Natural Climate Variability and Climate Change in Montana

Jared W. Oyler
Graduate Research Assistant
Software Engineer

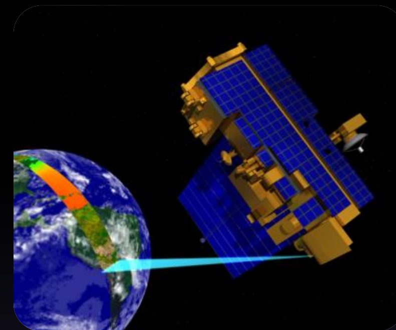
Numerical Terradynamic Simulation Group
Montana Climate Office
University of Montana

How do I spend my time?

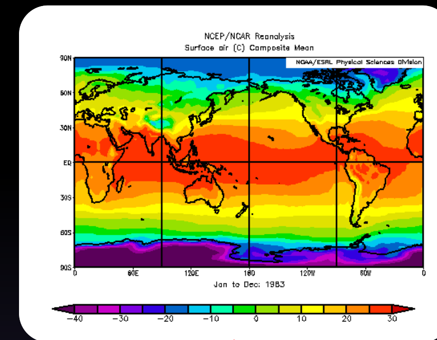
Weather Station Data

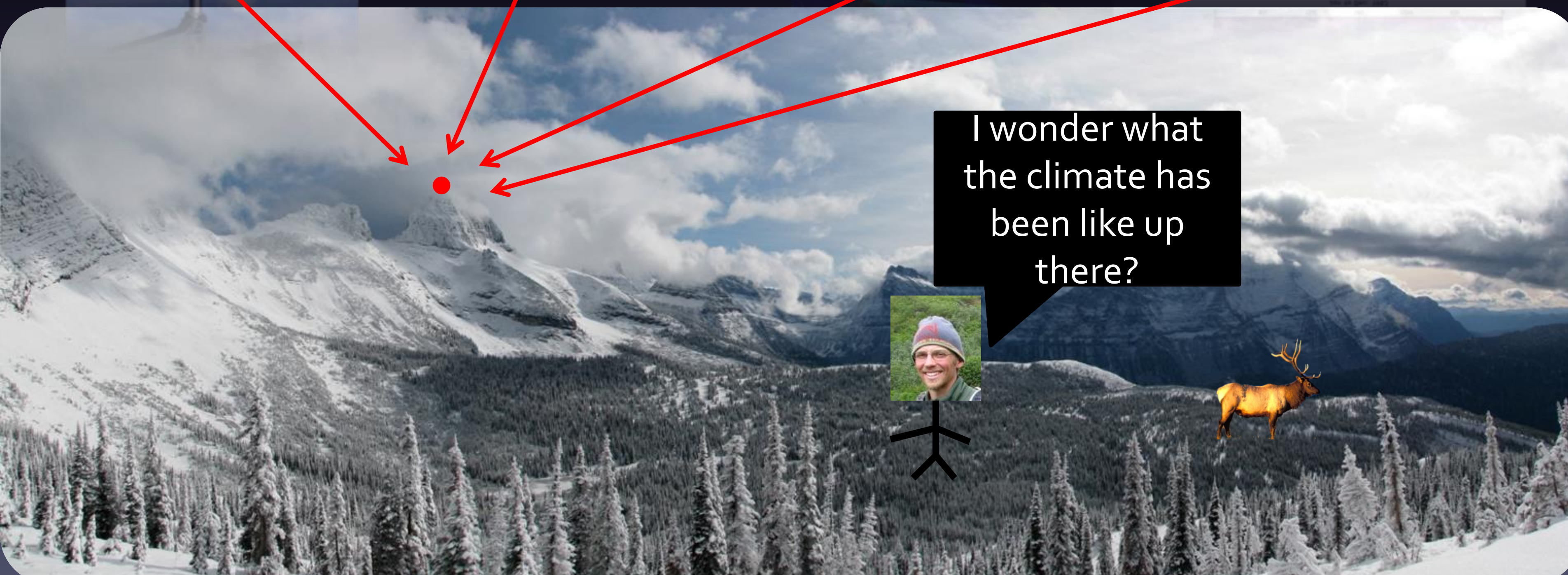
Topographic Data

Satellite Data



Large-scale Atmospheric Data





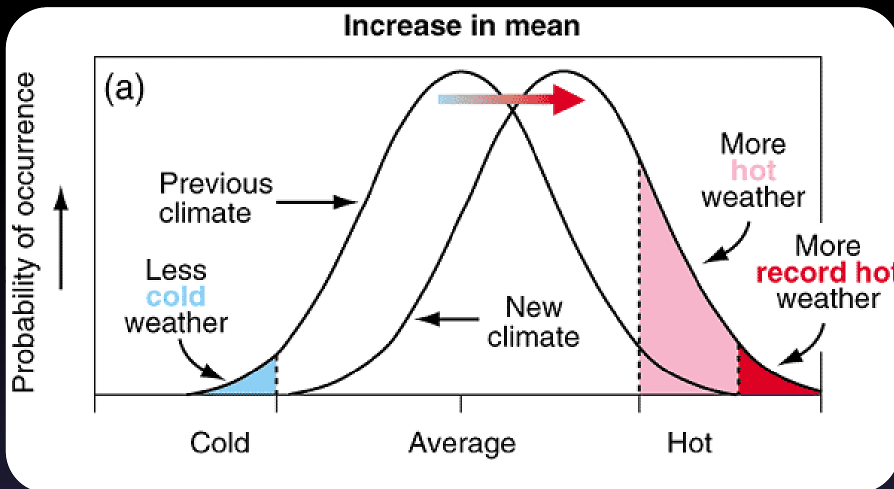
Outline

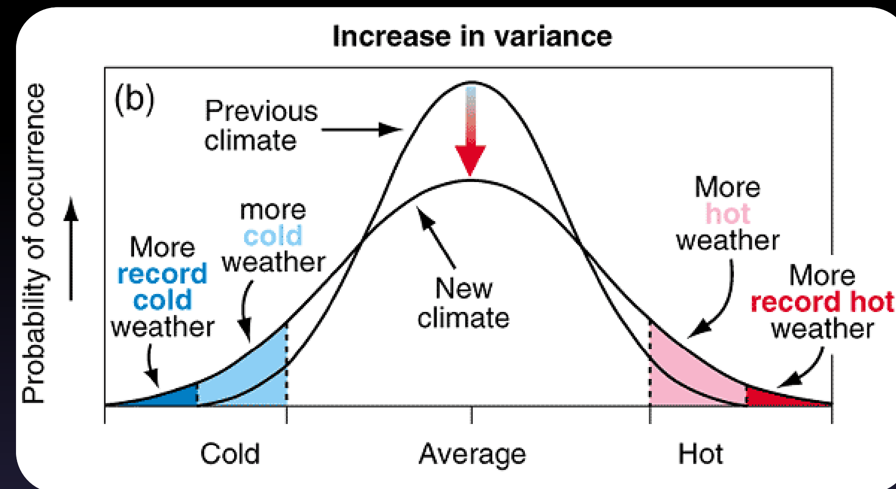
- Review of weather and climate basics
- General climate of Montana
- Climate change globally and in Montana
- Large-scale natural climate variability
- Future climate projections

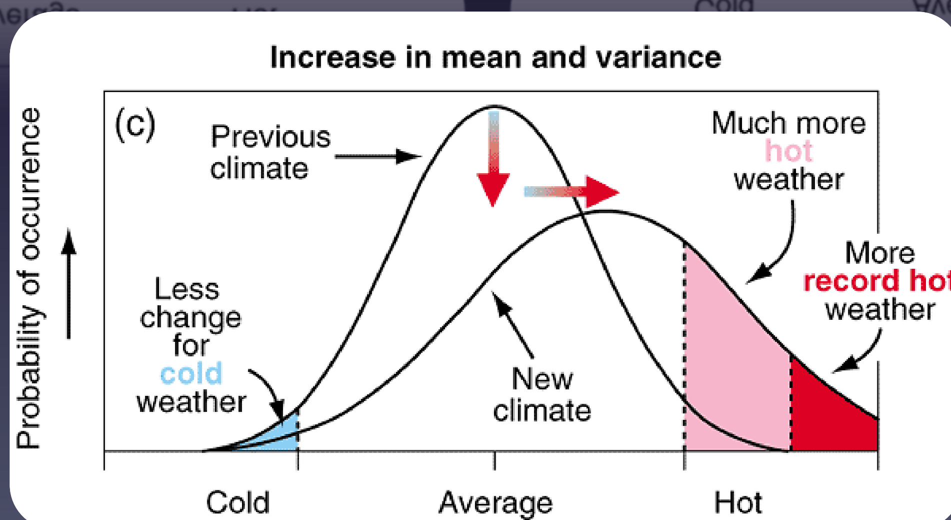
The Basics

- **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

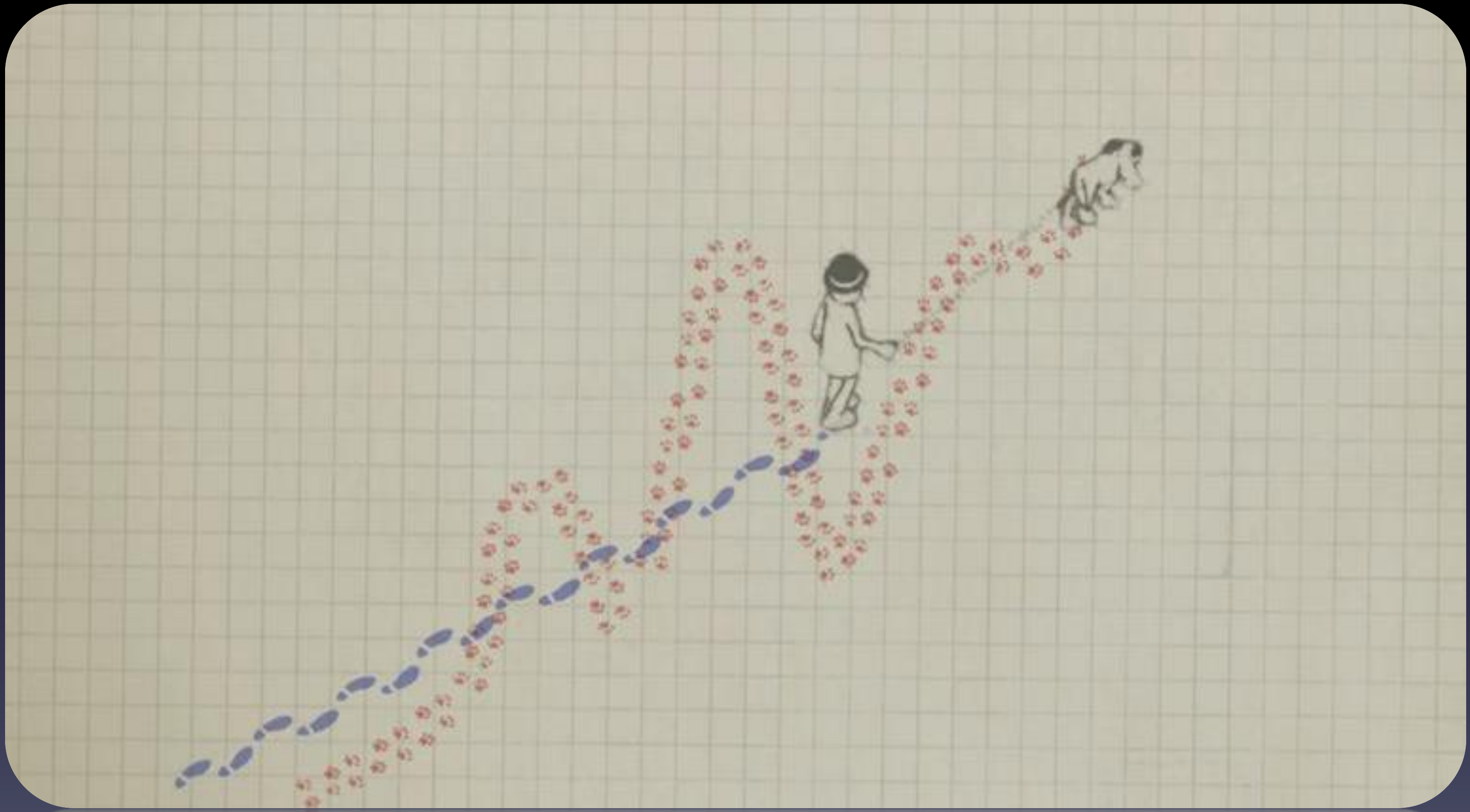






IPCC AR3 2001

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

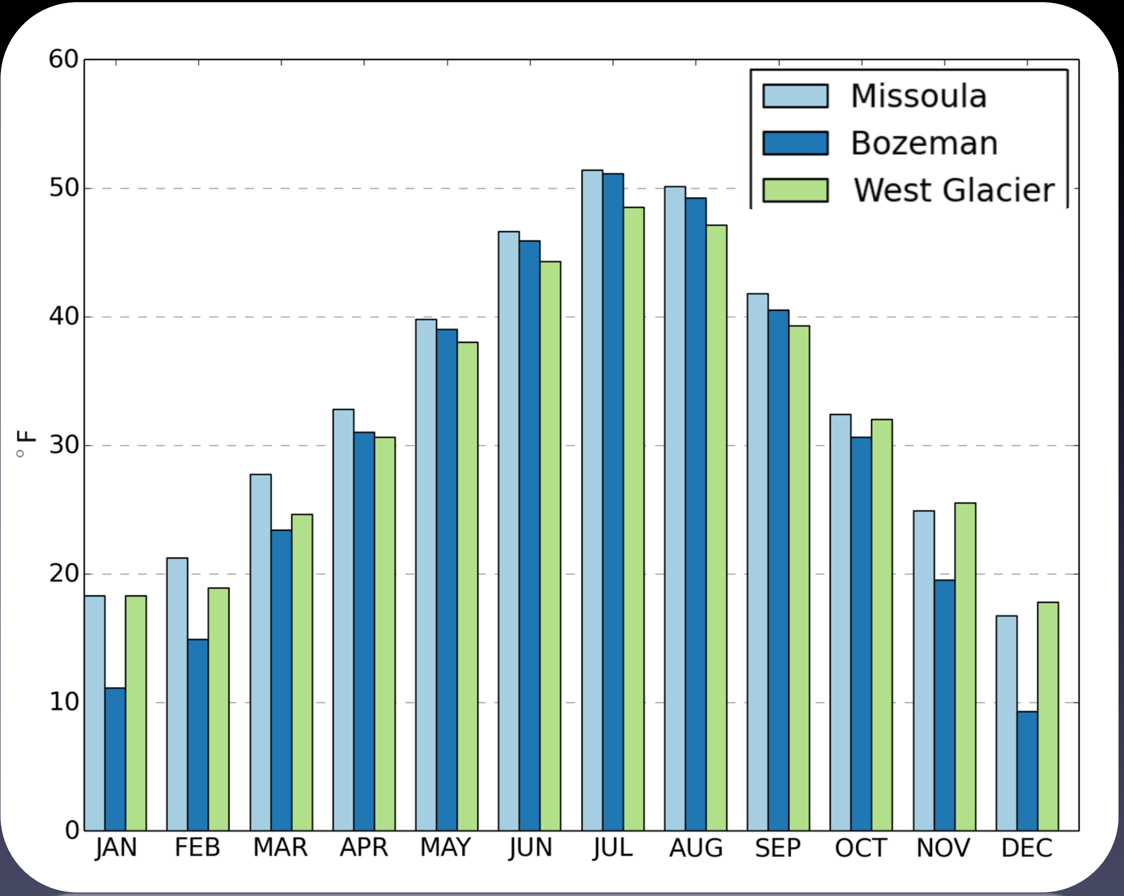
- East of the continental divide, mainly a **continental climate**
  - Large annual temperature range
  - Cold winters and hot, dry summers
- The continental divide forms a transition zone between **maritime** and **continental climates**
  - Maritime air masses bring storms during the winter with increased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

Climate Normals

Climate Normal: a 30-year average of a weather/climate variable (e.g.—temperature). Also includes degree days, probabilities, standard deviations, etc.

