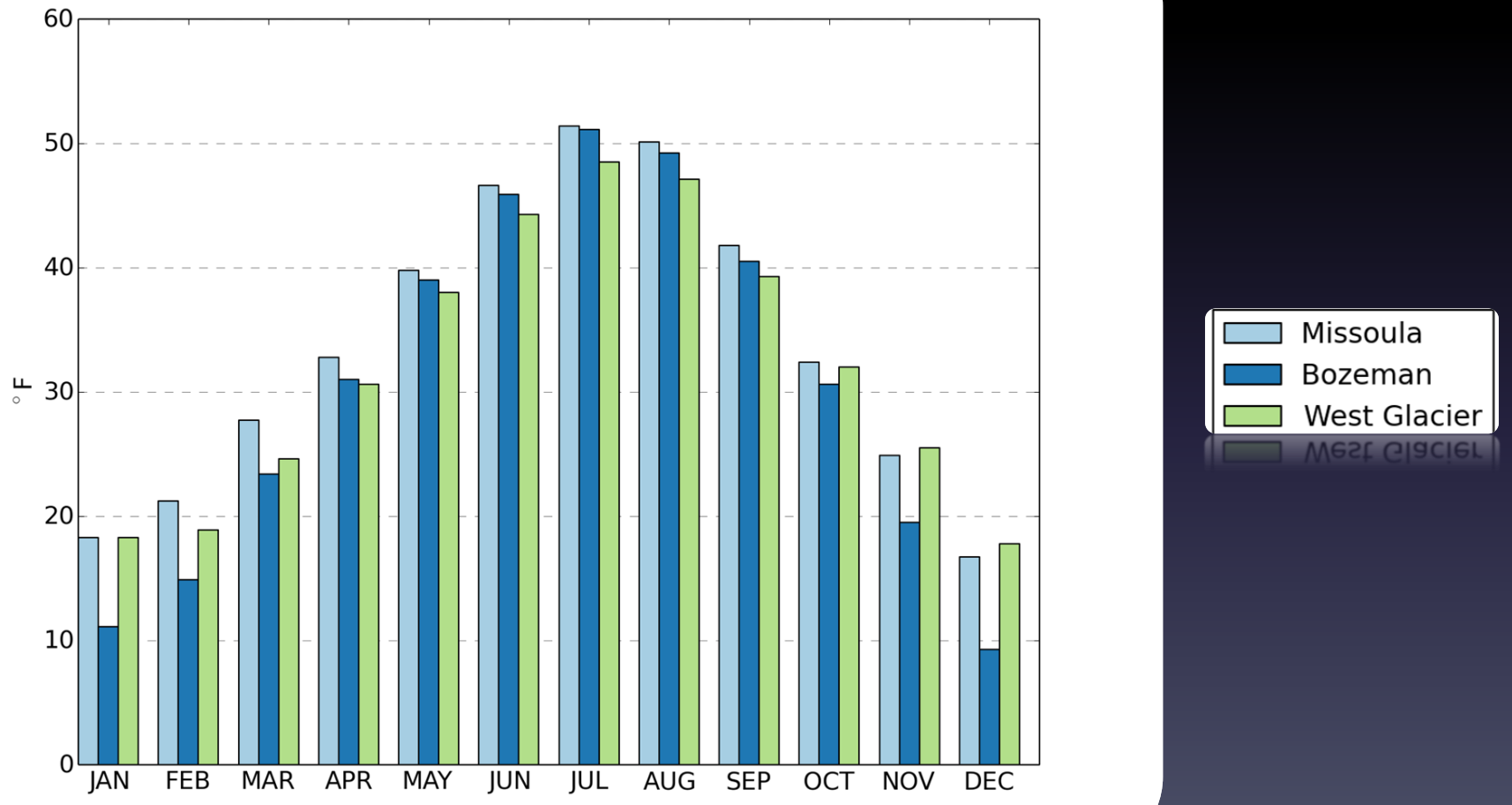
Climate of Montana

Precipitation: 1981 – 2010 Monthly Normals



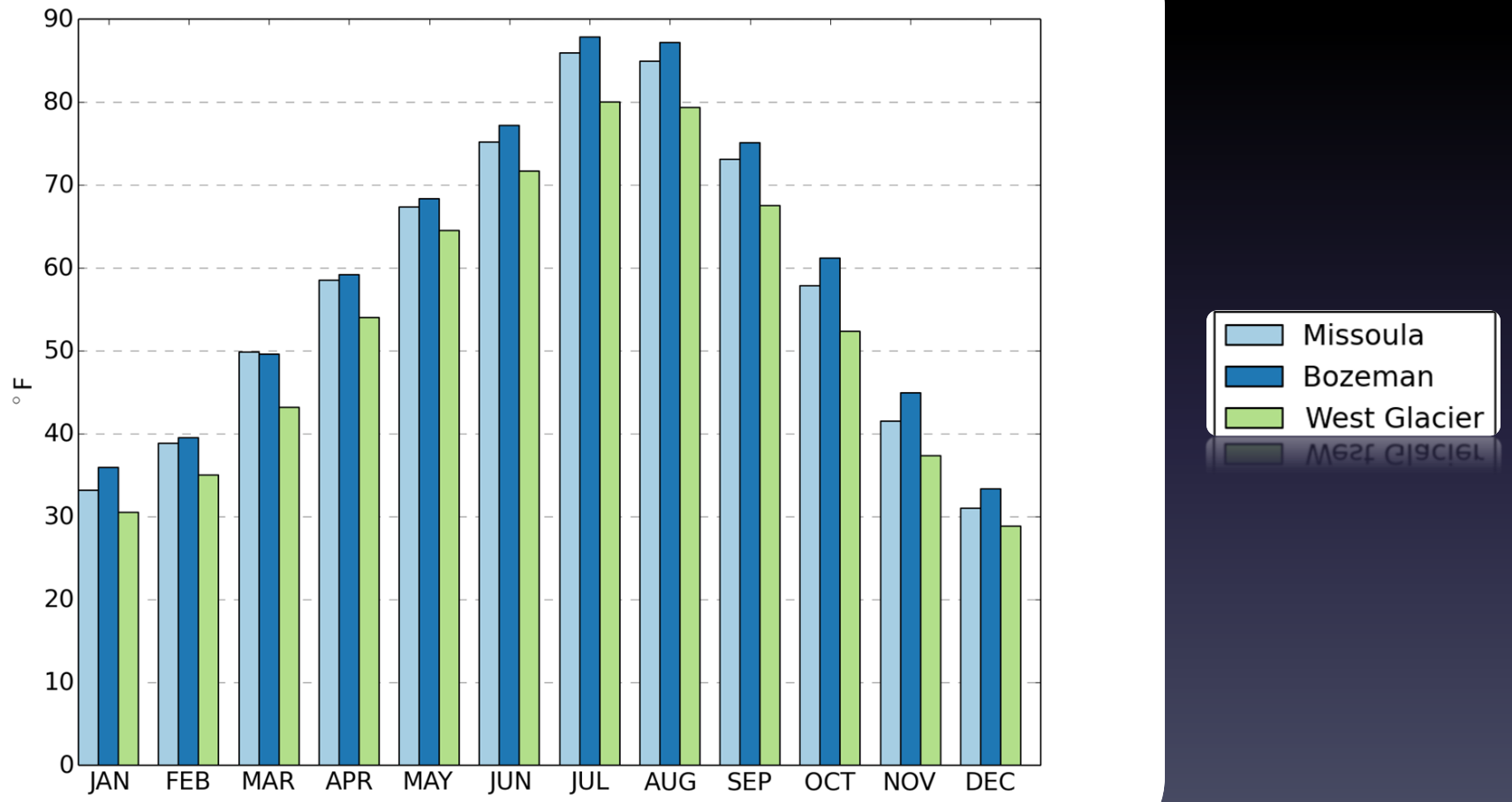
Climate of Montana

Minimum Temperature: 1981 – 2010 Monthly Normals



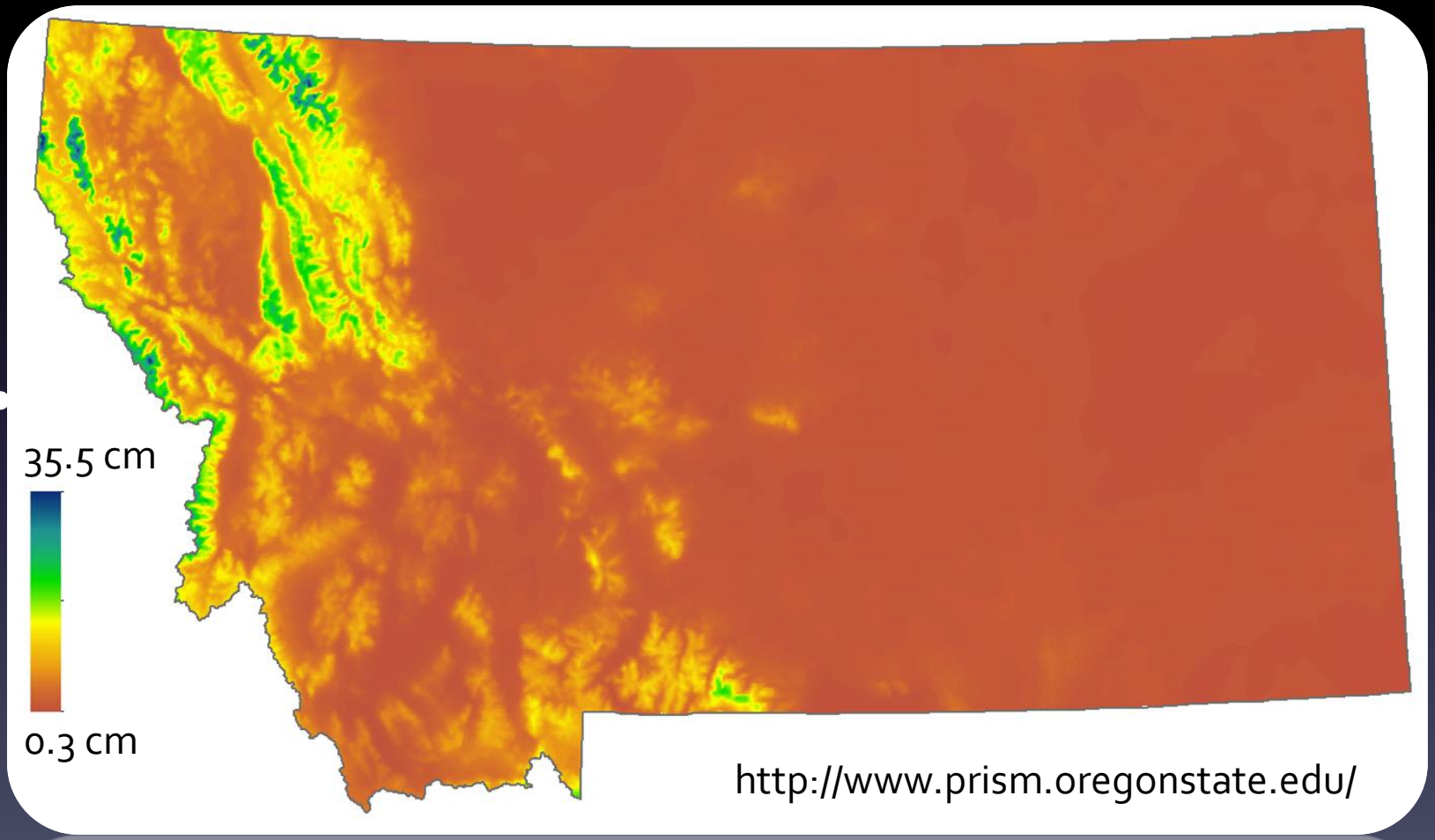
Climate of Montana

Maximum Temperature: 1981 – 2010 Monthly Normals



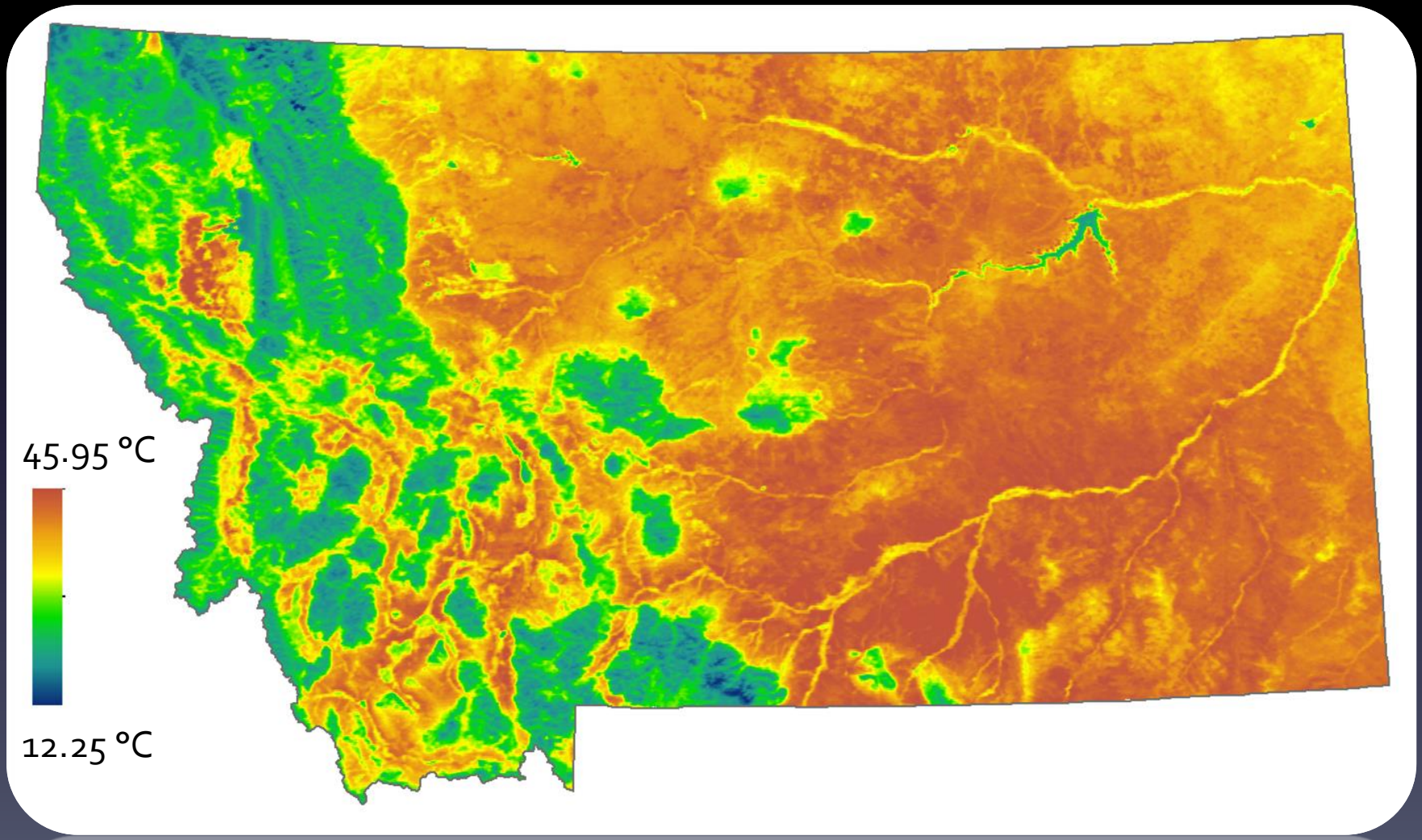
Climate of Montana

Precipitation: 1981 – 2010 January Normals



Climate of Montana

Tmax Avg. Land Skin Temperature : August 2003-2012



Mesoscale Climate Features

Moderating influence of Flathead Lake