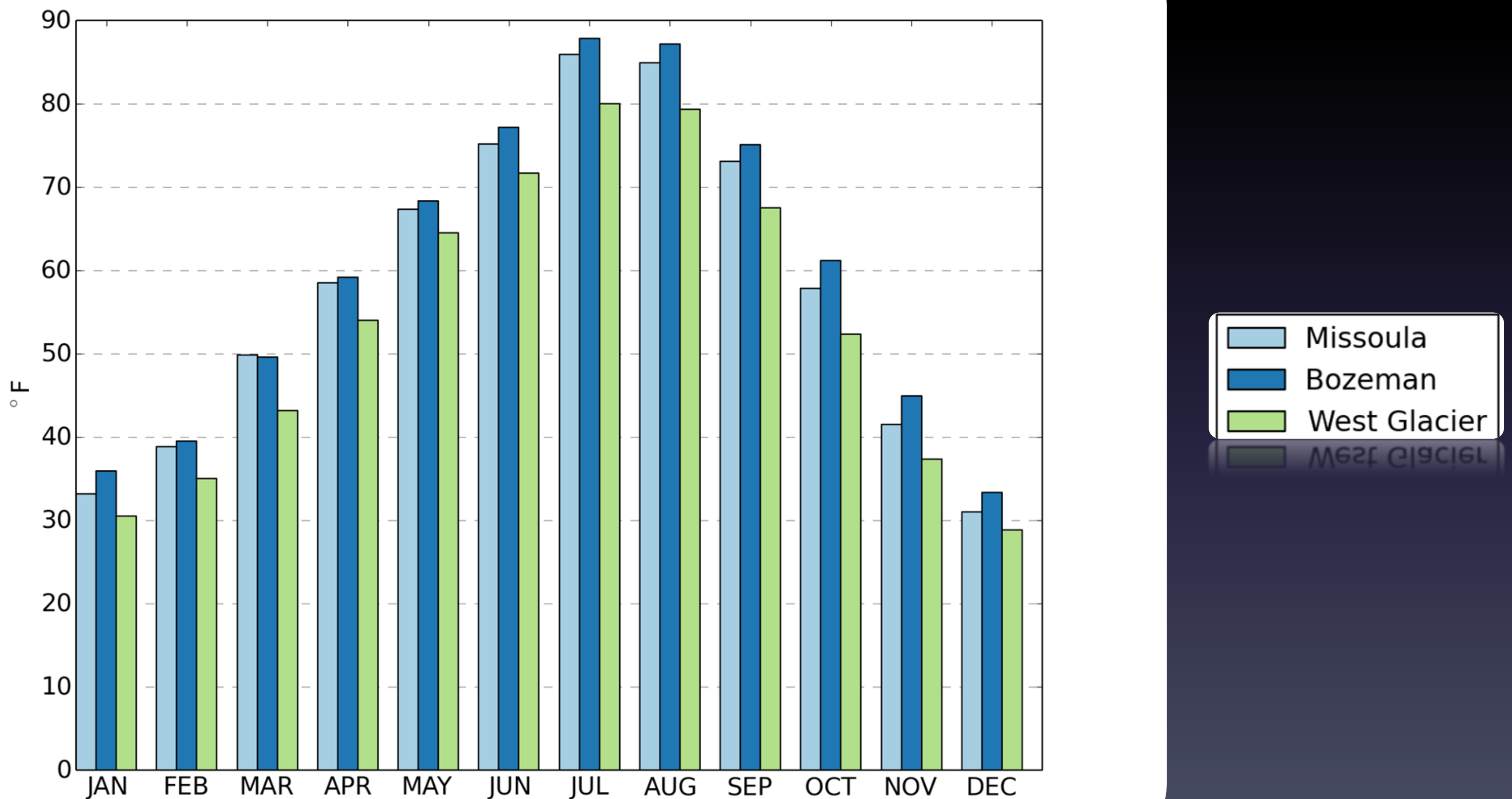
The latest climate normals are for 1981 – 2010. Updated on a decadal basis.

Minimum Temperature: 1981 – 2010 Monthly Normals



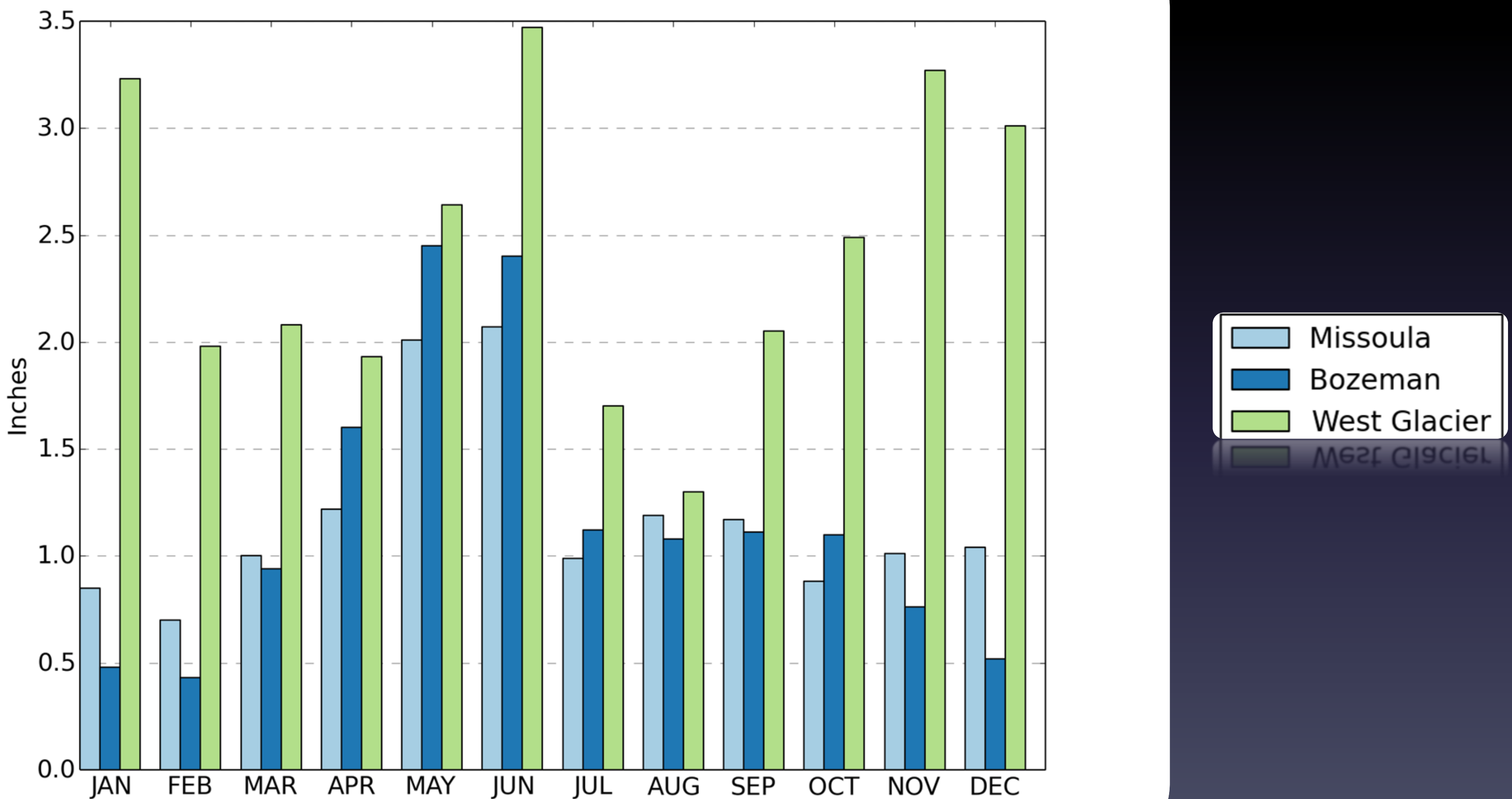
Climate Normals

Maximum Temperature: 1981 – 2010 Monthly Normals



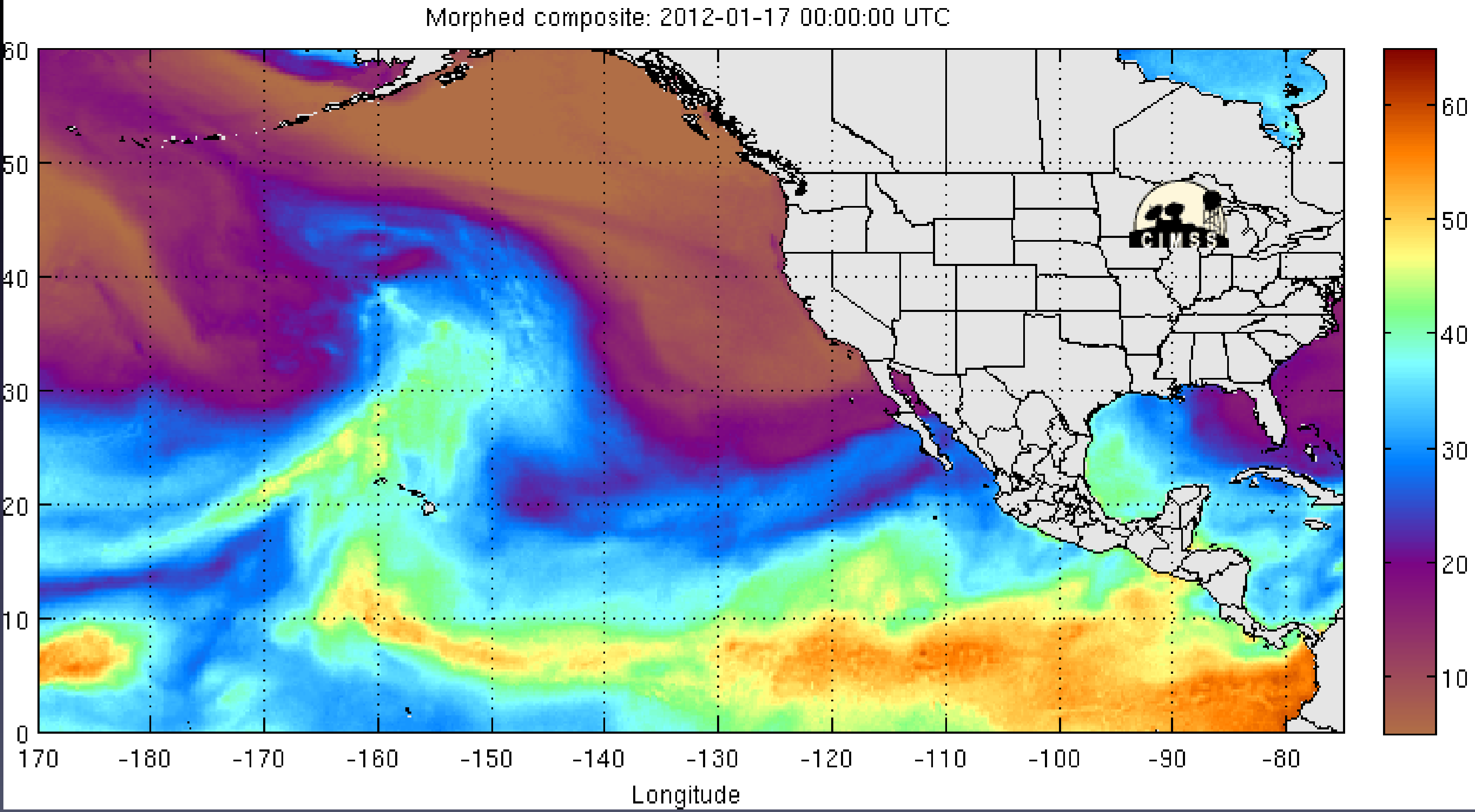
Climate Normals

Precipitation: 1981 – 2010 Monthly Normals



Climate of Montana

Example Pacific storm in winter



Topoclimate Patterns

Moderating influence of Flathead Lake

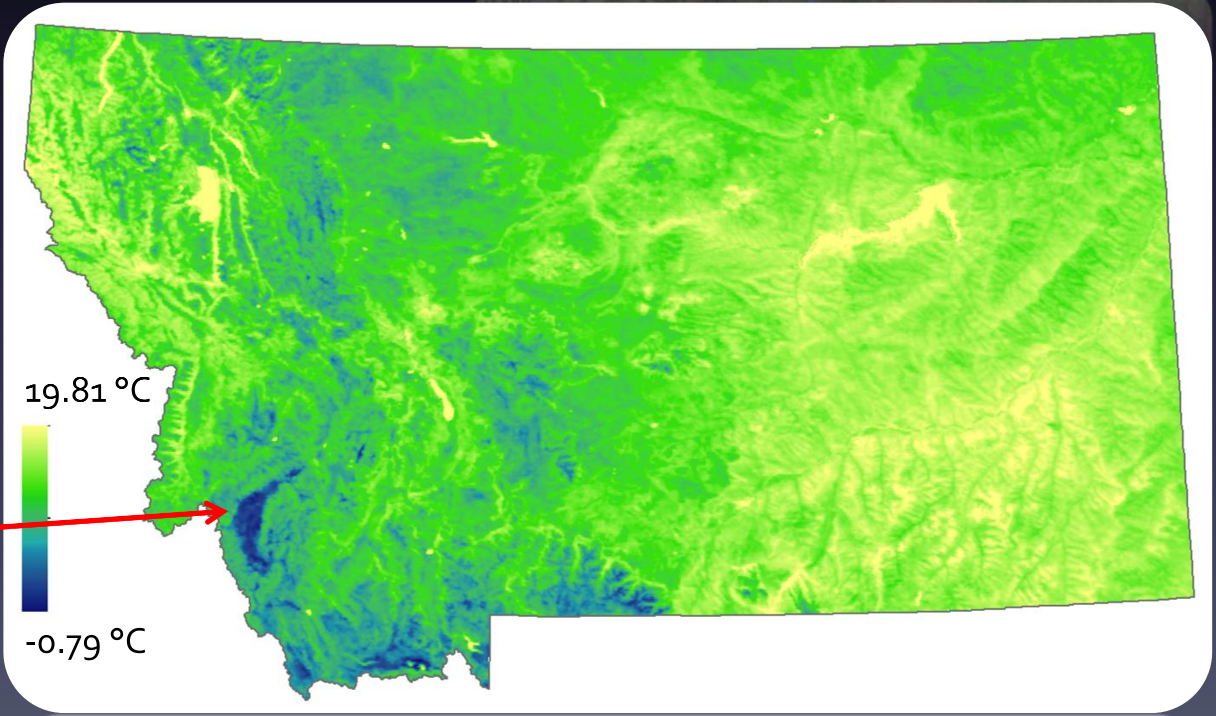
Cherry orchards and vineyards in Montana!?

Topoclimate Patterns

Tmin Avg. Land Skin Temperature : August 2003-2012

Temperature Inversions

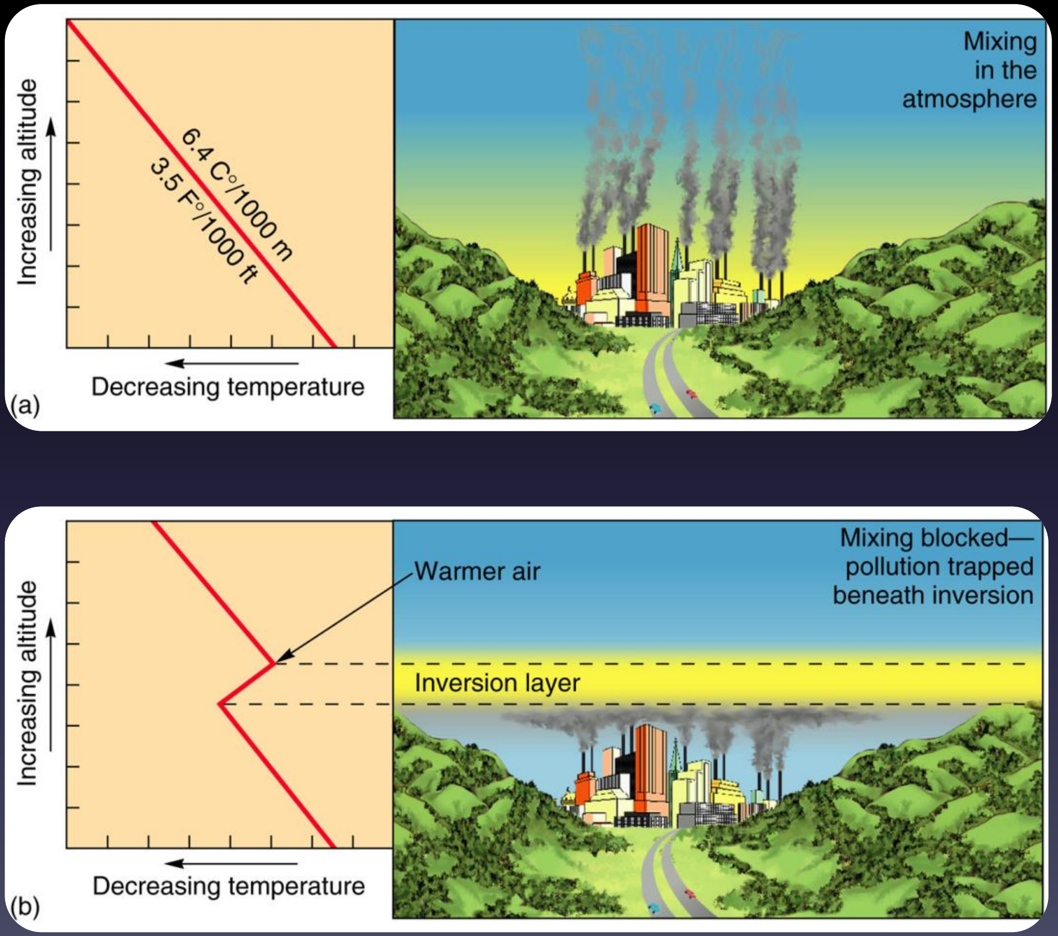
- Colder at lower elevations.
- Most commonly associated with minimum temperatures.



Why is it colder here?

Topoclimate Patterns

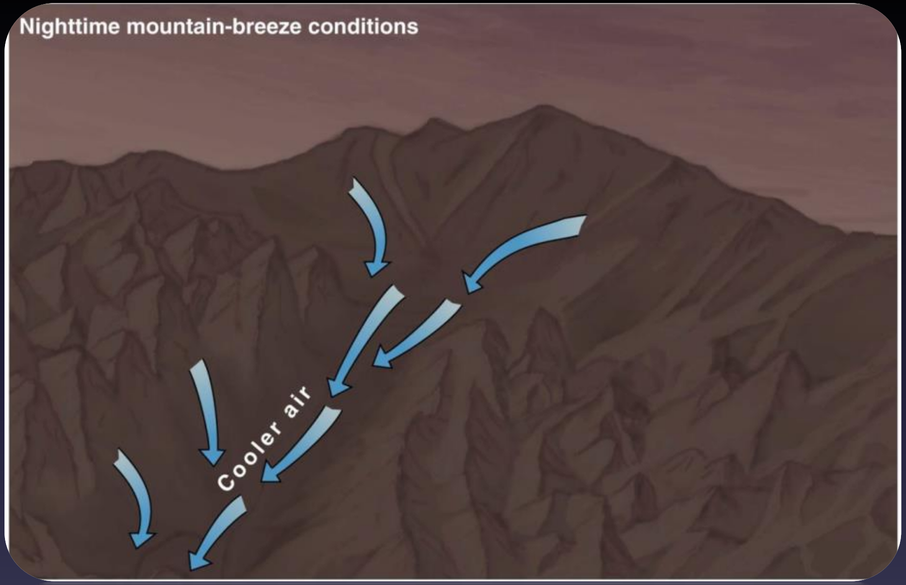
Radiation Inversion: on cold clear calm nights, longwave radiation can radiate from the ground quickly, escape into upper atmosphere and the air near the surface will be very cool (usually very shallow)



Topoclimate Patterns

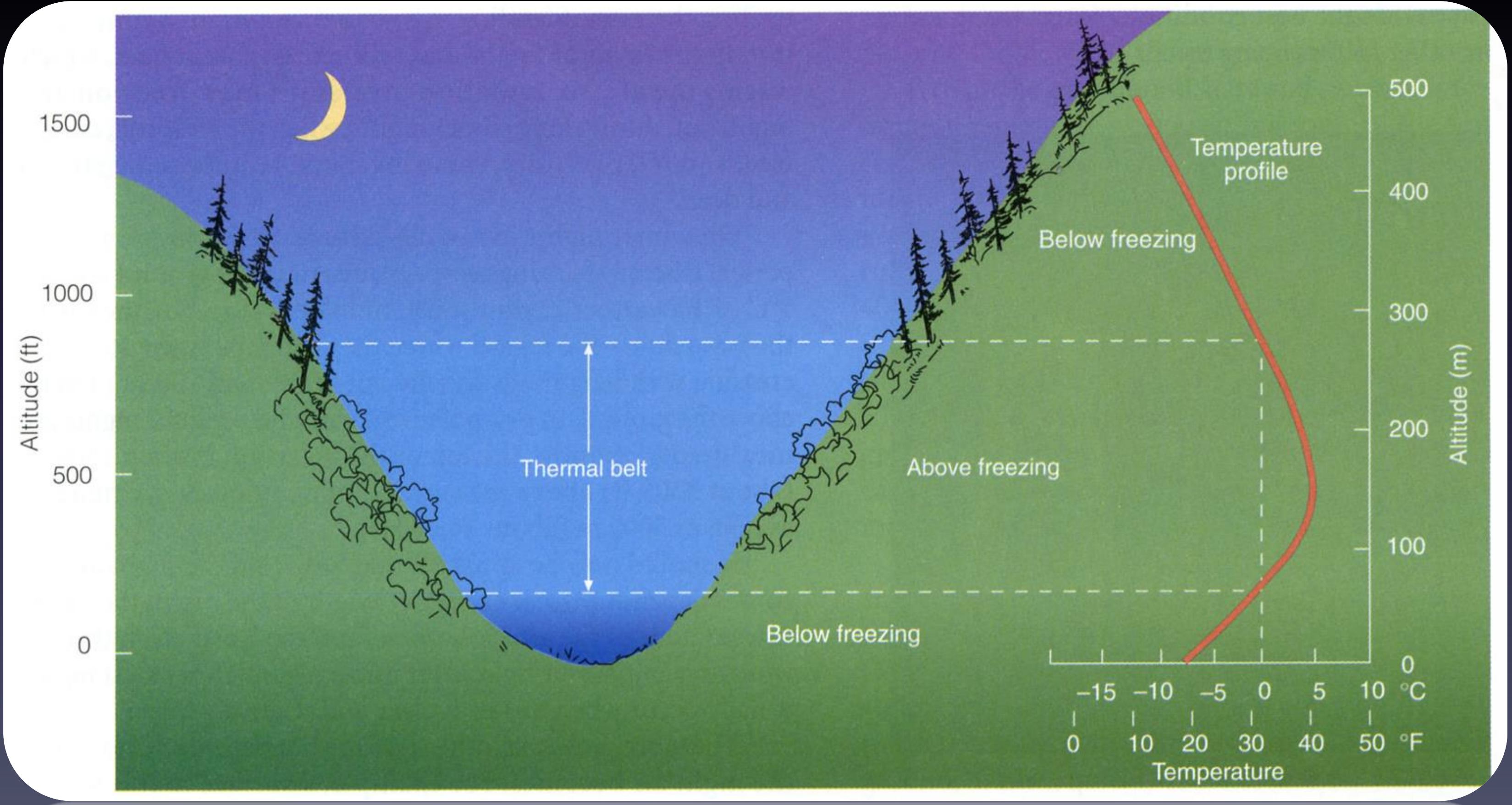
Cold-Air Drainage: cold air sinking into valleys can lead to inversions.

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



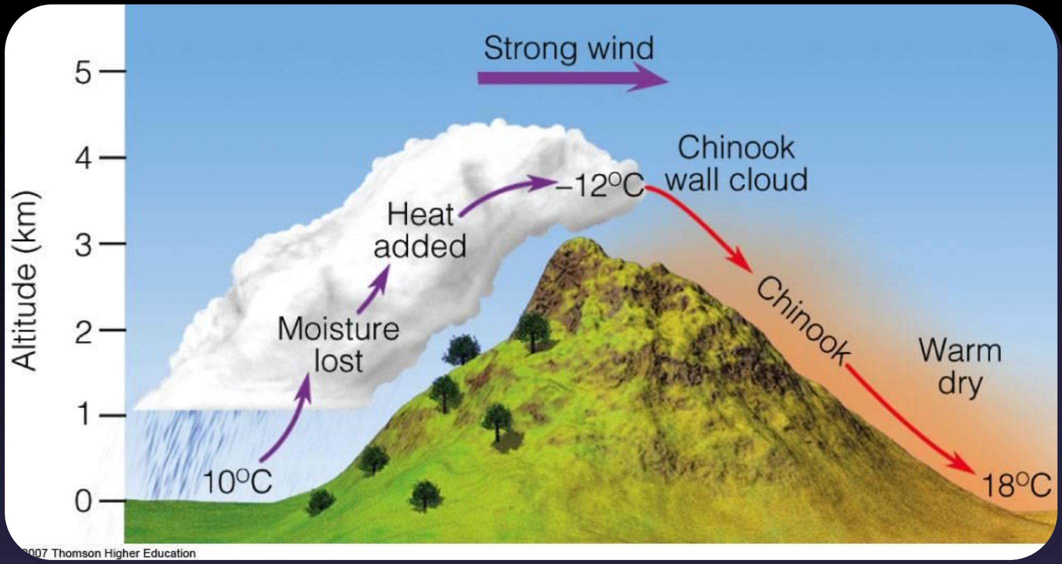
Topoclimate Patterns

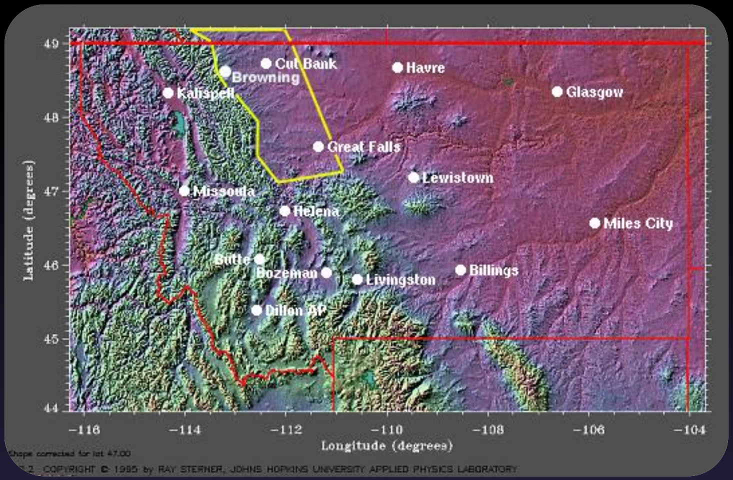
Thermal Belts



Topoclimate Patterns

Chinook Winds (Foehn)