Cherry orchards and vineyards in Montana!?

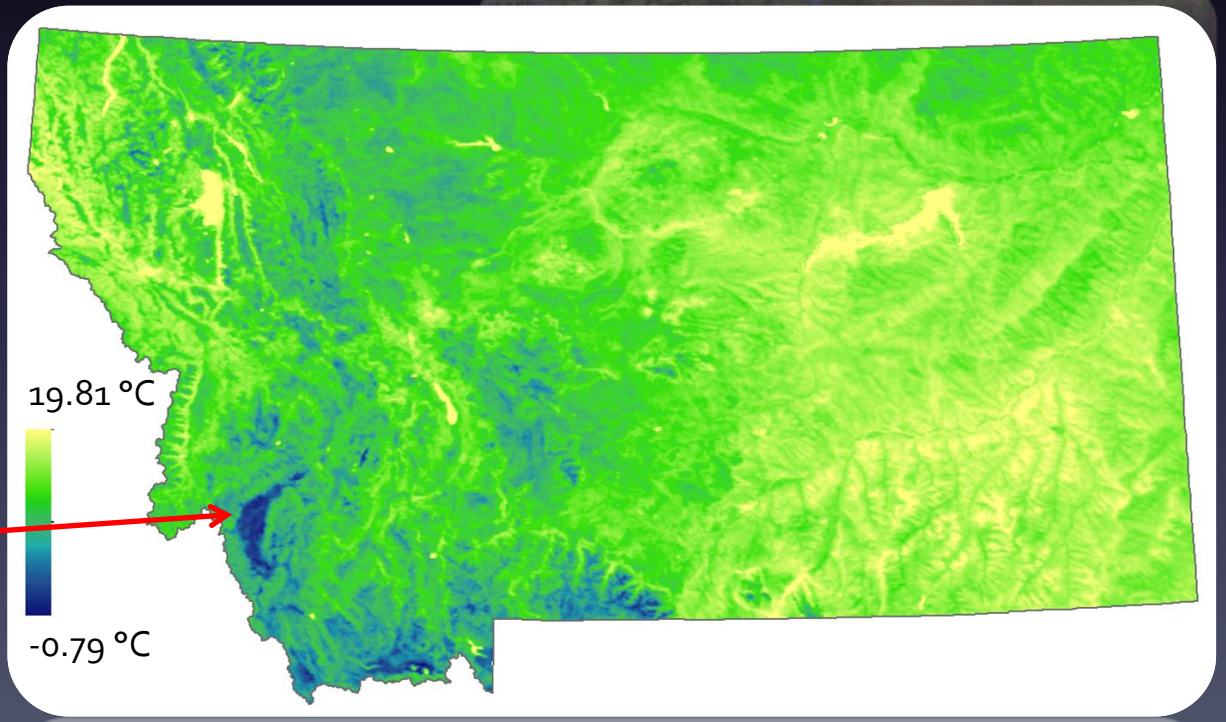
Mesoscale Climate Features

Tmin Avg. Land Skin Temperature : August 2003-2012

Temperature Inversions

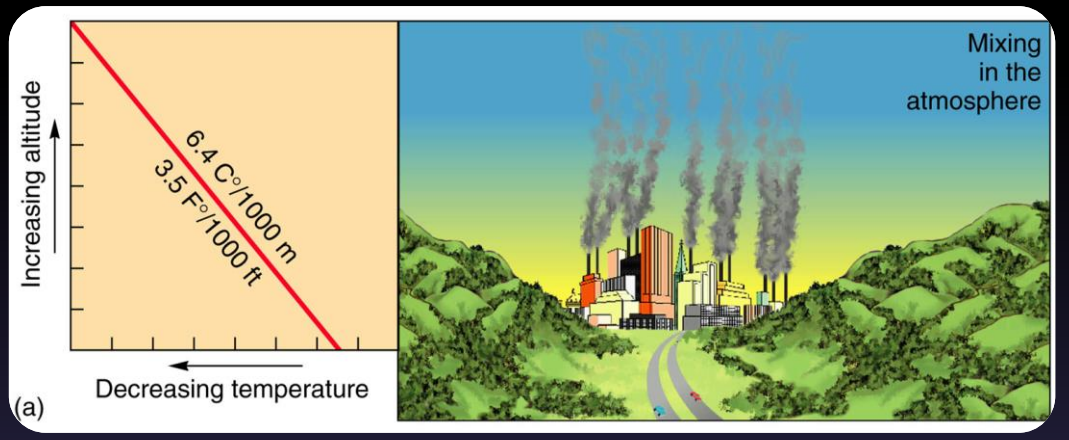
- Colder at lower elevations.
- Most commonly associated with minimum temperatures.

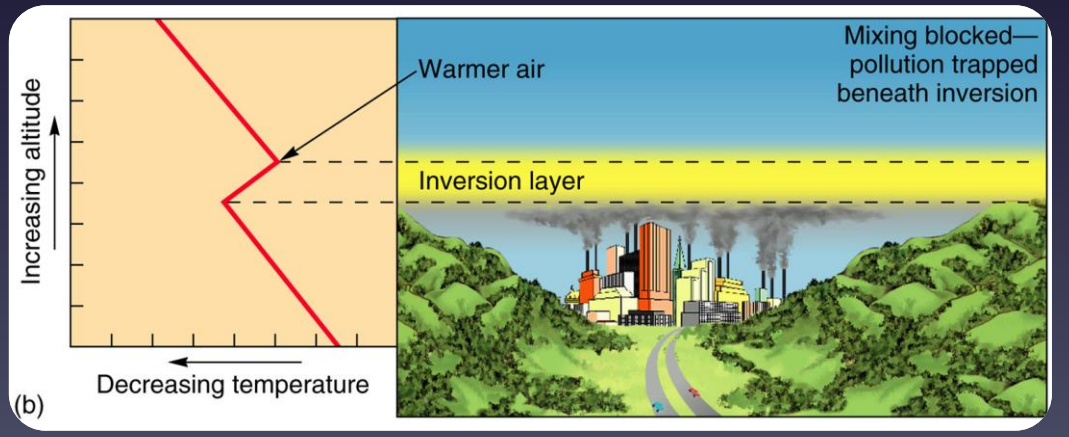
Why is it colder here?



Mesoscale Climate Features

Radiation Inversion: on cold clear calm nights, longwave radiation can radiate from the ground quickly, escape into upper atmosphere and the air near the surface will be very cool (usually very shallow)