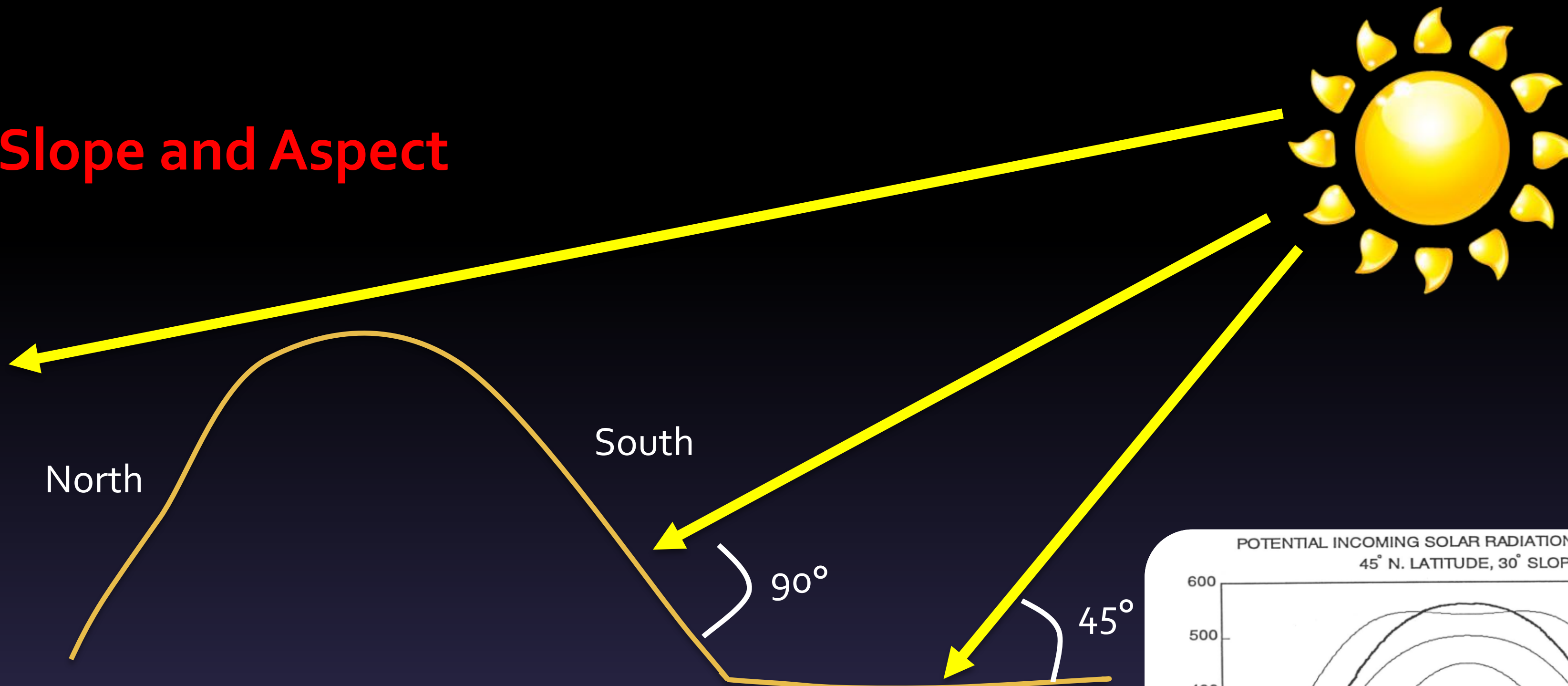




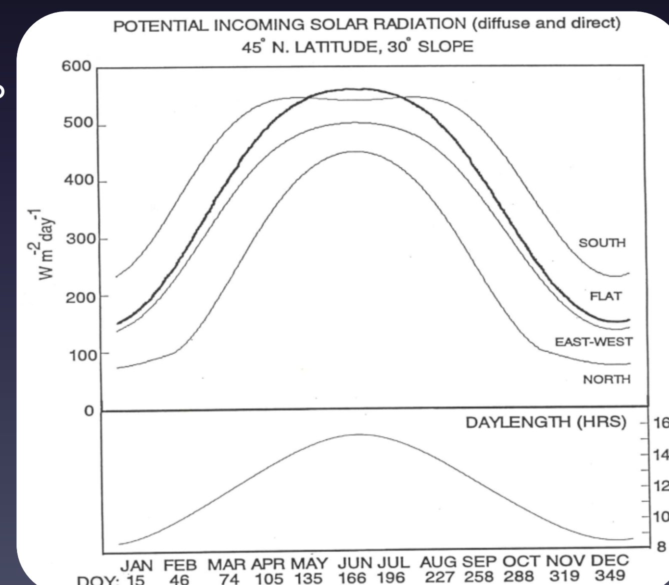
http://formontana.net/chinook.html

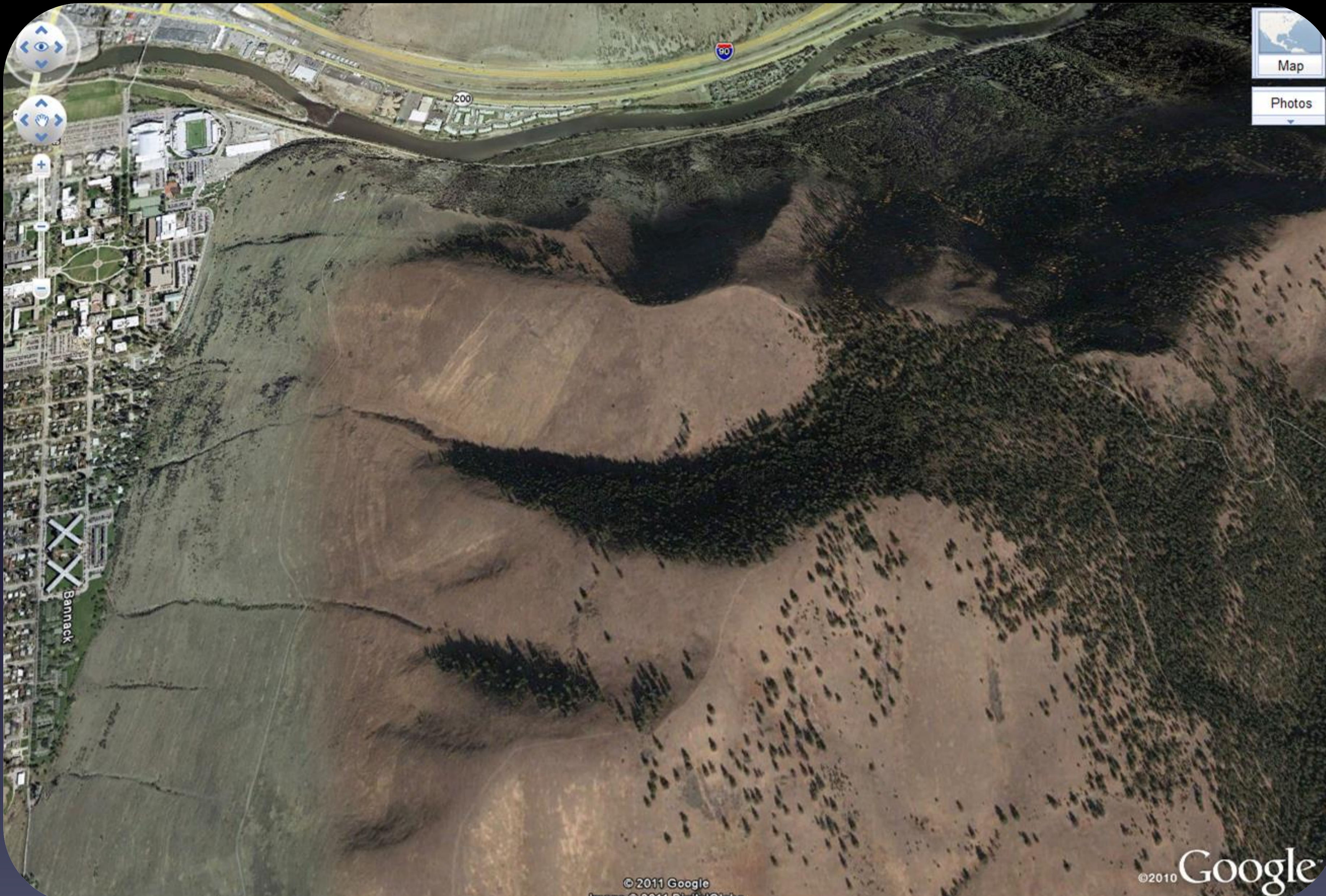
Topoclimate Patterns

Slope and Aspect



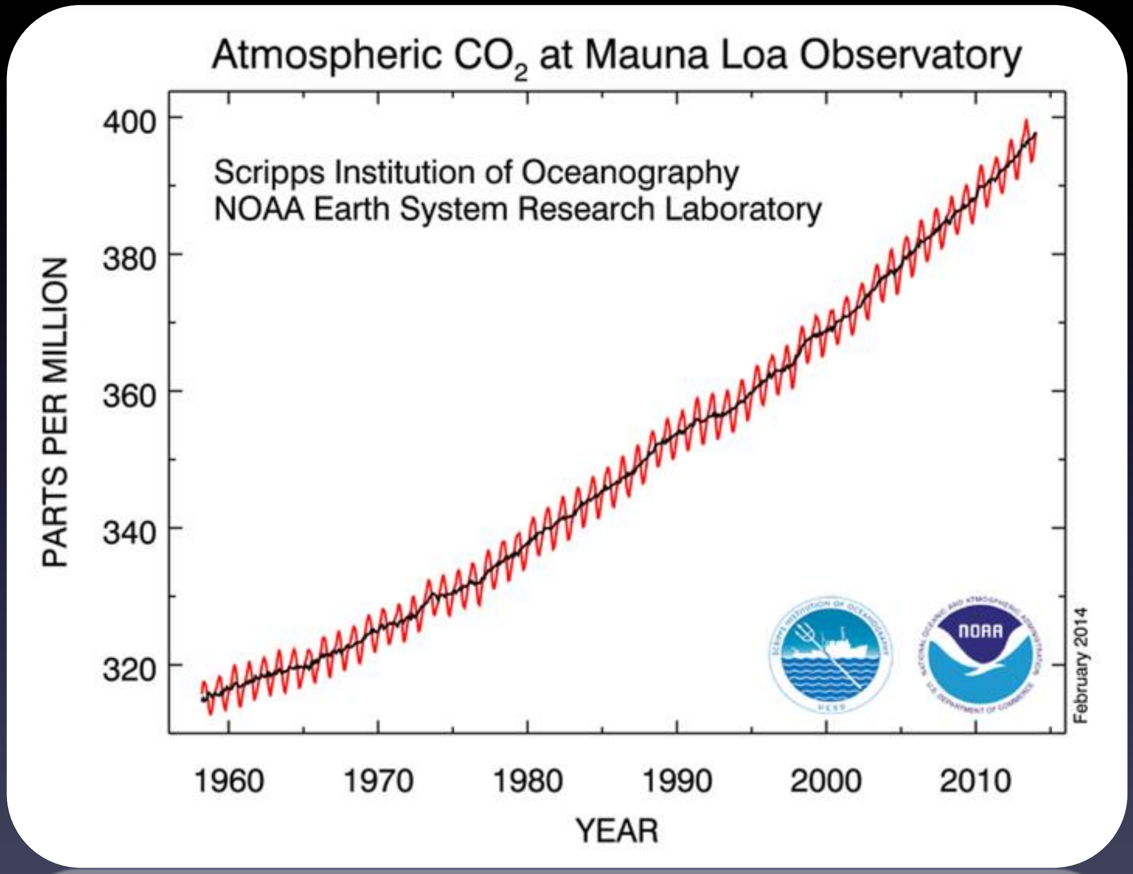
Slope		Angle of Incidence
45°	facing Sun	90°
Flat		45°
45°	away from Sun	0°



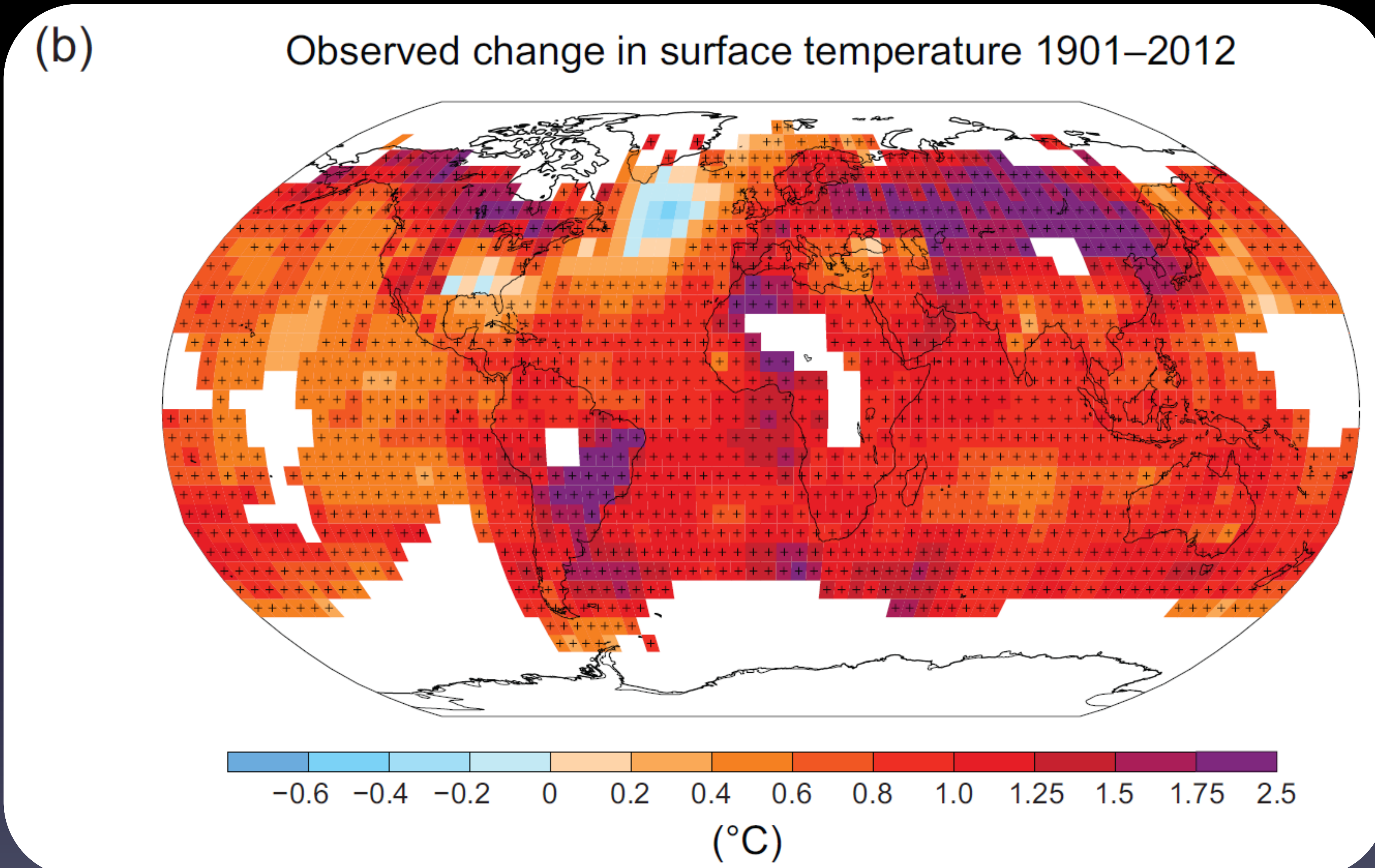

Map
Photos
90
200
Bannack
© 2011 Google
Image © 2011 DigitalGlobe
©2010 Google

Climate Change in Montana

Keeling Curve

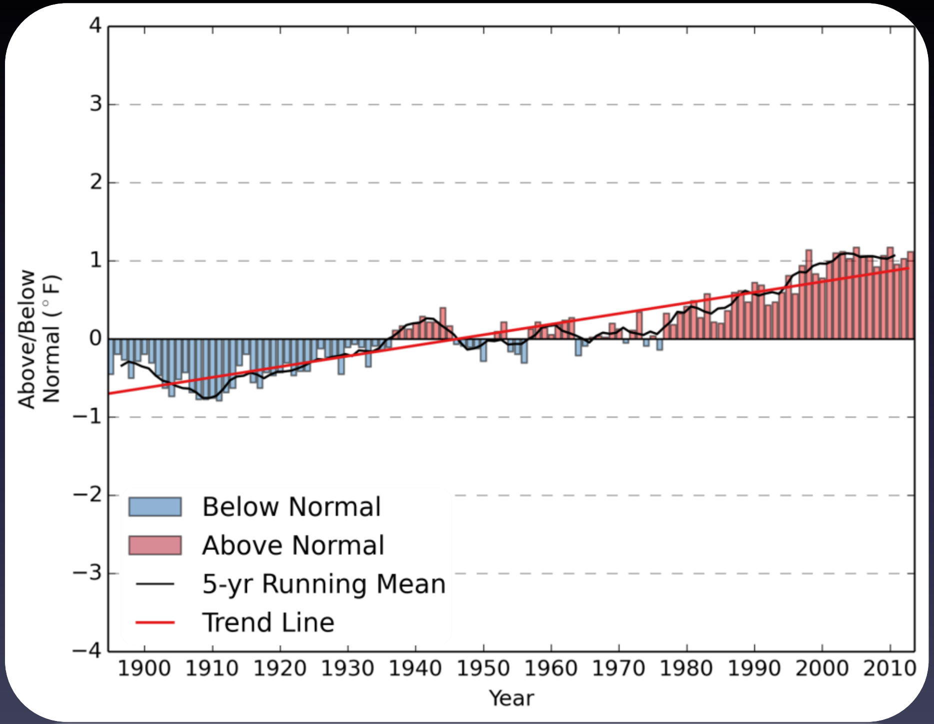


IPCC AR5 SPM

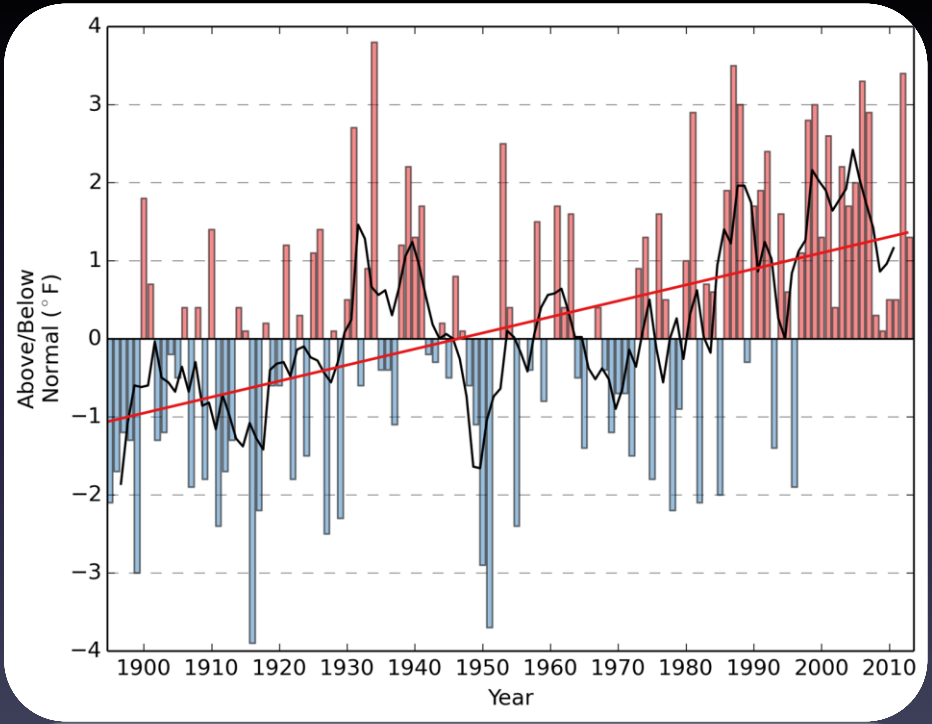

(b)
Observed change in surface temperature 1901–2012
−0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1.0 1.25 1.5 1.75 2.5
(°C)

1895-2013 Temperature Trends

Global Trend: +1.62°F



Montana Trend: +2.44°F

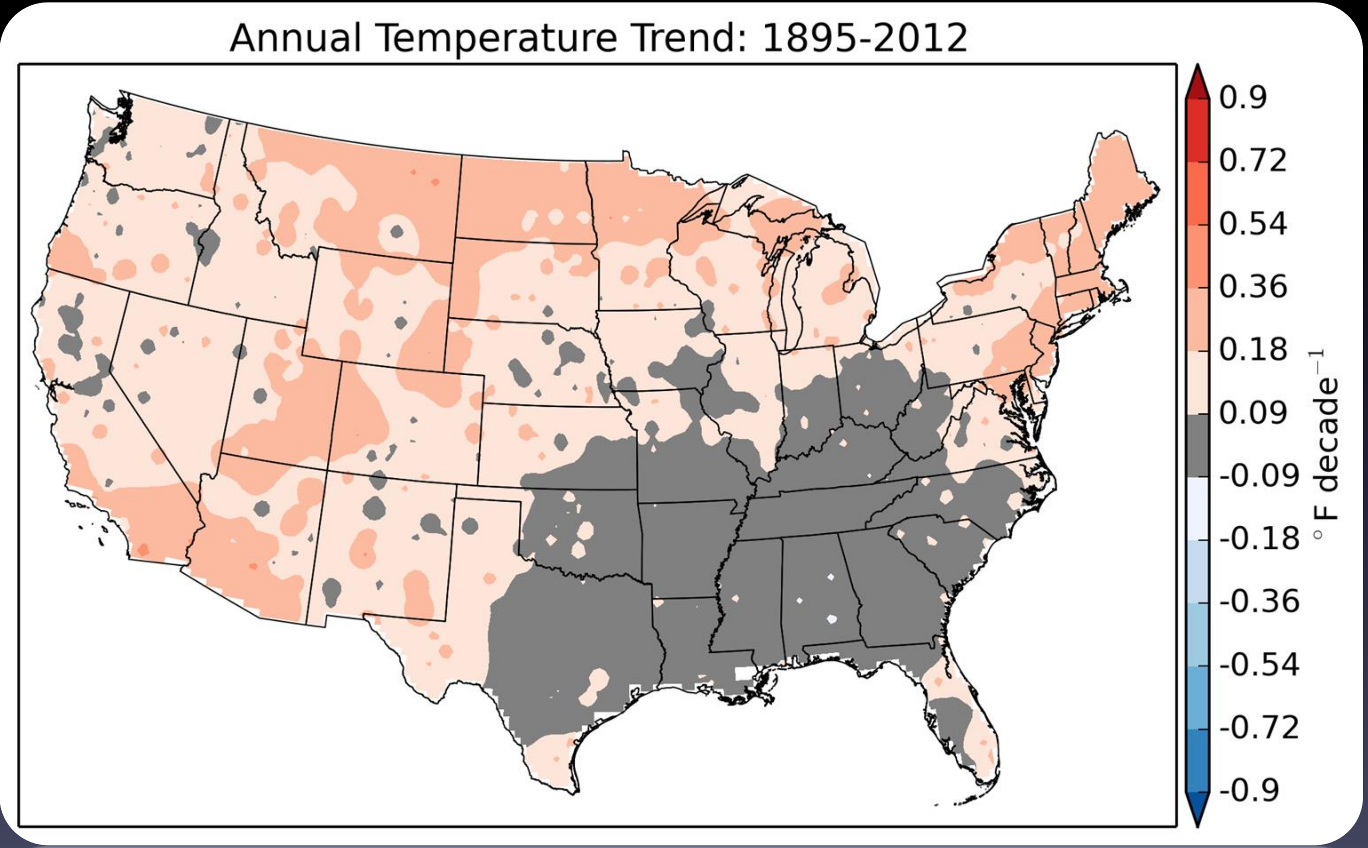


Contiguous U.S.
Annual Temperature Trends

1895-2012 Change in Average Temperature

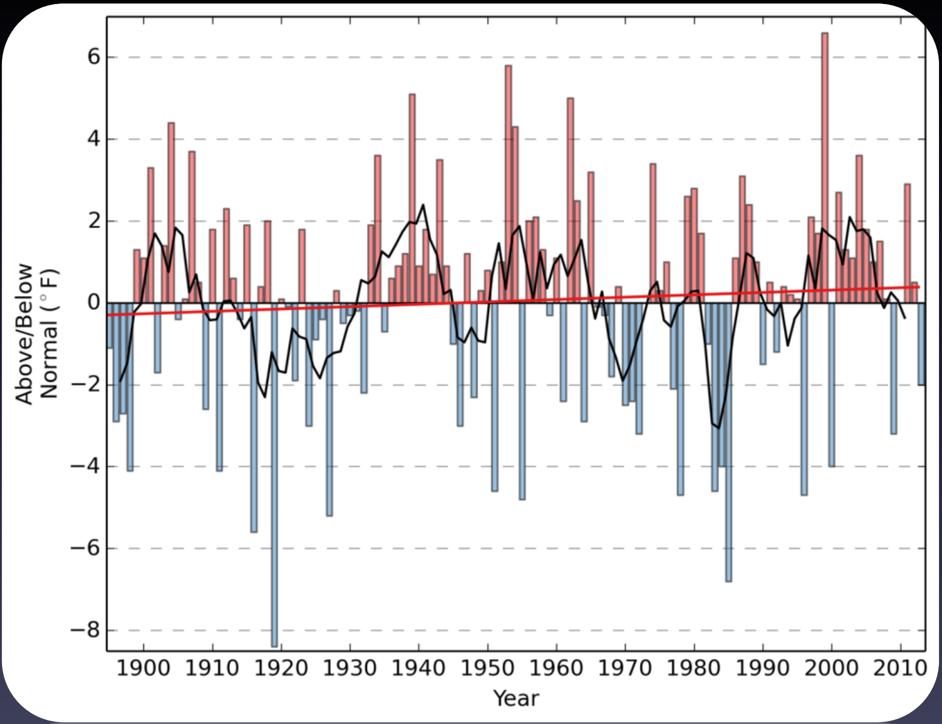
Montana:+2.6°F

CONUS: +1.5°F

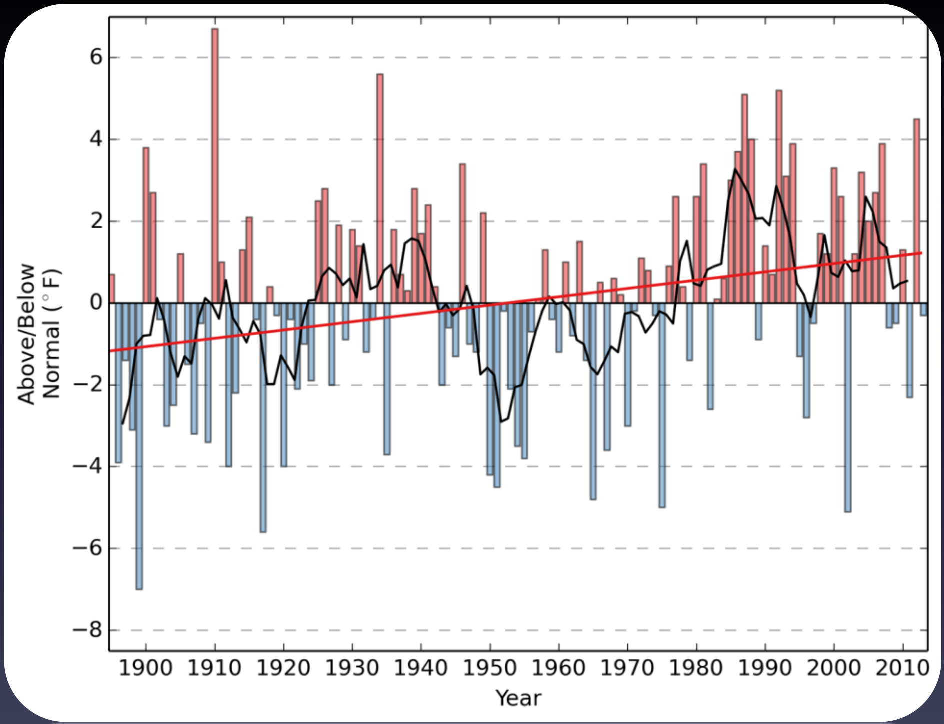


1895-2013 Temperature Trends

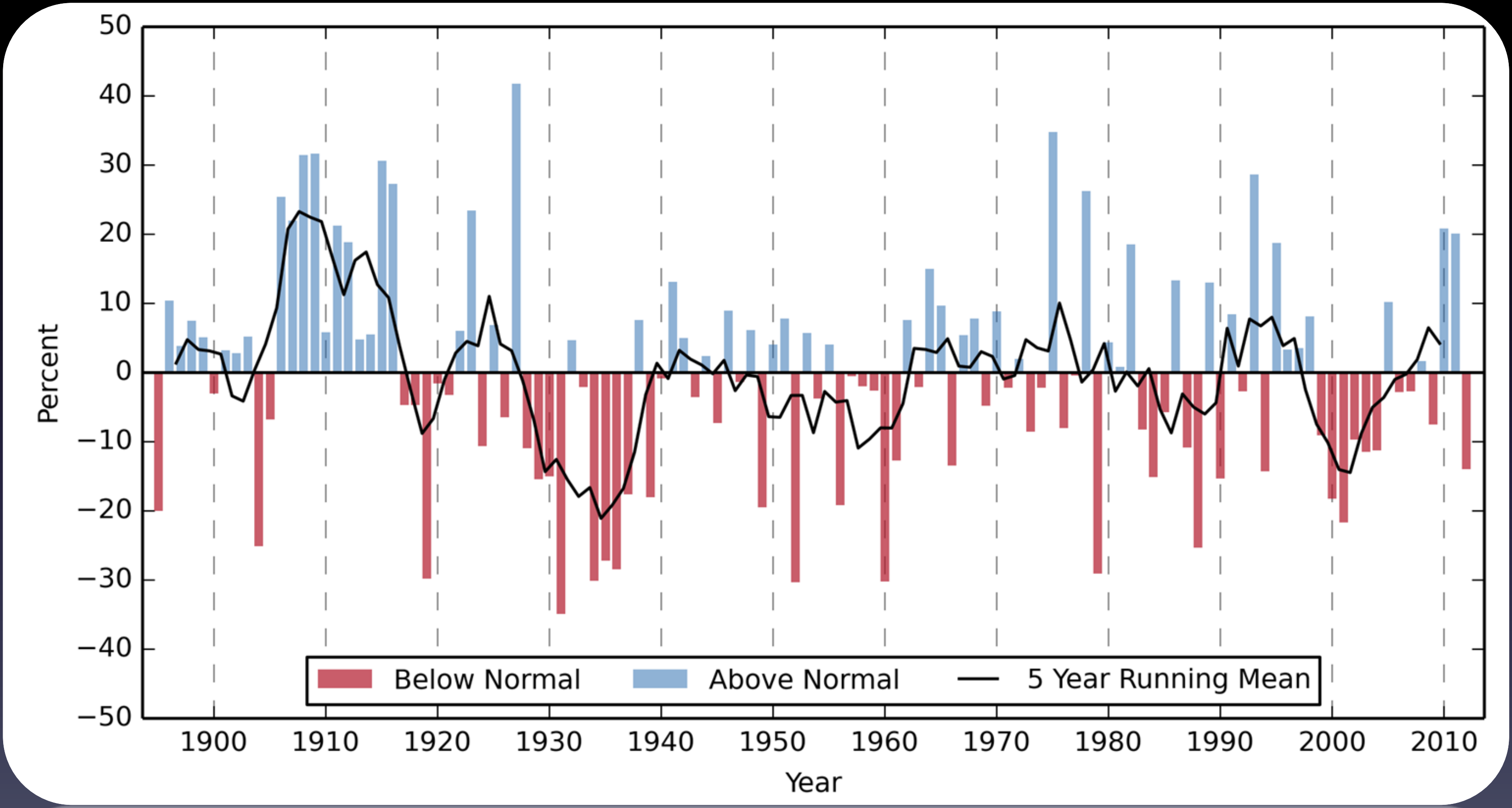
Montana Fall/Early Winter Trend: +0.69°F