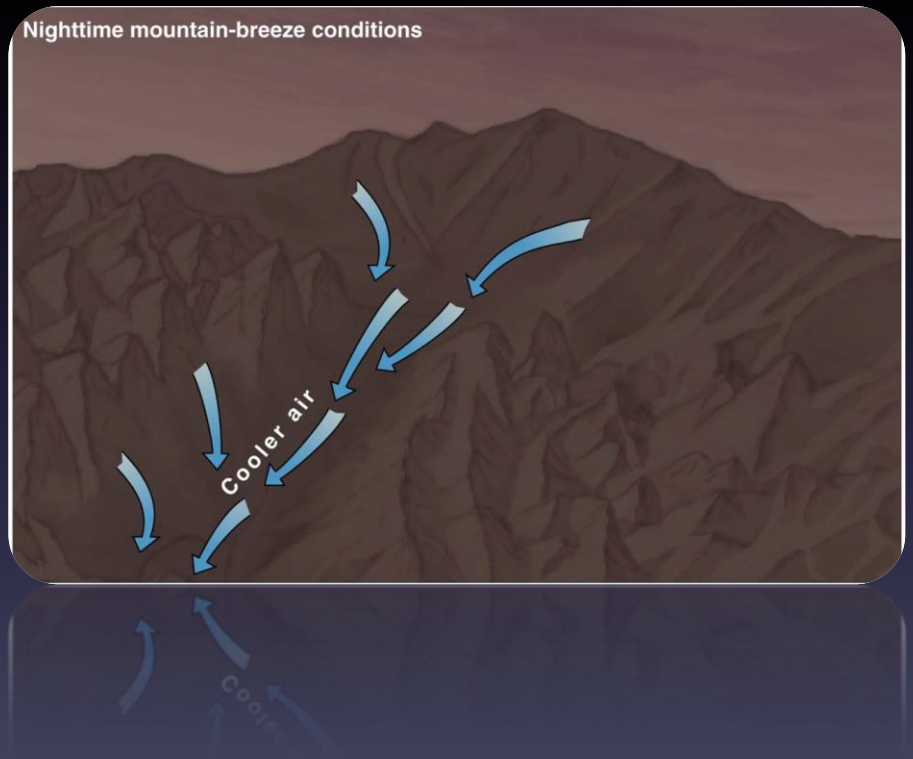




Mesoscale Climate Features

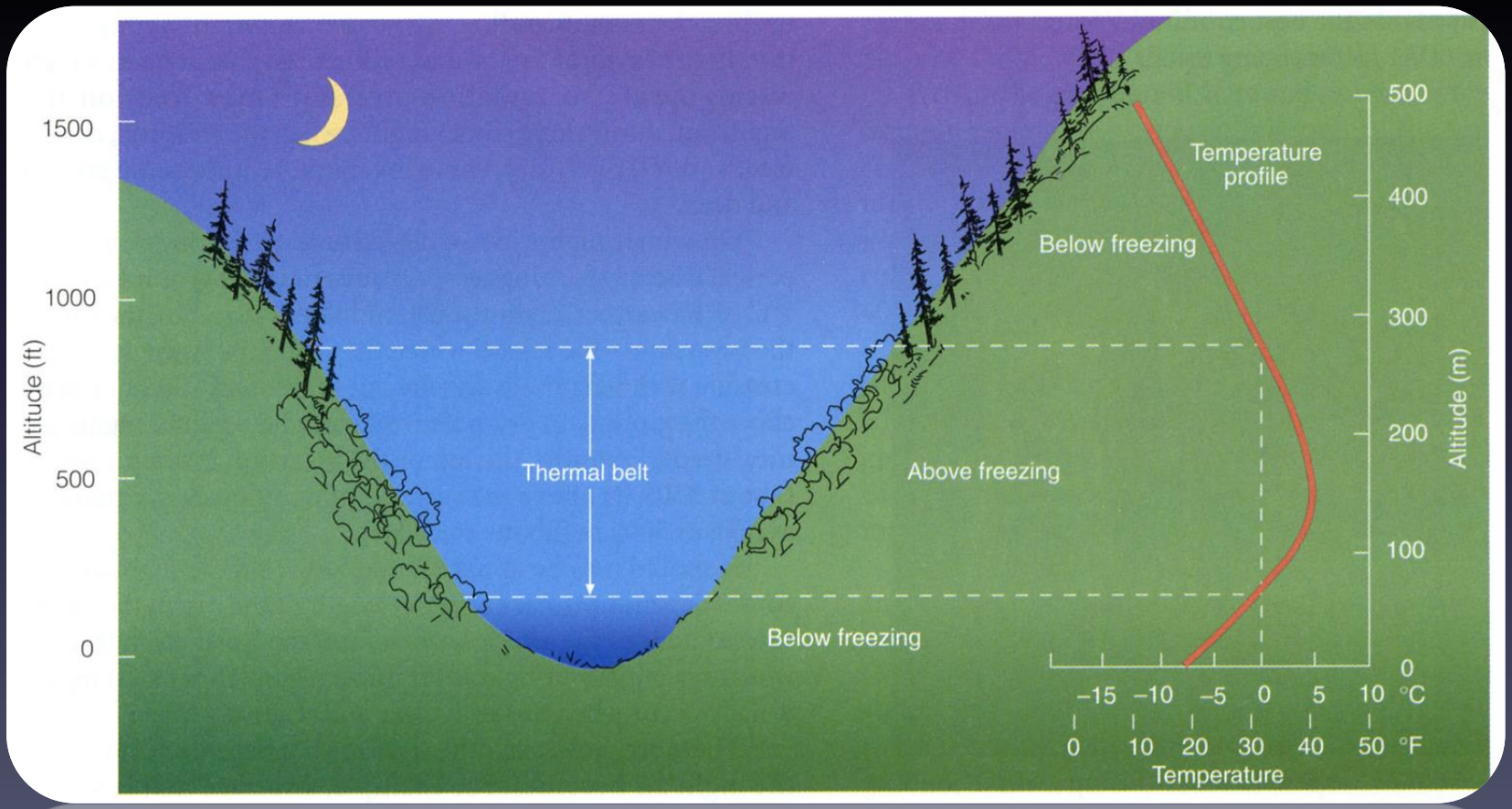
Cold-Air Drainage: cold air sinking into valleys can lead to inversions.

- Cold air is more dense than warm air.
- This causes the cold air to "drain" (like water) downhill!



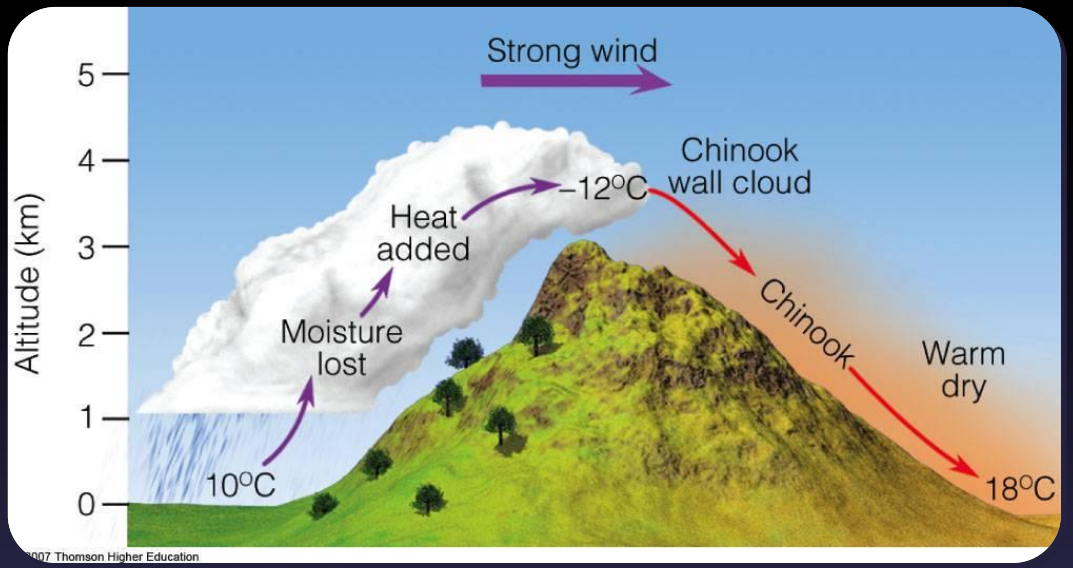
Mesoscale Climate Features

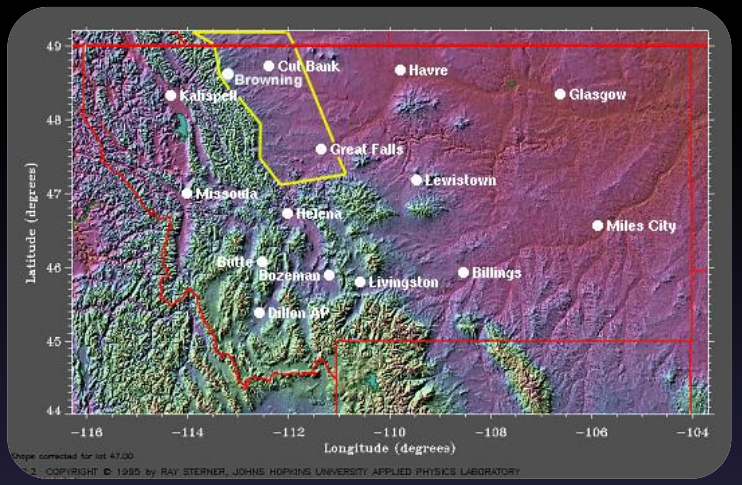
Thermal Belts



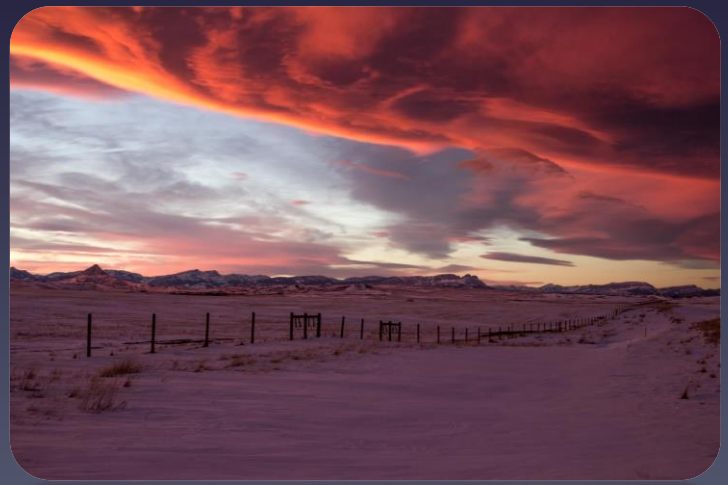
Mesoscale Climate Features

Chinook Winds (Foehn)



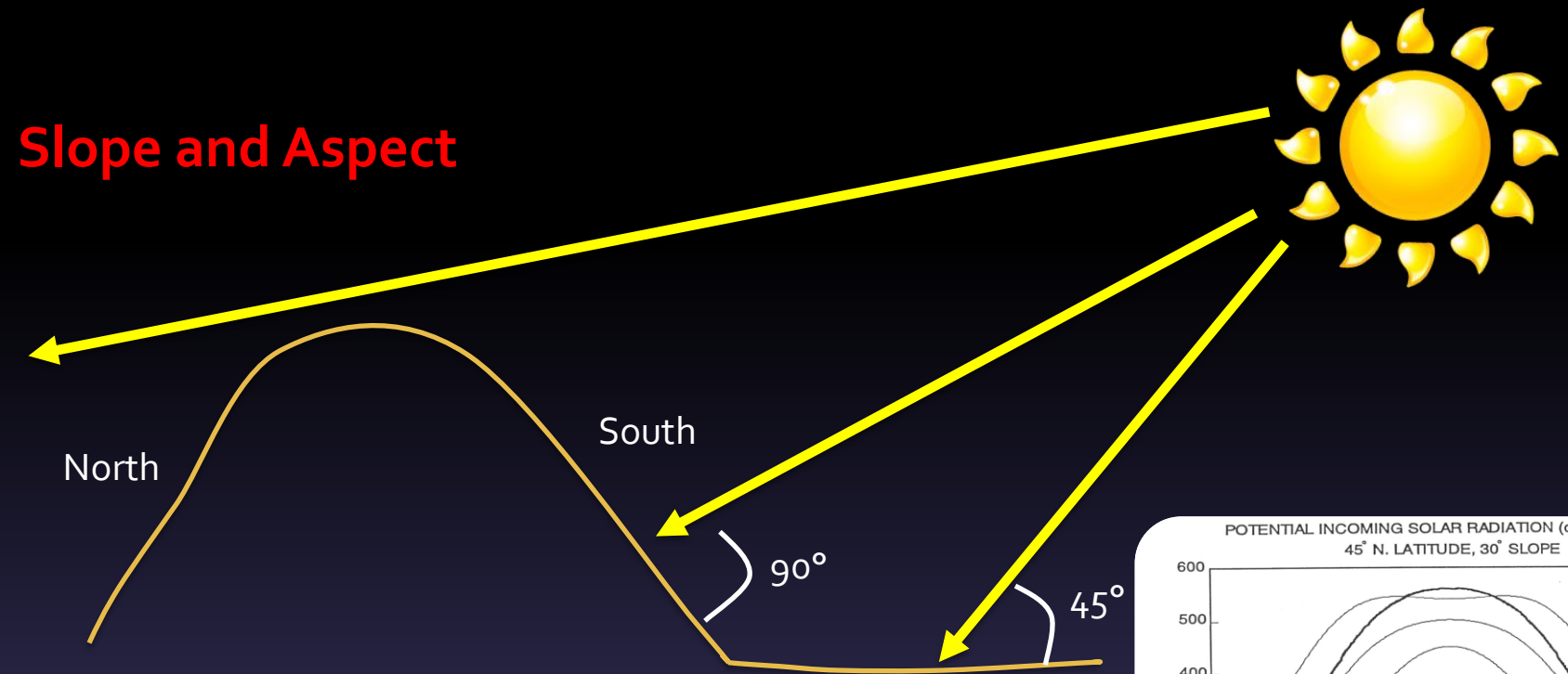


http://formontana.net/chinook.html

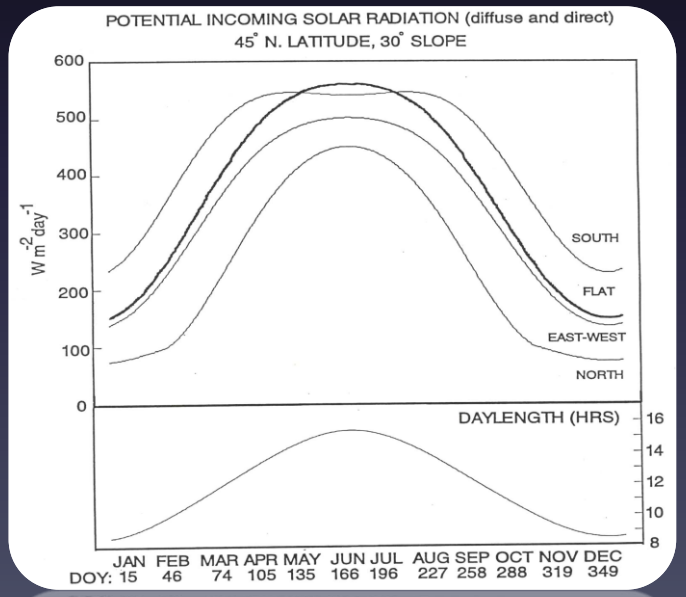


Microscale Climate Features

Slope and Aspect



Slope	Angle of Incidence
45° facing Sun	90°
Flat	45°
45° away from Sun	0°




Map
Photos
200
90
Bannack
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Image © 2011 DigitalGlobe
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Natural Climate Variability in Montana