Montana Spring Trend: +2.42°F

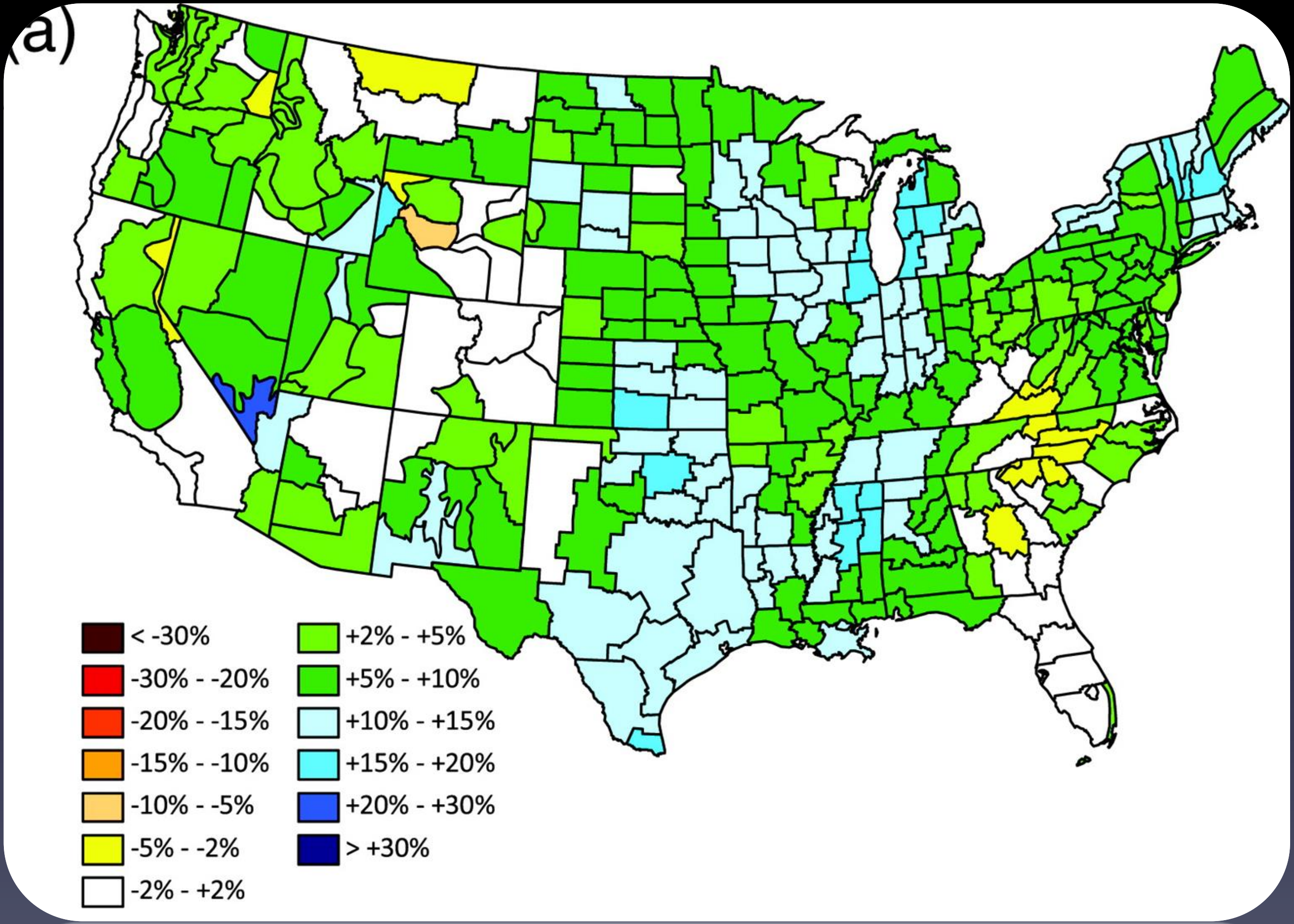


Montana Precipitation



Montana Precipitation Trends

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



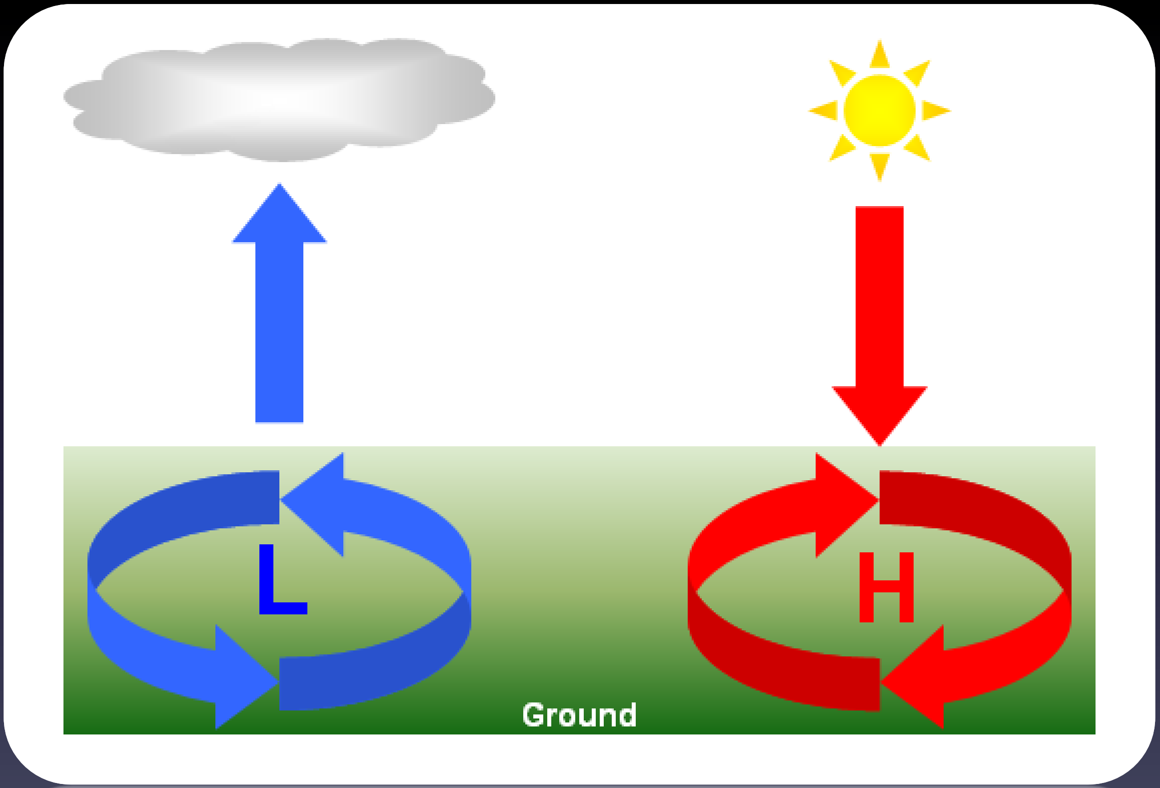
McRoberts, D. B., & Nielsen-Gammon, J. W. (2011). A New Homogenized Climate Division Precipitation Dataset for Analysis of Climate Variability and Climate Change. Journal of Applied Meteorology and Climatology, 50(6), 1187–1199. doi:10.1175/2010JAMC2626.1

Natural Climate Variability in Montana

Air Pressure

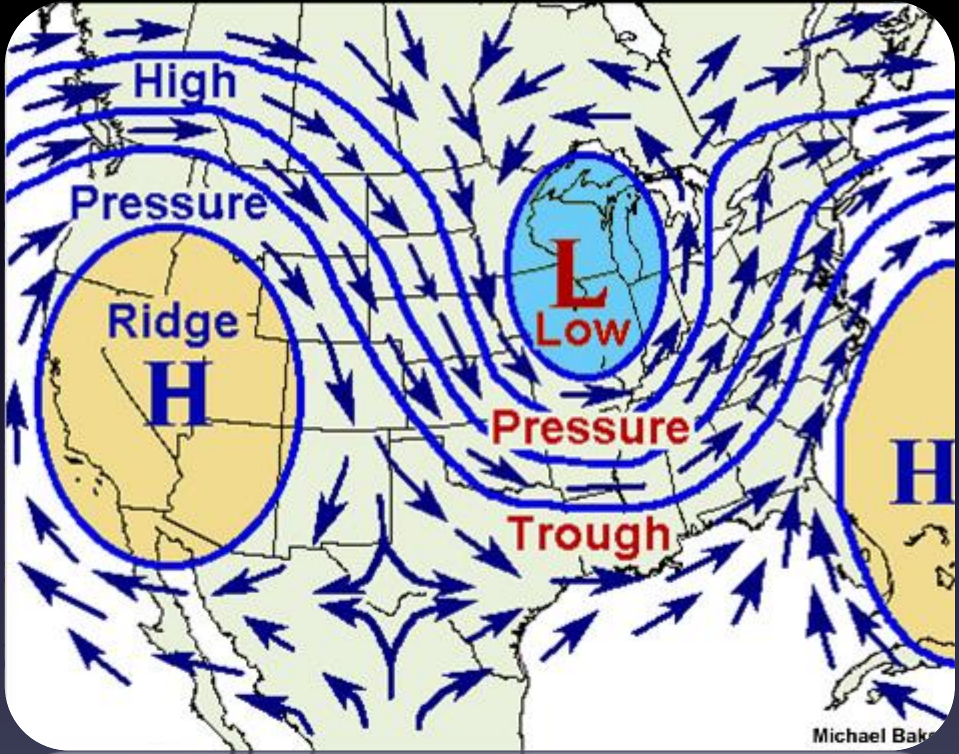
Air pressure: the mass of air above a given area

Low and high pressure systems

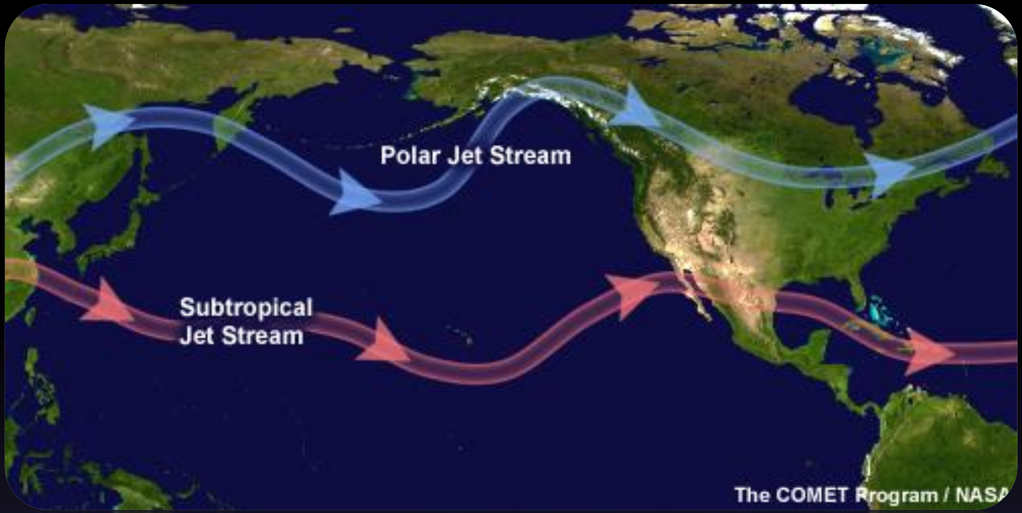


http://www.nc-climate.ncsu.edu/edu/k12/.Convergence

Ridges and Troughs

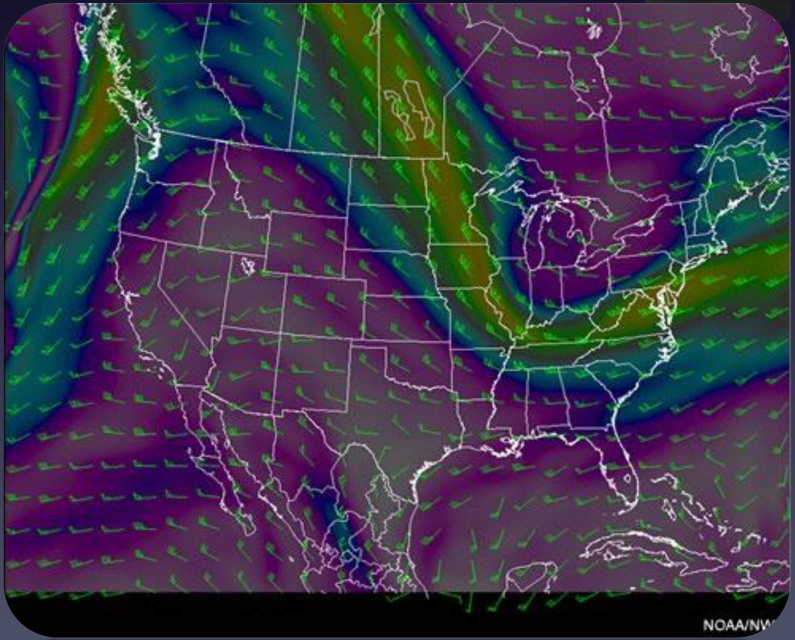


Jet Streams: strong, narrow currents of air in the upper atmosphere. Form at the boundary of contrasting air masses



Effective at steering storms. Creates the main storm tracks

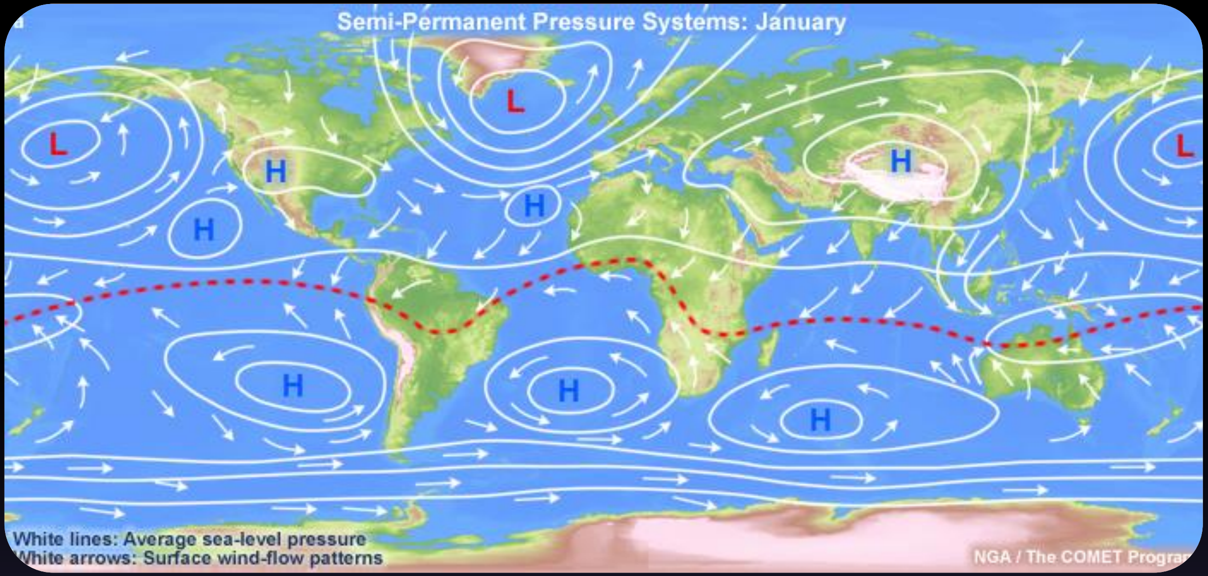
Strength/location varies by season and day-to-day

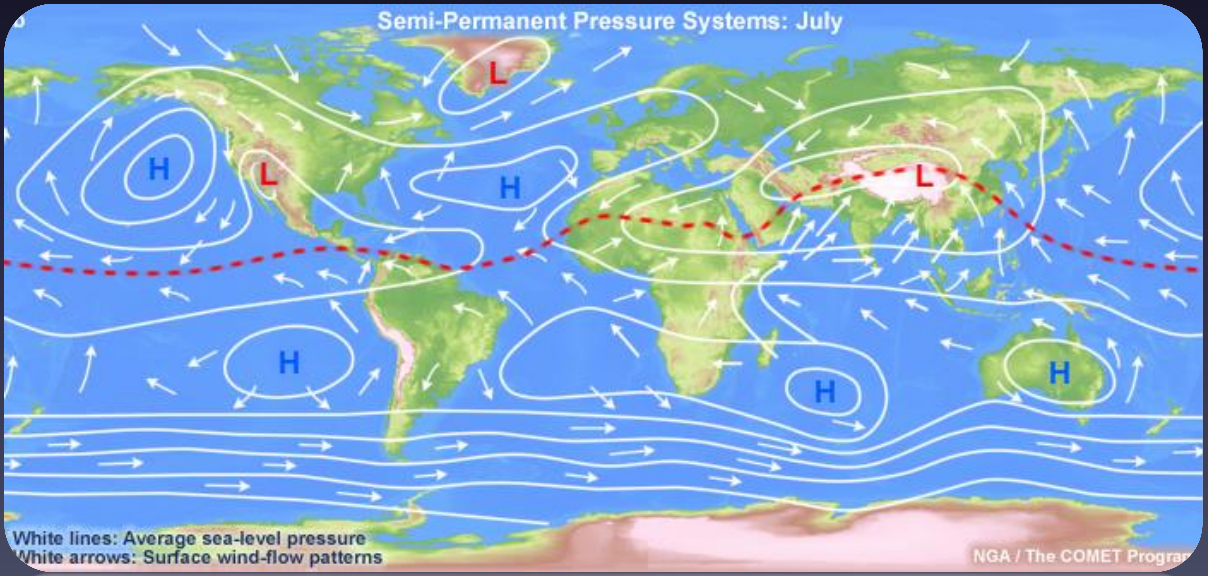


http://www.meted.ucar.edu/fire/s290/unit7/print.htm

Semi-Permanent Pressure Systems

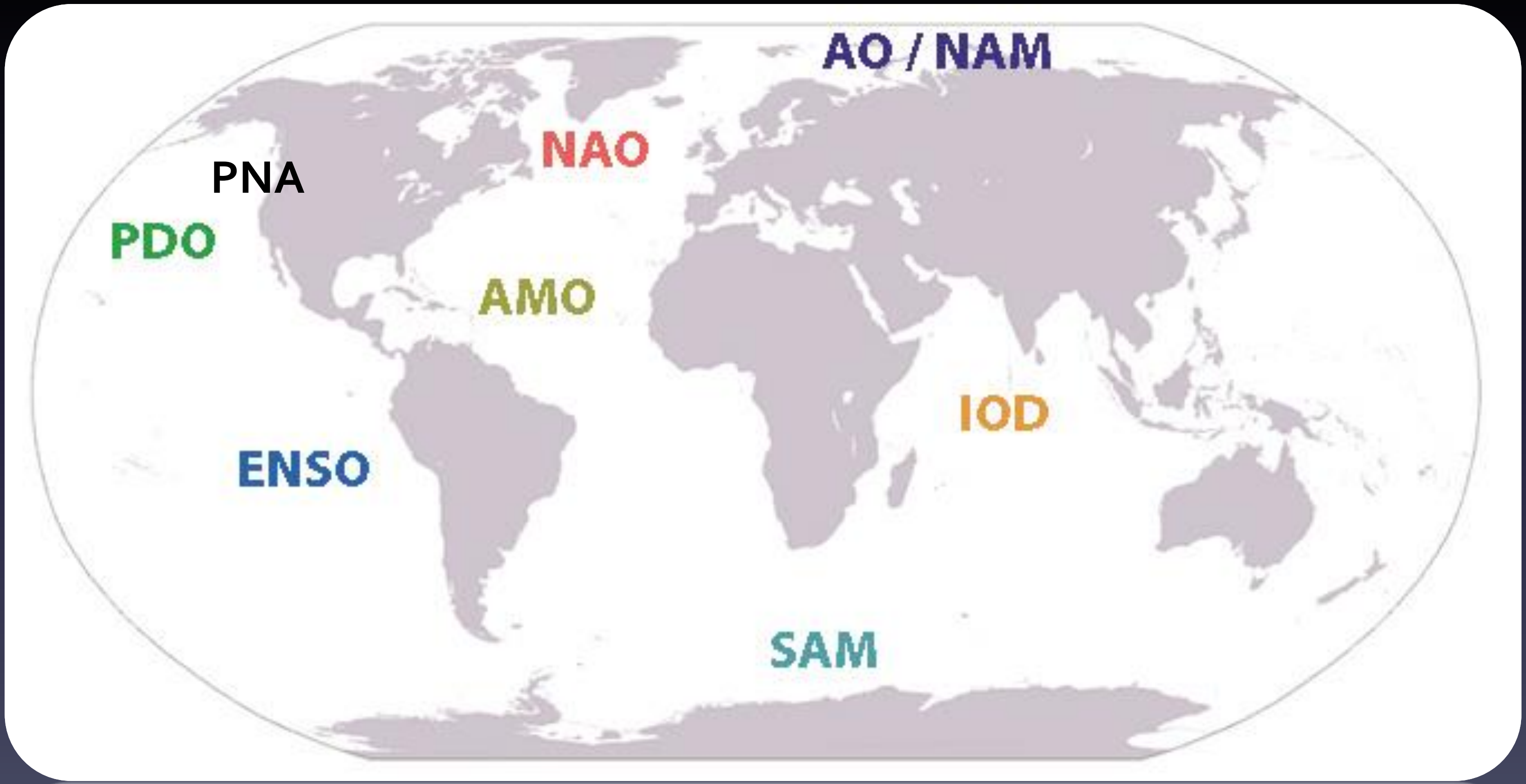
Position, strength, duration of these systems affect storm tracks, frontal positions, seasonal monsoons, etc.





http://www.meted.ucar.edu/tropical/textbook_2nd_edition/navmenu.php?tab=4&page=2.3.0

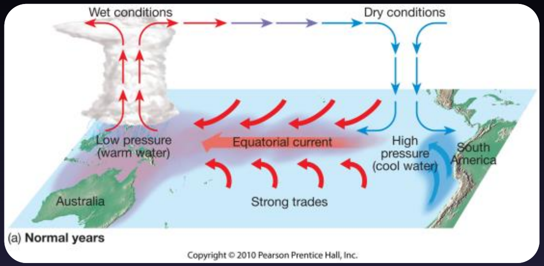
"Modes" of Natural Climate Variability



El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO)

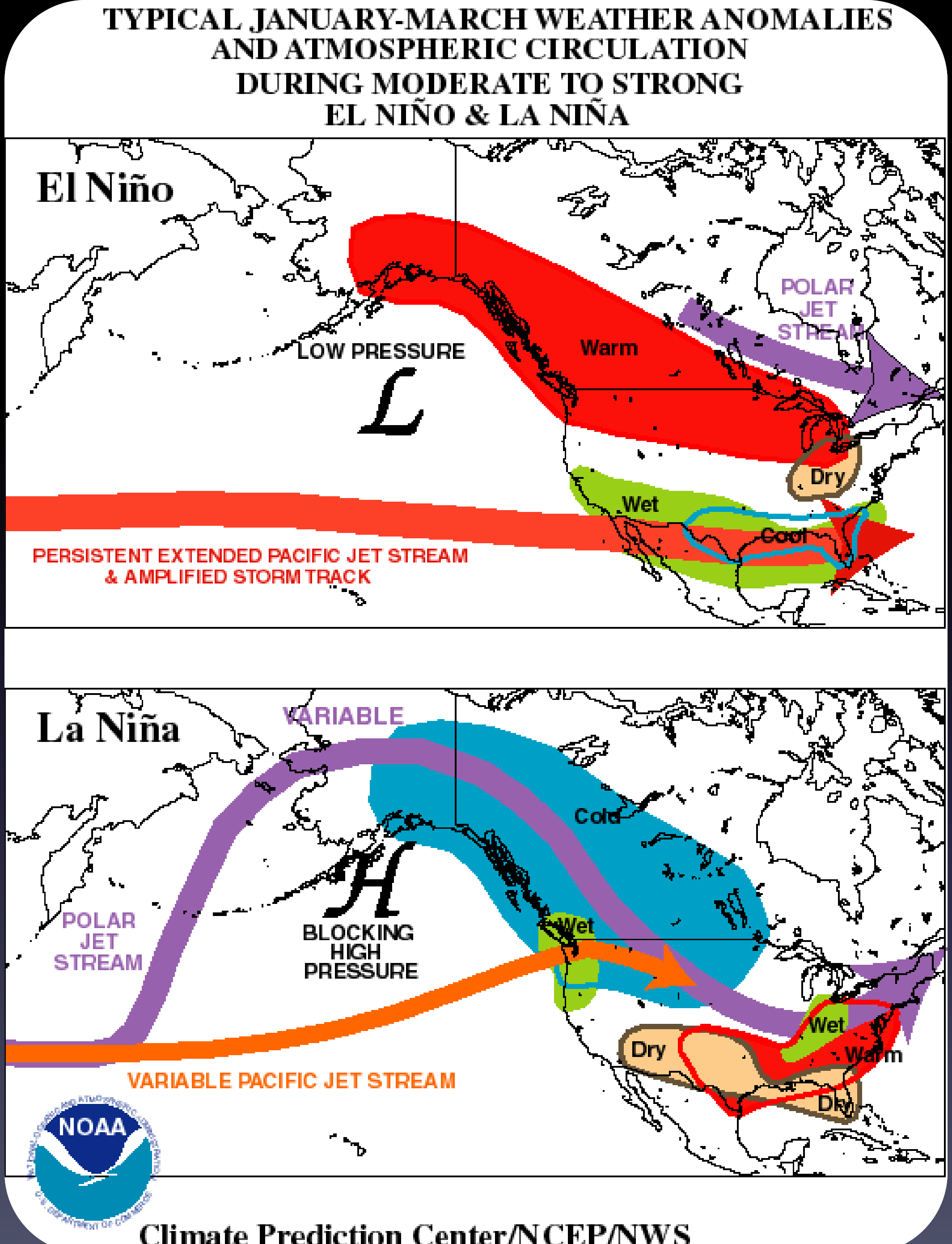
- A system of interactions between the tropical Pacific Ocean and the atmosphere above it
  - **El Niño**: warm phase
  - **La Niña**: cold phase



- 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**

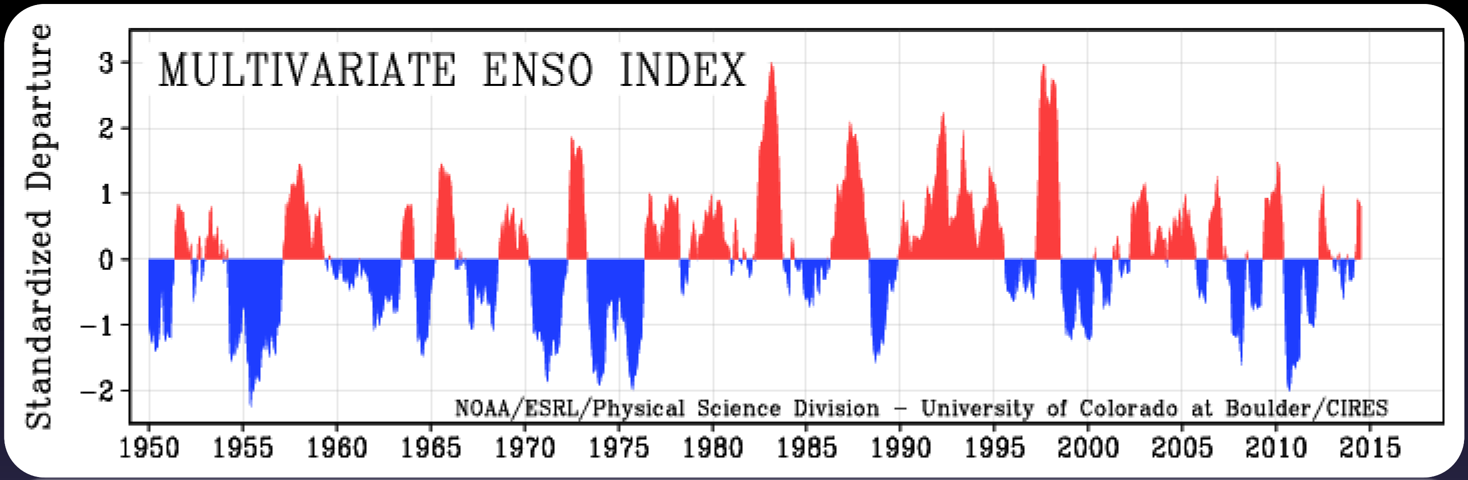
El Niño/ La Niña Impacts

Shift in jet streams



ENSO

Multivariate ENSO Index



Outlook

65% of El Nino emerging in fall and early winter. Forecasters favor a weak event.

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

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

Natural Variability and Temperature Trends in Western U.S.

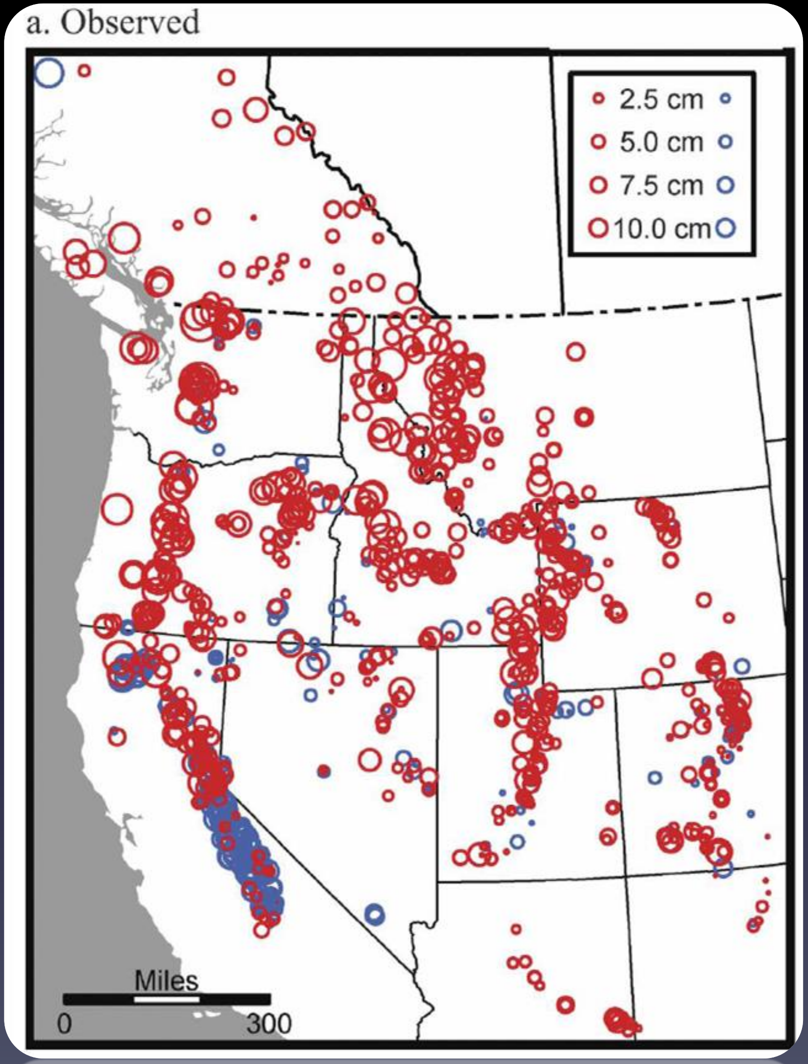
- Trends in circulation patterns (NAM/AO,PNA) in winter and spring
  - Likely account for 40-50% of warming trend in western North America
- Opposite trends in circulation patterns (NAM/AO, PNA) in fall
  - Likely masked the anthropogenic warming signal in western North America during the fall season

Abatzoglou, J.T., Redmond, K.T., 2007. Asymmetry between trends in spring and autumn temperature and circulation regimes over western North America. Geophysical Research Letters 34, L18808.
Wu, Q., and D. M. Straus (2004), AO, COWL, and observed climate trends, J. Clim., 17, 2139–2156.