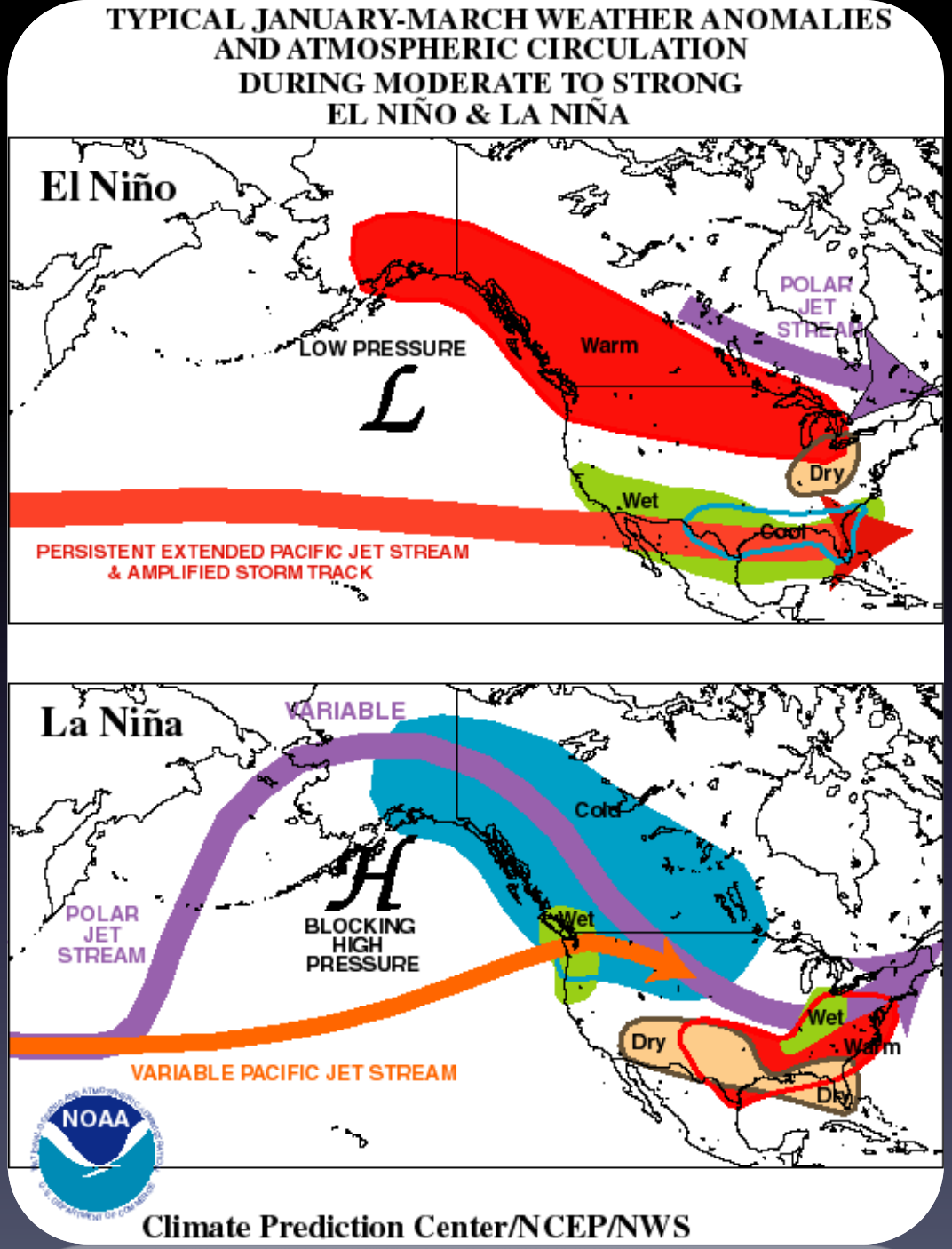
El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO)

- A system of interactions between the tropical Pacific Ocean and the atmosphere above it
  - **El Niño**: warm phase
  - **La Niña**: cold phase
- Interval of El Niño occurrence is 3 – 5 years but can be anywhere from 2 – 12 years
- **Produces the greatest interannual variability of temperature and precipitation on a global scale**

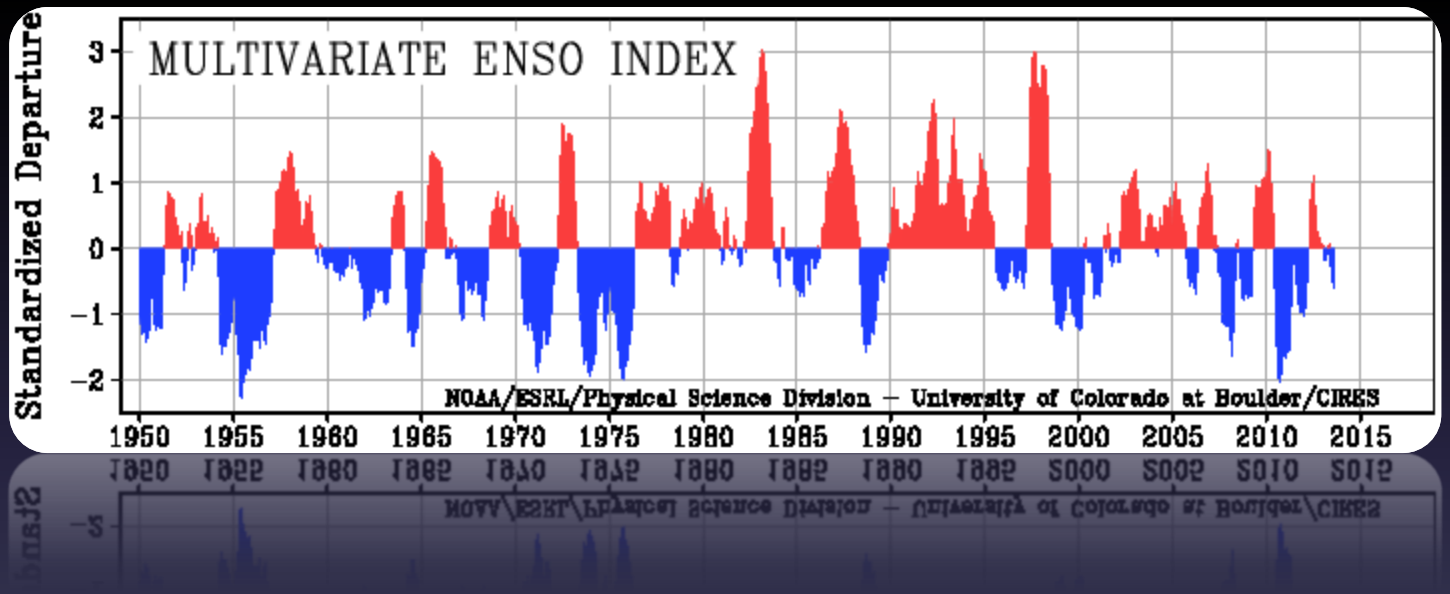
El Niño/ La Niña Impacts

Shift in jet streams



ENSO

Multivariate ENSO Index



Outlook

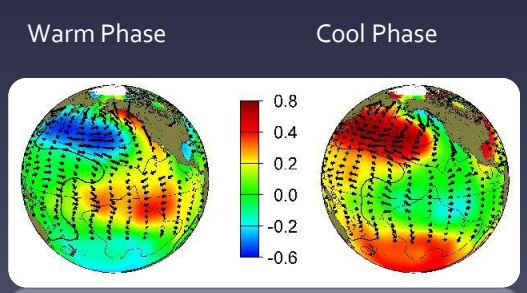
ENSO-neutral conditions.

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/

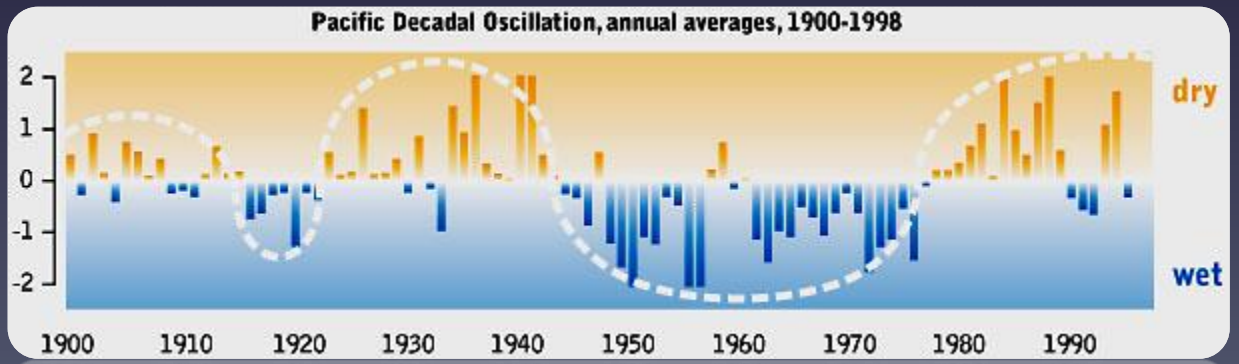
http://www.bom.gov.au/climate/enso/

Pacific Decadal Oscillation

- Similar to ENSO, but more long lived
- Shifts on inter-decadal time scale: every 20 – 30 years
  - Warm/positive phase: drier in Montana
  - Cool/negative phase: wetter in Montana
- Recently transitioned to cool/negative phase



http://jisao.washington.edu/pdo/

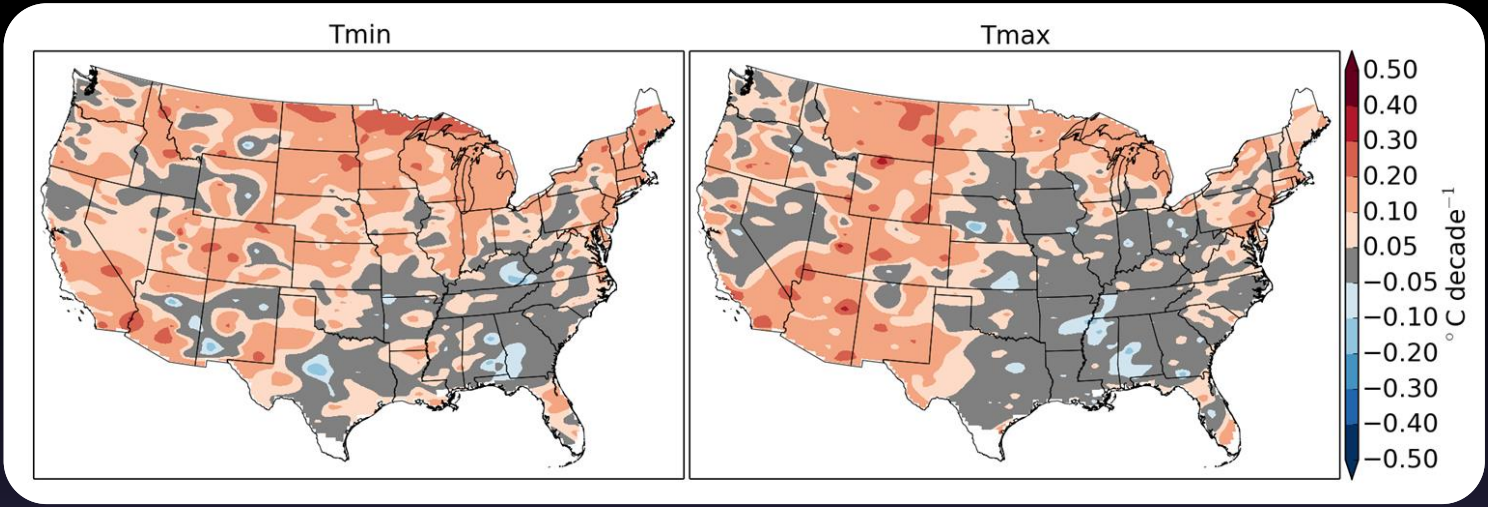


http://www.montana.edu/wwwvr/activities/activities02/drought.html

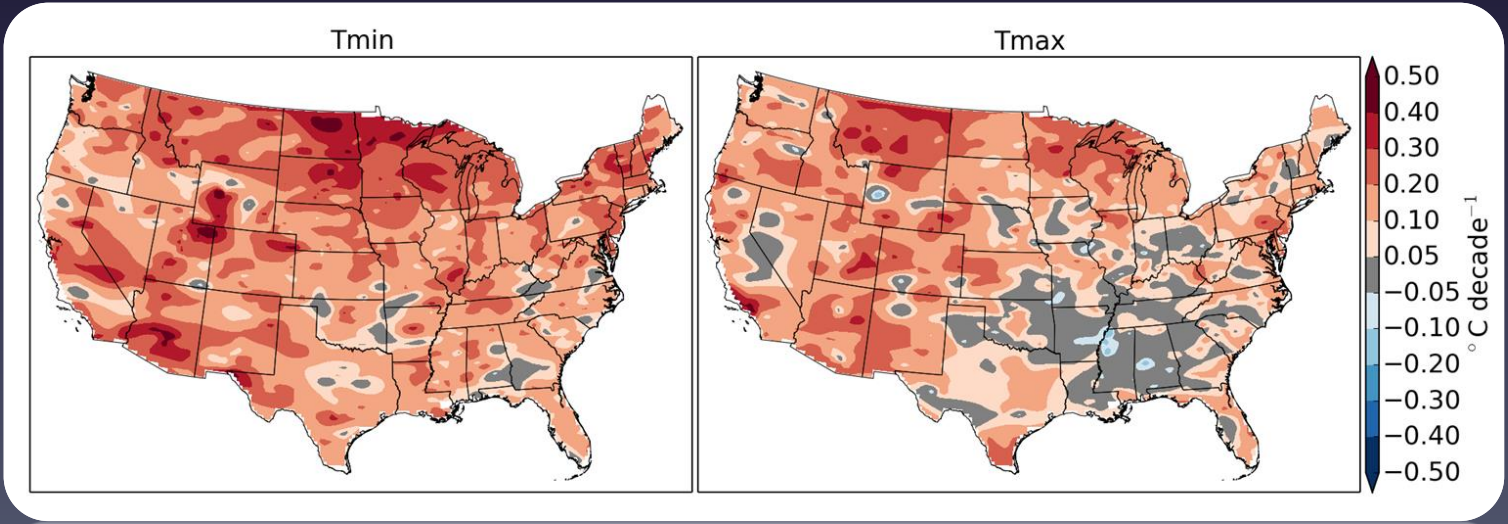
Climate Trends in Montana

Montana Temperature Trends

1895 – 2012 Trend in Annual Temperatures



1948 – 2012 Trend in Annual Temperatures

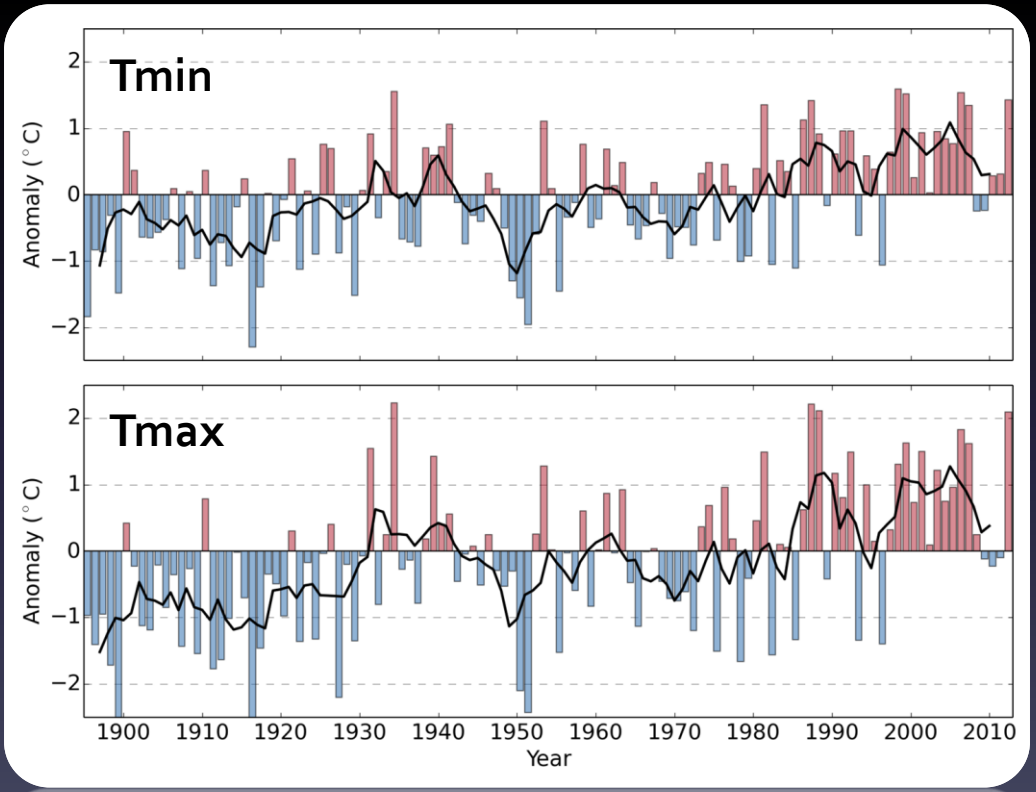


Montana Temperature Trends

Increase in annual temperature 1895-2012

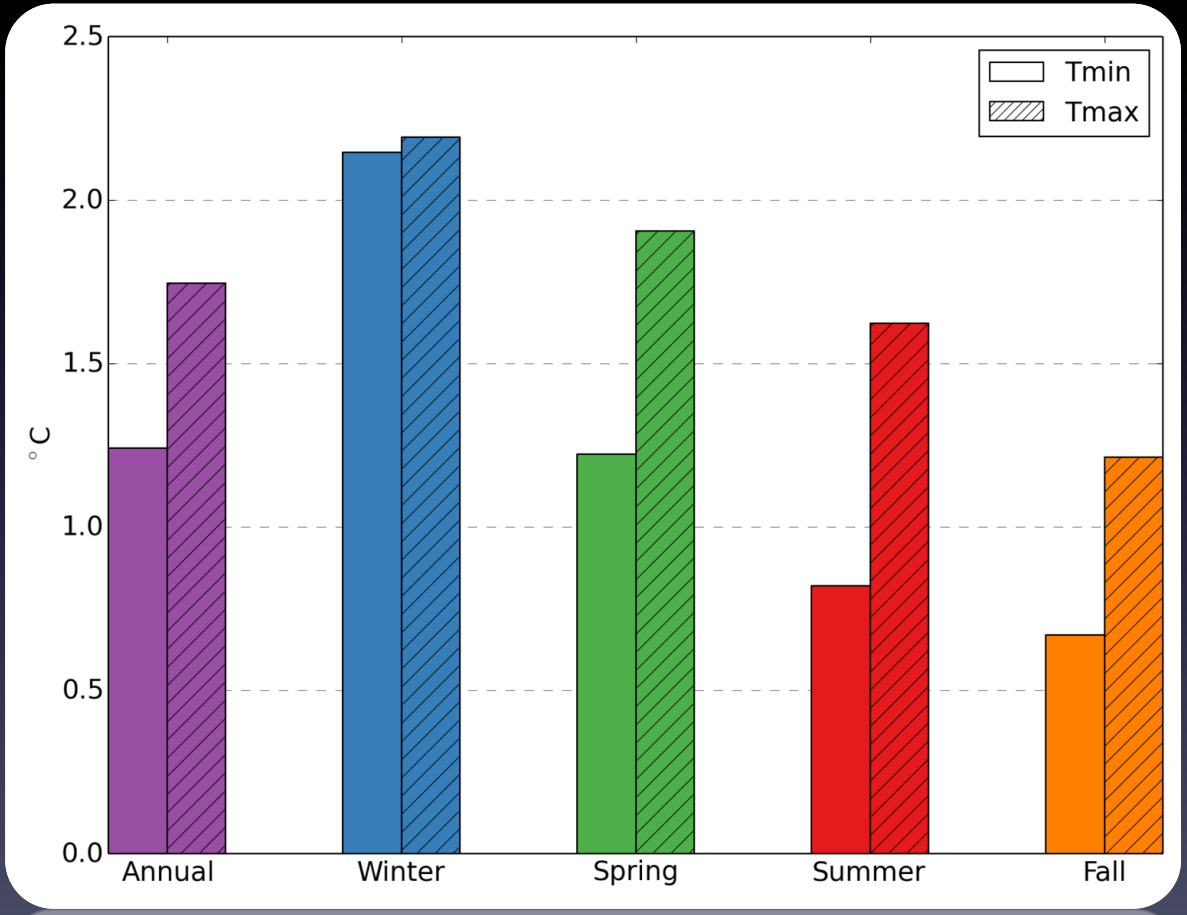
	Tmin (°C)	Tmax (°C)
Montana	1.241	1.745
CONUS	0.970	0.792

Montana Annual Temperature Anomalies (1961-1990 baseline)