Effects on Snowpack Trends

- Up to 50% of the decrease in western U.S. snowpack (especially in the PNW, N. Rockies) over the last half century can likely be attributed to changes in Pacific climate variability and circulation patterns
- However, degree of change cannot be explained by natural variability alone
- A case of decadal natural variability in atmospheric circulation having a positive reinforcement on anthropogenic-driven warming

Trend in April 1 SWE 1960-2002



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., 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, 332–335.

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

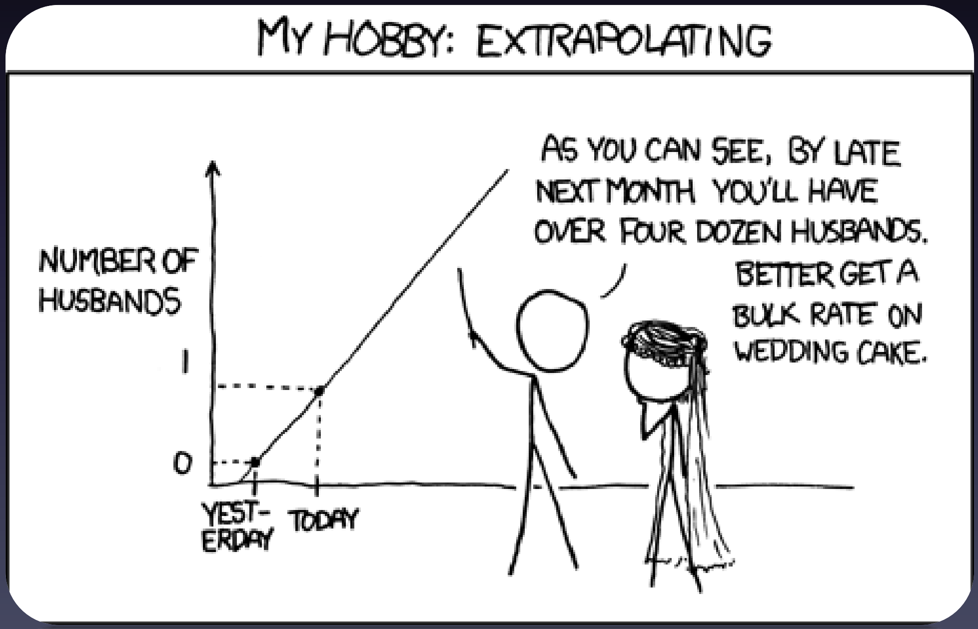
Glaciers in Glacier NP

- 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 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

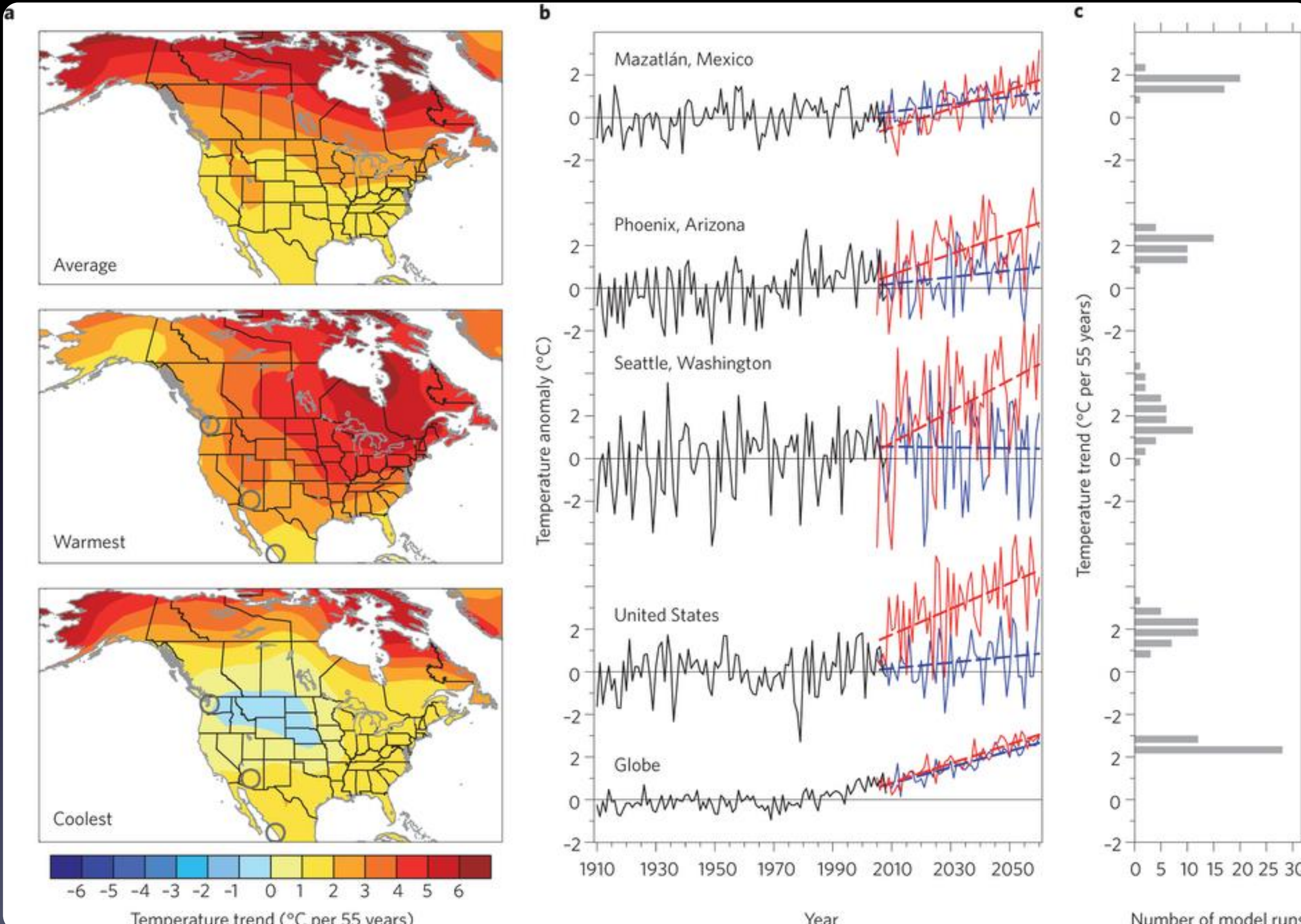


Climate Projections

- **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

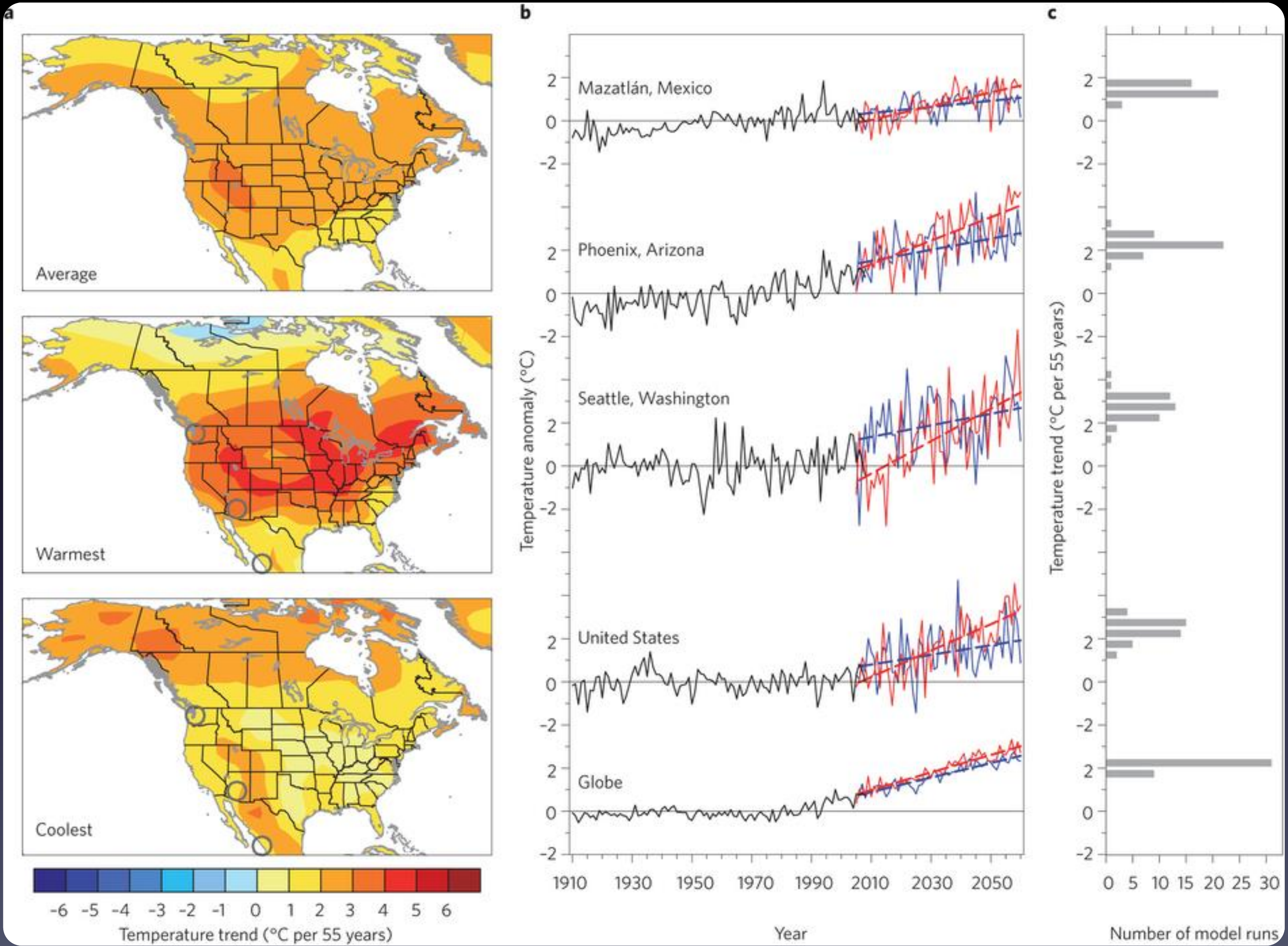
Winter temperature trends 2005–2060

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.



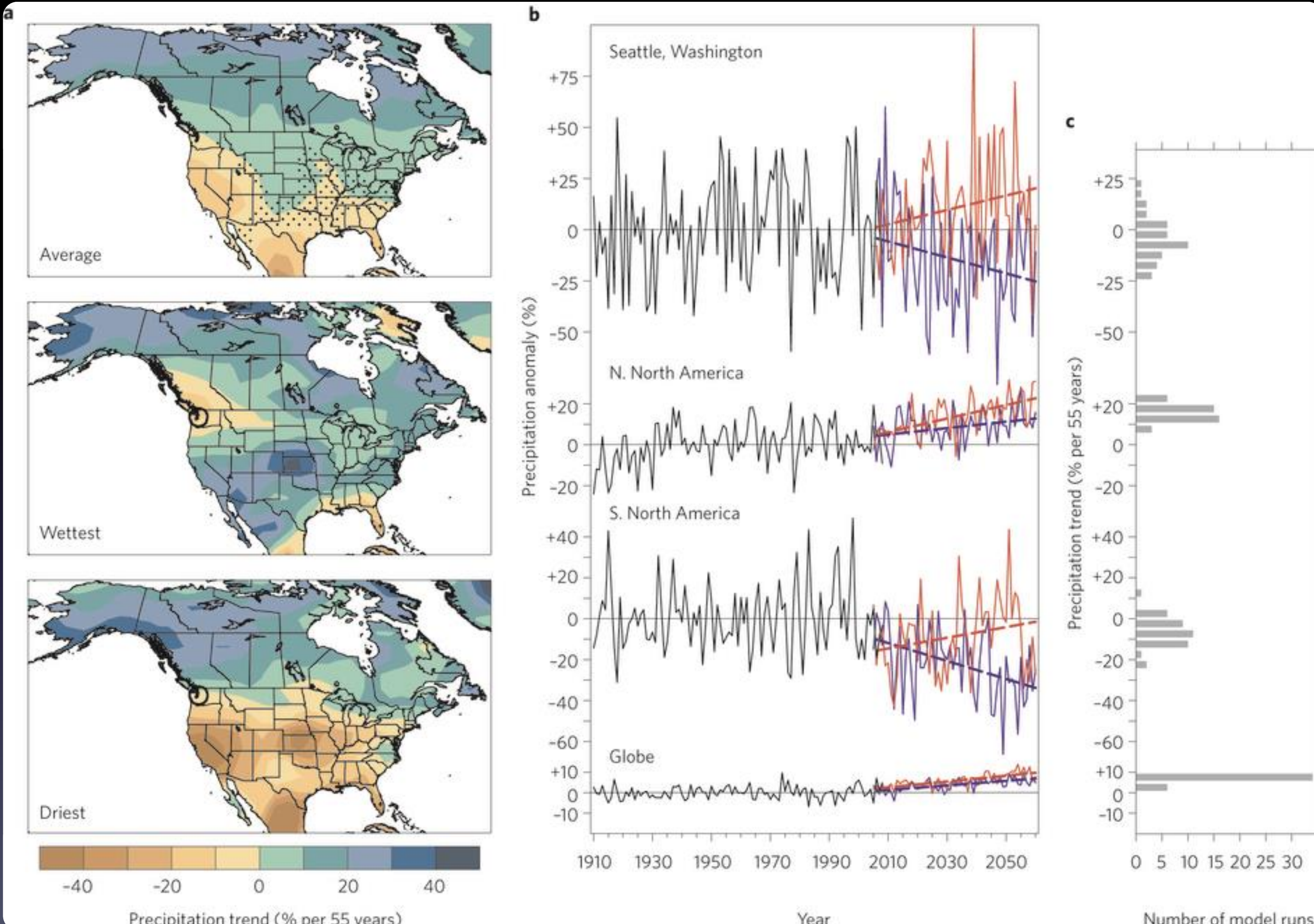
Summer temperature trends 2005–2060

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.



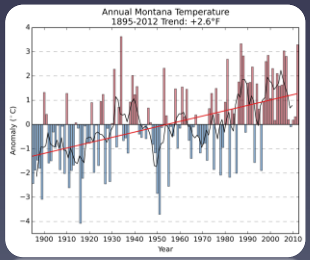
Main Takeaway

External Global Climate Forcing ⇅

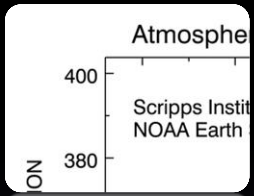
Internal hemispheric/synoptic-scale natural variability ⇅

Local Meso/Micro-scale Climate Features ⇅

Climate Trends in Montana

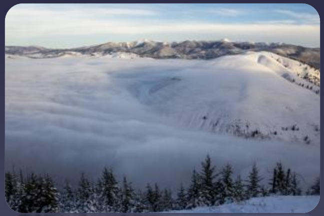


Greenhouse gas emissions



ENSO,PDO,NAM/AO,PNA

Topography, Land Cover



Climate Change Impacts

Regional impacts for Montana

Questions/Comments

- **Montana Climate Office**
  - http://www.climate.umt.edu
- **Dr. Kelsey Jencso**, State Climatologist
- **Dr. Ashley Ballantyne**, Asst. State Climatologist
- **Mike Sweet**, Information Services
- **Jared Oyler**, Climate science and Product Developer
  - jared.oyler@ntsg.umt.edu