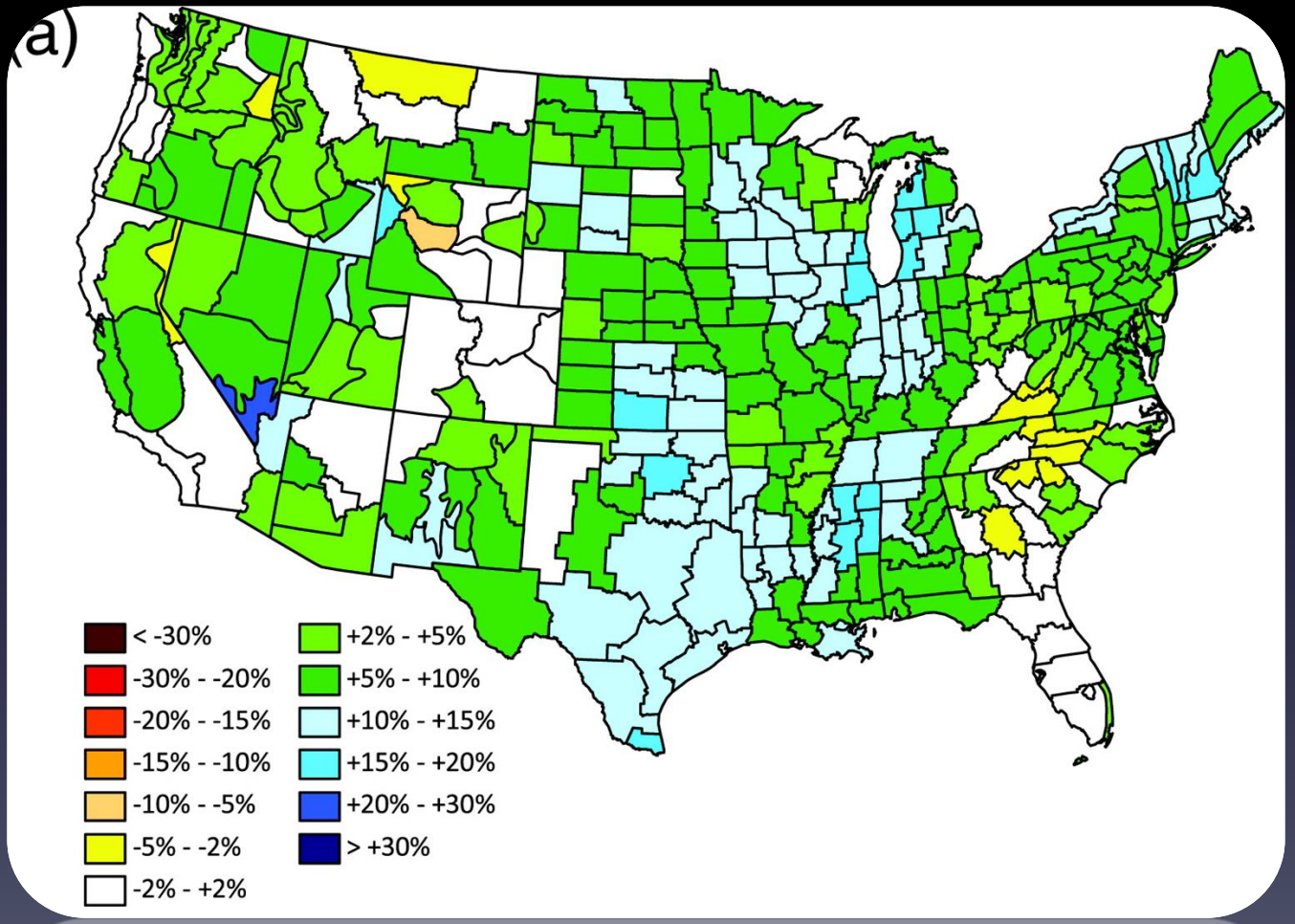
Montana Temperature Trends

Increase in seasonal Montana temperature 1895-2012



Montana Precipitation Trends

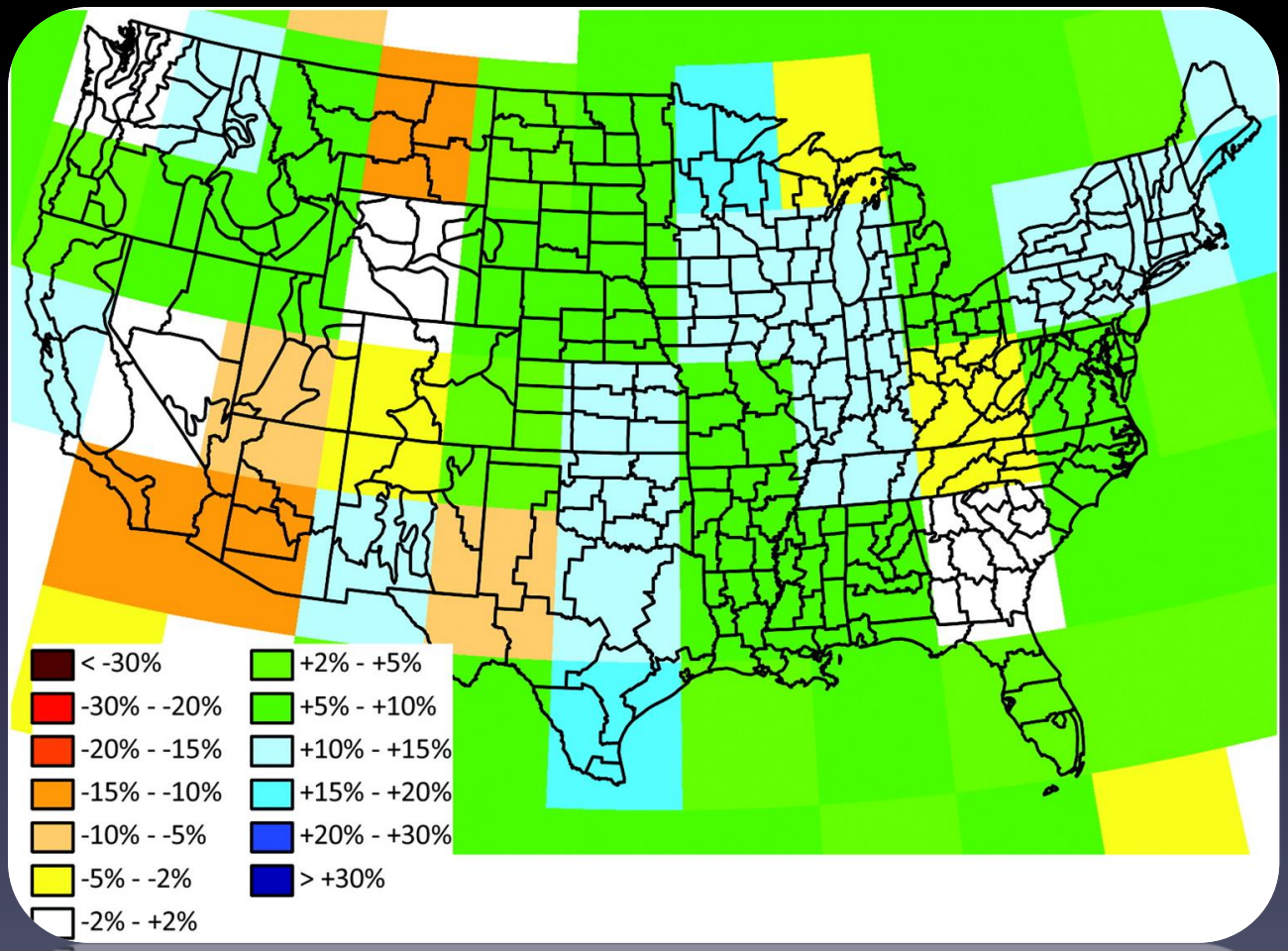
Linear trends of annual precipitation from the 1895–2009 (% per century)



McRoberts, D. B., & Nielsen-Gammon, J. W. (2011). A New Homogenized Climate Division Precipitation Dataset for Analysis of Climate Variability and Climate Change. Journal of Applied Meteorology and Climatology, 50(6), 1187–1199. doi:10.1175/2010JAMC2626.1

Montana Precipitation Trends

Linear trends of annual precipitation from the 1900–2009 (% per century)



McRoberts, D. B., & Nielsen-Gammon, J. W. (2011). A New Homogenized Climate Division Precipitation Dataset for Analysis of Climate Variability and Climate Change. Journal of Applied Meteorology and Climatology, 50(6), 1187–1199. doi:10.1175/2010JAMC2626.1

Montana Precipitation Trends

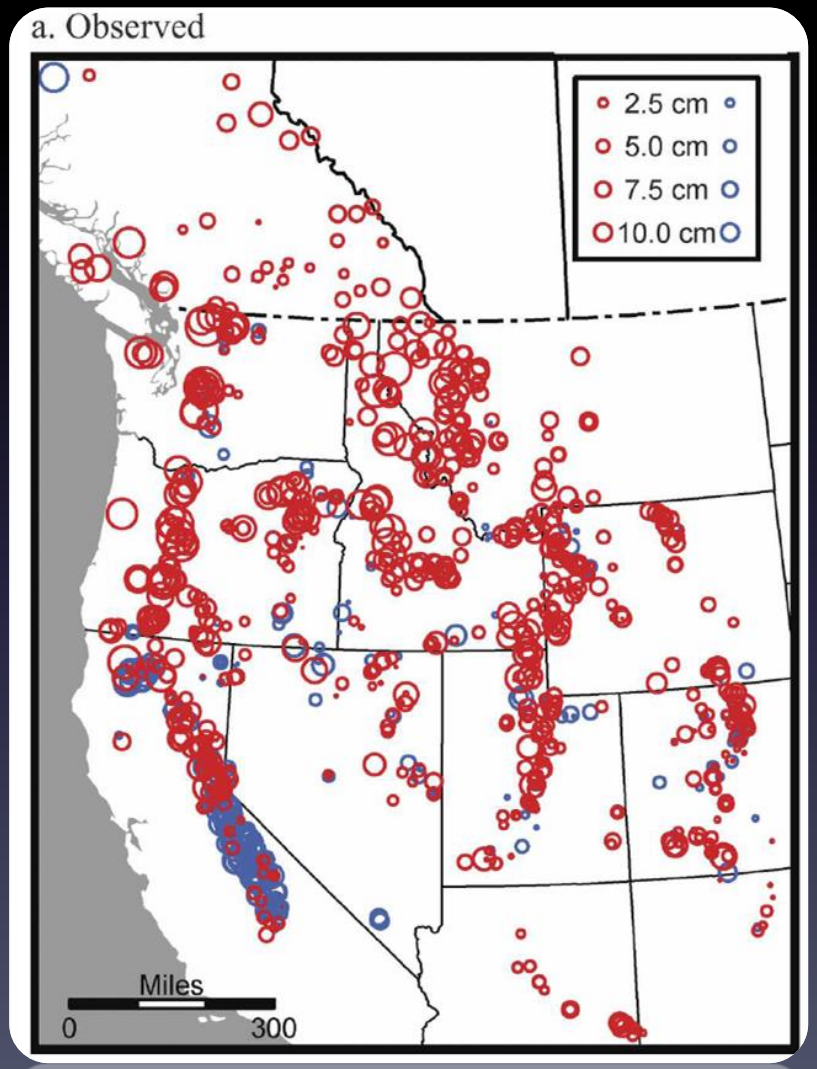
- Harder to separate natural variability and anthropogenic climate change contributions to regional precipitation trends
  - Precipitation has large variability in space and time
- Precipitation components
  - Amount
  - Frequency
  - Intensity
  - Duration
  - Type
  - Timing

Snowpack

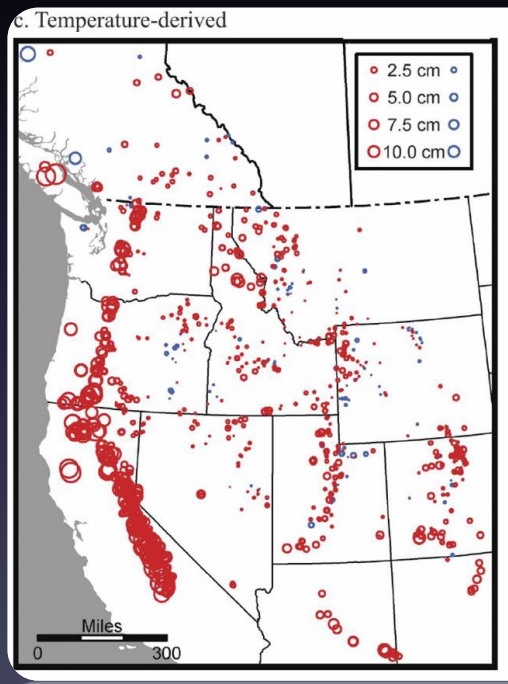
- Much of Montana is semi-arid
- Majority of surface water comes from mountain snowpack
  - Municipal and industrial water supplies
  - Energy production, agriculture, and ecosystems
- Quantity and timing of water released from snowpack are critical societal and environmental concerns
- Import snowpack components
  - Snowpack duration
  - Peak SWE
  - April 1 SWE
  - Timing of melt

Trends in Snowpack

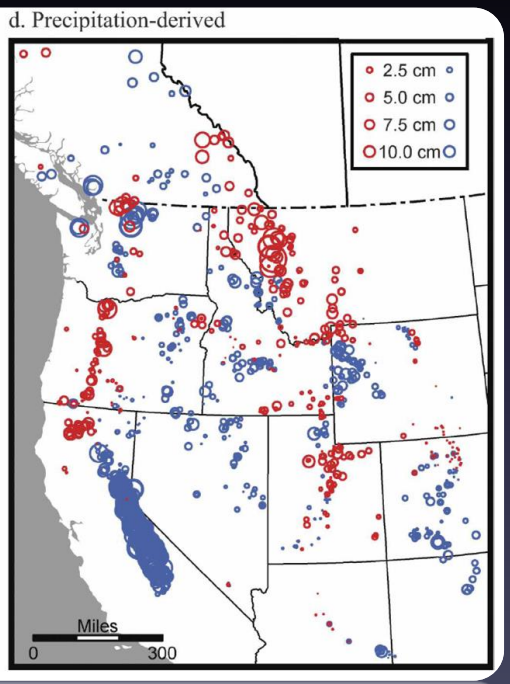
Trend in April 1 SWE 1960-2002



Temperature Only Trend

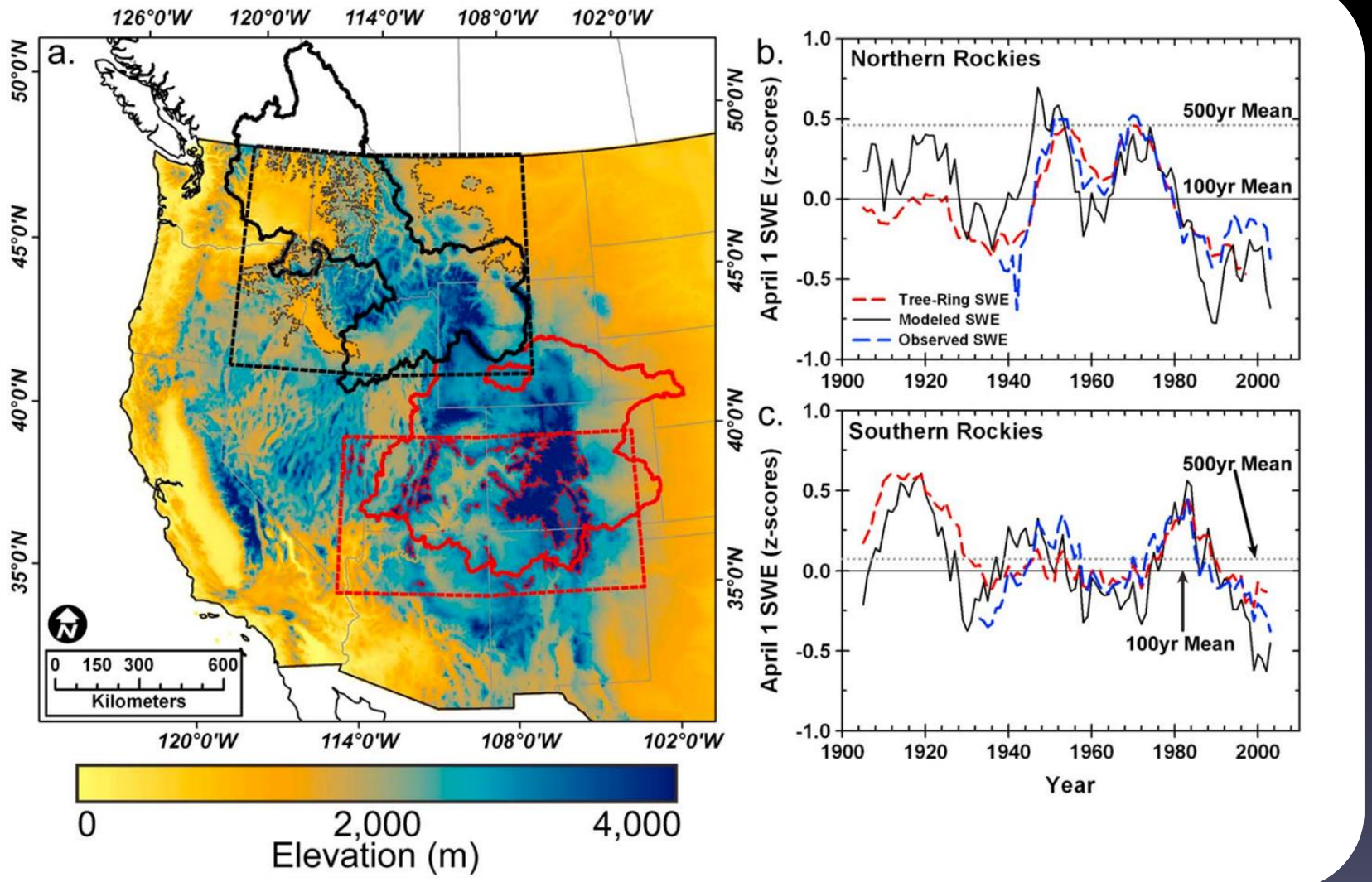


Prcp Only Trend



Mote, P. (2006). Climate-driven variability and trends in mountain snowpack in western North America. Journal of Climate, 19(23), 6209–6220.

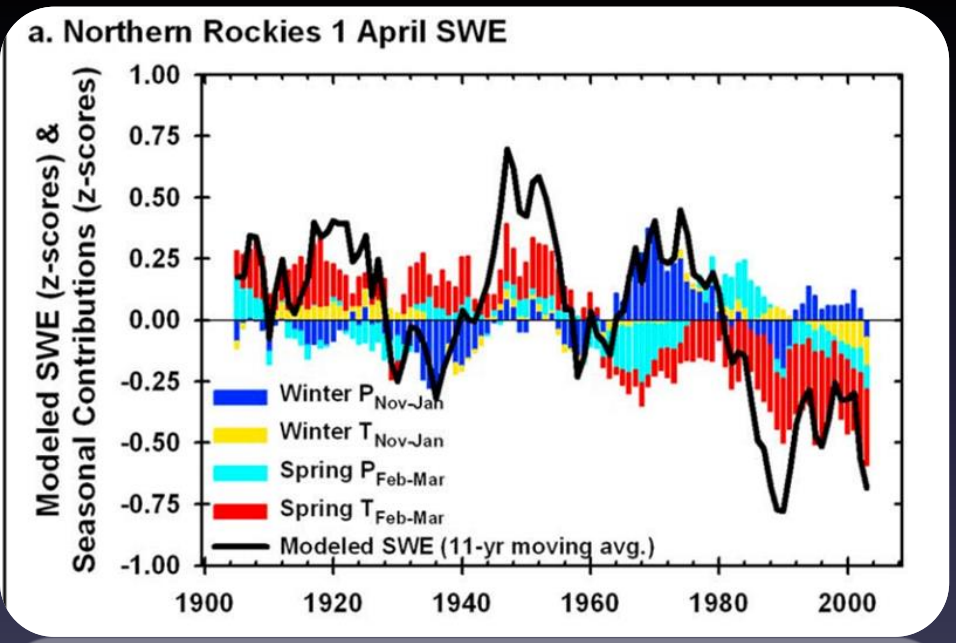
Trends in Snowpack

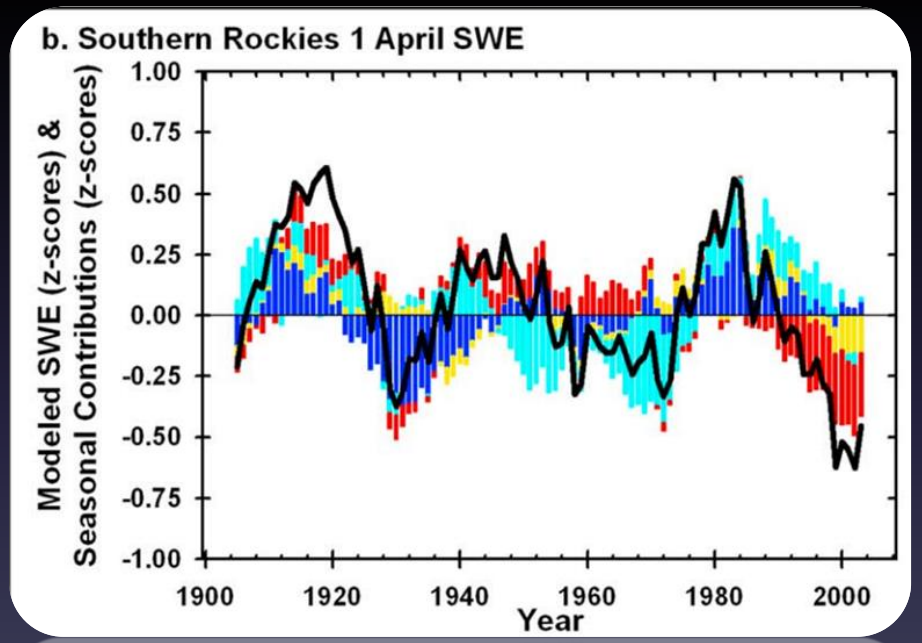


Pederson, G. T., Betancourt, J. L., & McCabe, G. J. (2013). Regional patterns and proximal causes of the recent snowpack decline in the Rocky Mountains, U.S. Geophysical Research Letters, 40(9), 1811–1816. doi:10.1002/grl.50424

Trends in Snowpack

Regional estimates of the seasonal temperature and precipitation contributions to 1 April SWE





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Trends in Snowpack

Summary for N. Rockies

- The bad news:
  - Overall decreases in regional snowpack
  - Peak SWE and melt out occurring earlier
  - Decrease in duration of snowpack
- The good news:
  - Increase in later spring precipitation has likely helped buffer some of the decreases in snowpack
  - A decadal shift in large-scale Pacific climate variability around 1976-1984 may account for 30%-50% of:
    - Western North America springtime warming
    - Decreasing winter precipitation in the N.Rockies

Abatzoglou, J.T., 2011. Influence of the PNA on declining mountain snowpack in the Western United States. International Journal of Climatology 31, 1135–1142.
Pederson, G.T., Gray, S.T., Ault, T., Marsh, W., Fagre, D.B., Bunn, A.G., Woodhouse, C.A., Graumlich, L.J., 2011. Climatic Controls on the Snowmelt Hydrology of the Northern Rocky Mountains. Journal of Climate 24, 1666–1687.
Pederson, G.T., Gray, S.T., Woodhouse, C.A., Betancourt, J.L., Fagre, D.B., Littell, J.S., Watson, E., Luckman, B.H., Graumlich, L.J., 2011. The Unusual Nature of Recent Snowpack Declines in the North American Cordillera. Science 333, 332.

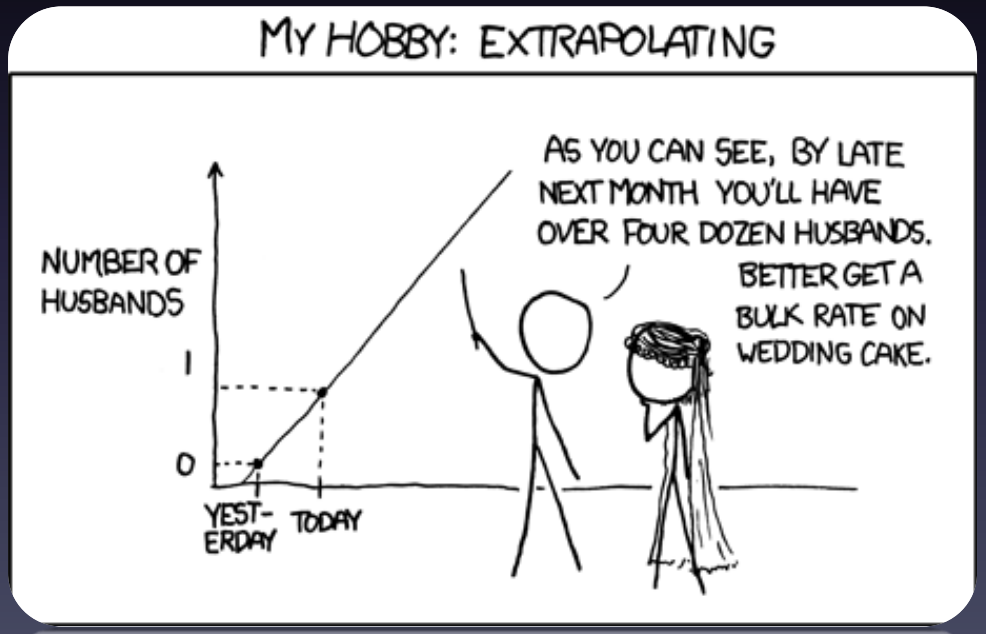
Glaciers in Glacier NP

- Glacier maximum occurred in 1850s
  - Produced by ~70 years of cool/wet summers with high winter snowpack.
- After 1850, glacial retreat starts
  - Extended period (>50 yr) of summer drought and low snowpack
  - 1917 – 1941: Exceptional drought, low snowpack accelerated retreat
  - 1940s-1970s: retreat slowed, some small advances
  - 1970s-present: retreat has increased
- Like overall snowpack trends, likely related to Pacific climate variability (e.g.—PDO) and anthropogenic climate change

Boulder Glacier

Hall, M.H.P., Fagre, D.B., 2003. Modeled climate-induced glacier change in Glacier National Park, 1850-2100. BioScience 53, 131–140.
Pederson, G.T., 2004. Decadal-scale climate drivers for glacial dynamics in Glacier National Park, Montana, USA. Geophysical Research Letters 31, L12203.

Future Climate Projections in Montana

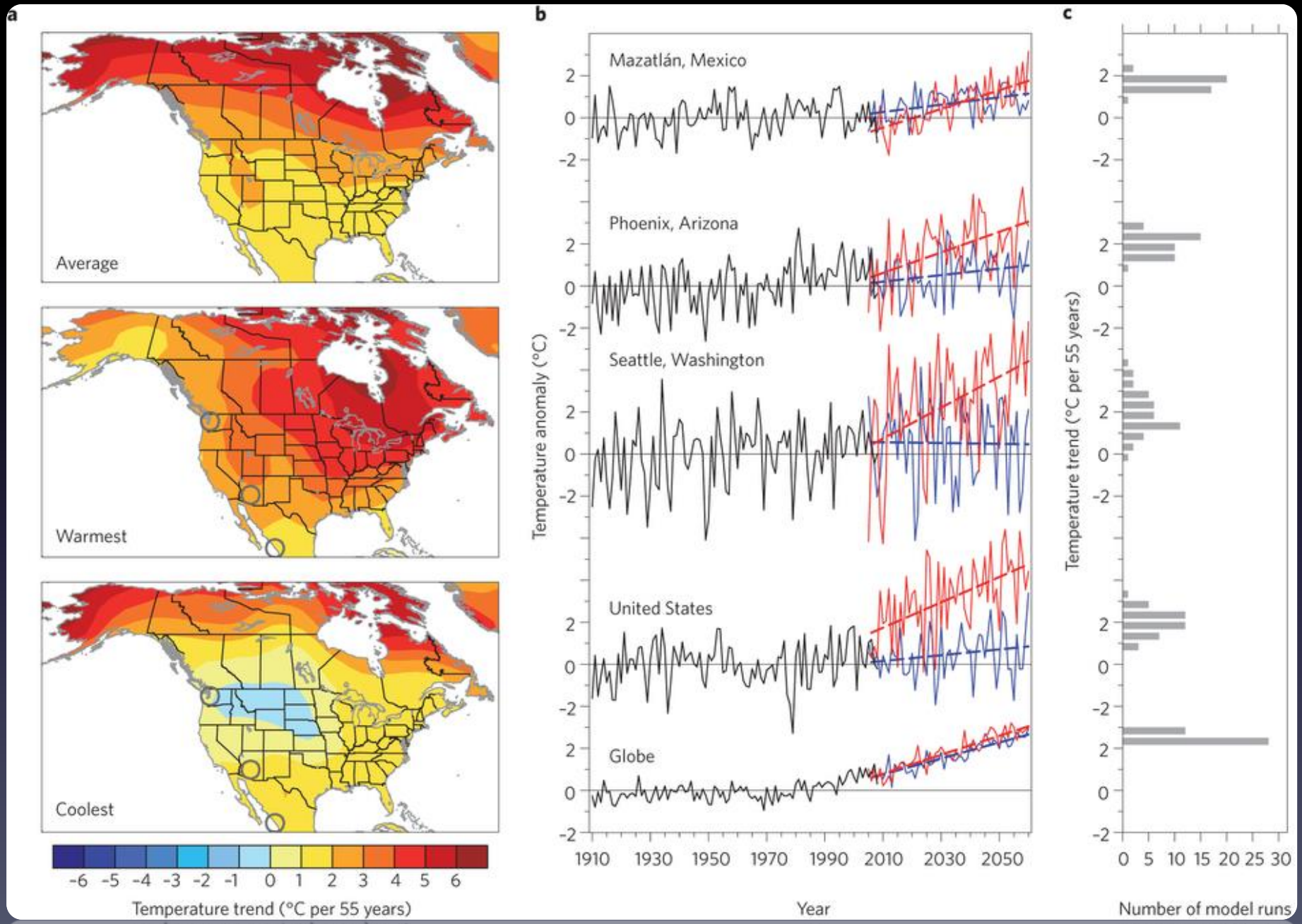


Climate Projections

- **Basic story**
  - Continued long-term increase in temperatures are highly likely
  - Trends in precipitation are less certain, but likely to have increased precipitation in all seasons except for a decrease in summer precipitation

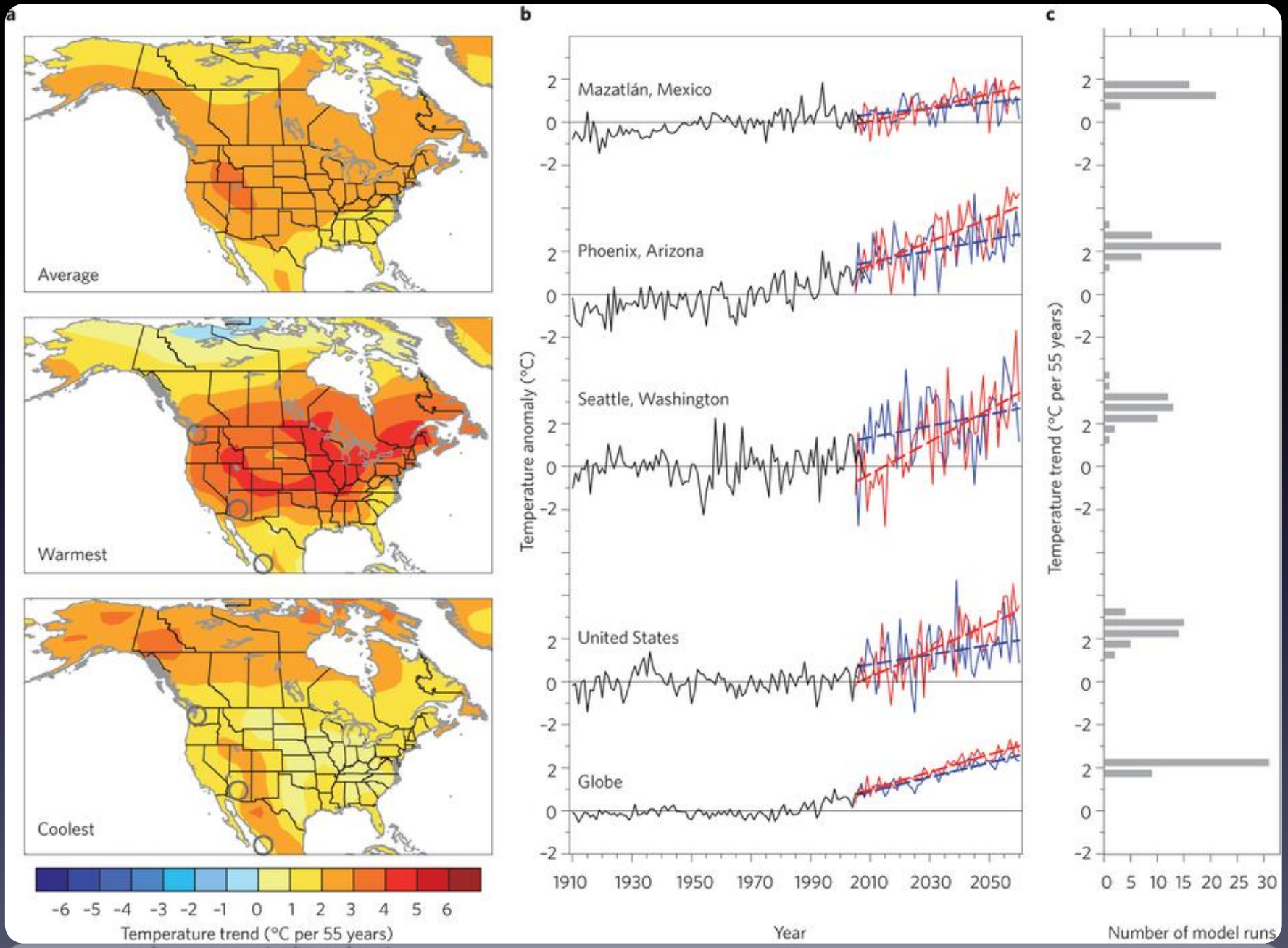
Winter temperature trends 2005–2060

Deser, C., Knutti, R., Solomon, S., Phillips, A.S., 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change 2, 775–780.



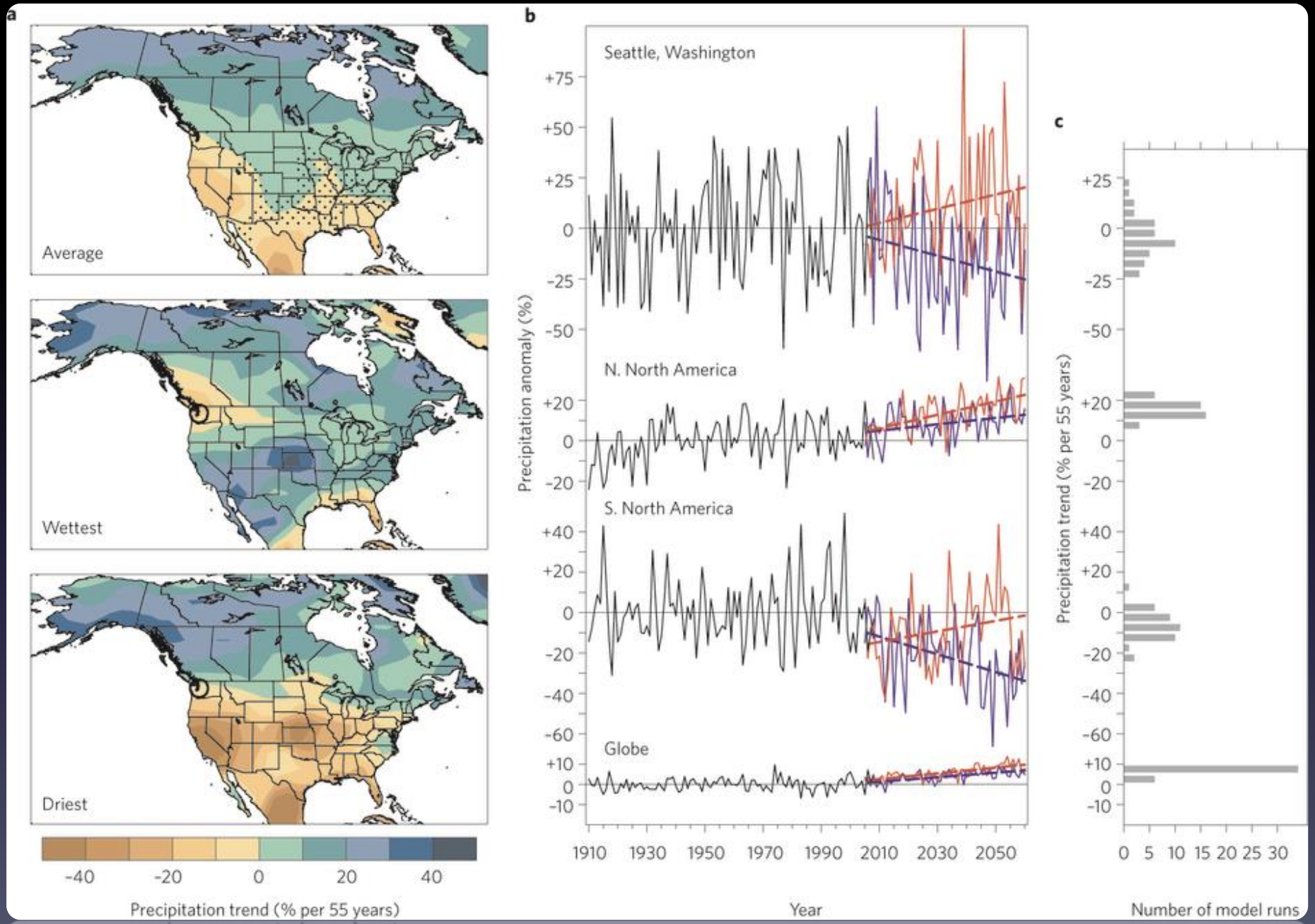
Summer temperature trends 2005–2060

Deser, C., Knutti, R., Solomon, S., Phillips, A.S., 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change 2, 775–780.

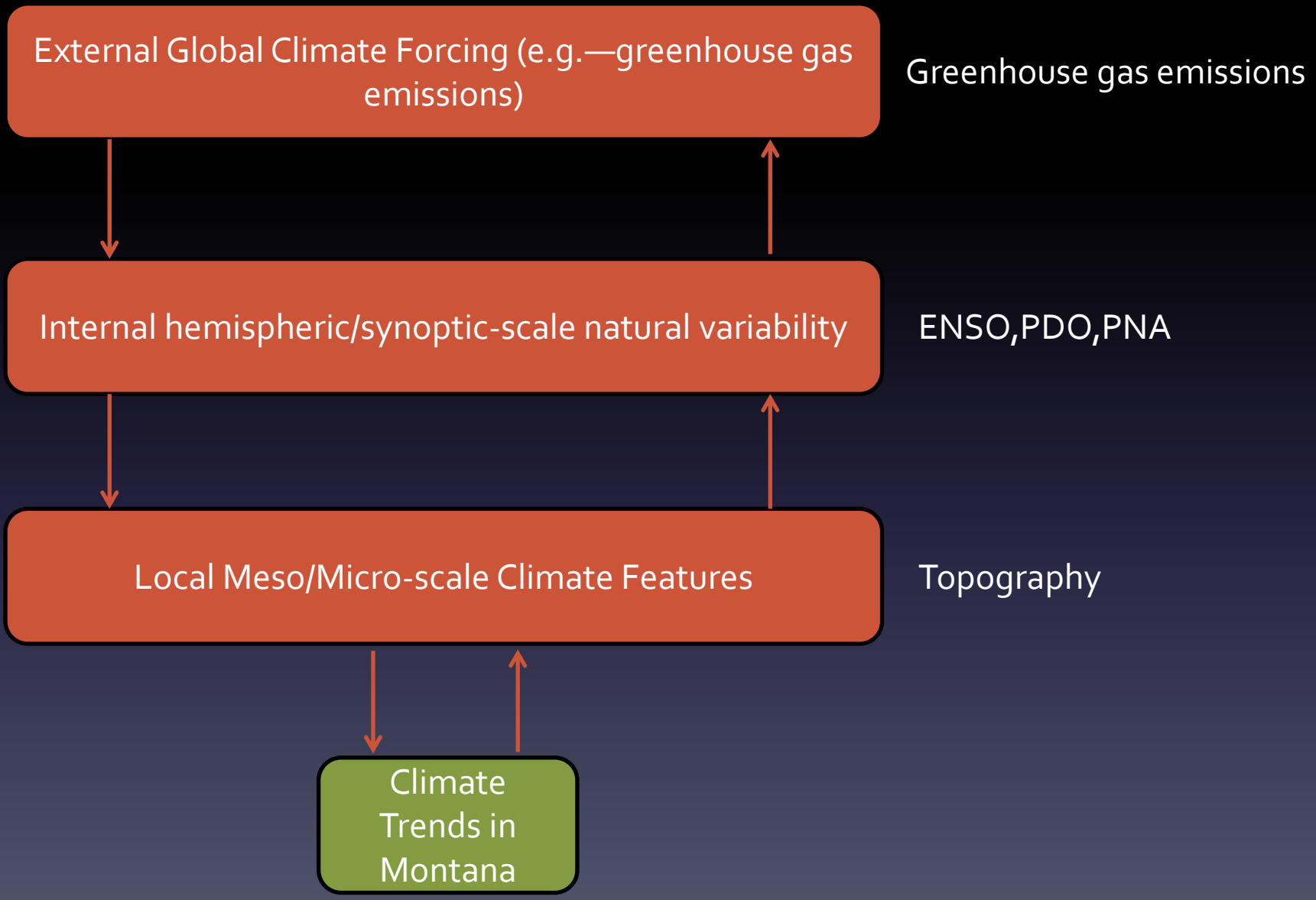


Winter precipitation trends 2005–2060

Deser, C., Knutti, R., Solomon, S., Phillips, A.S., 2012. Communication of the role of natural variability in future North American climate. Nature Climate Change 2, 775–780.



Main Takeaway



Climate Change Impacts

Regional impacts for Montana and Northern Rockies