Regional Climate Variability in the Western U.S.: *Observed vs. Anticipated*

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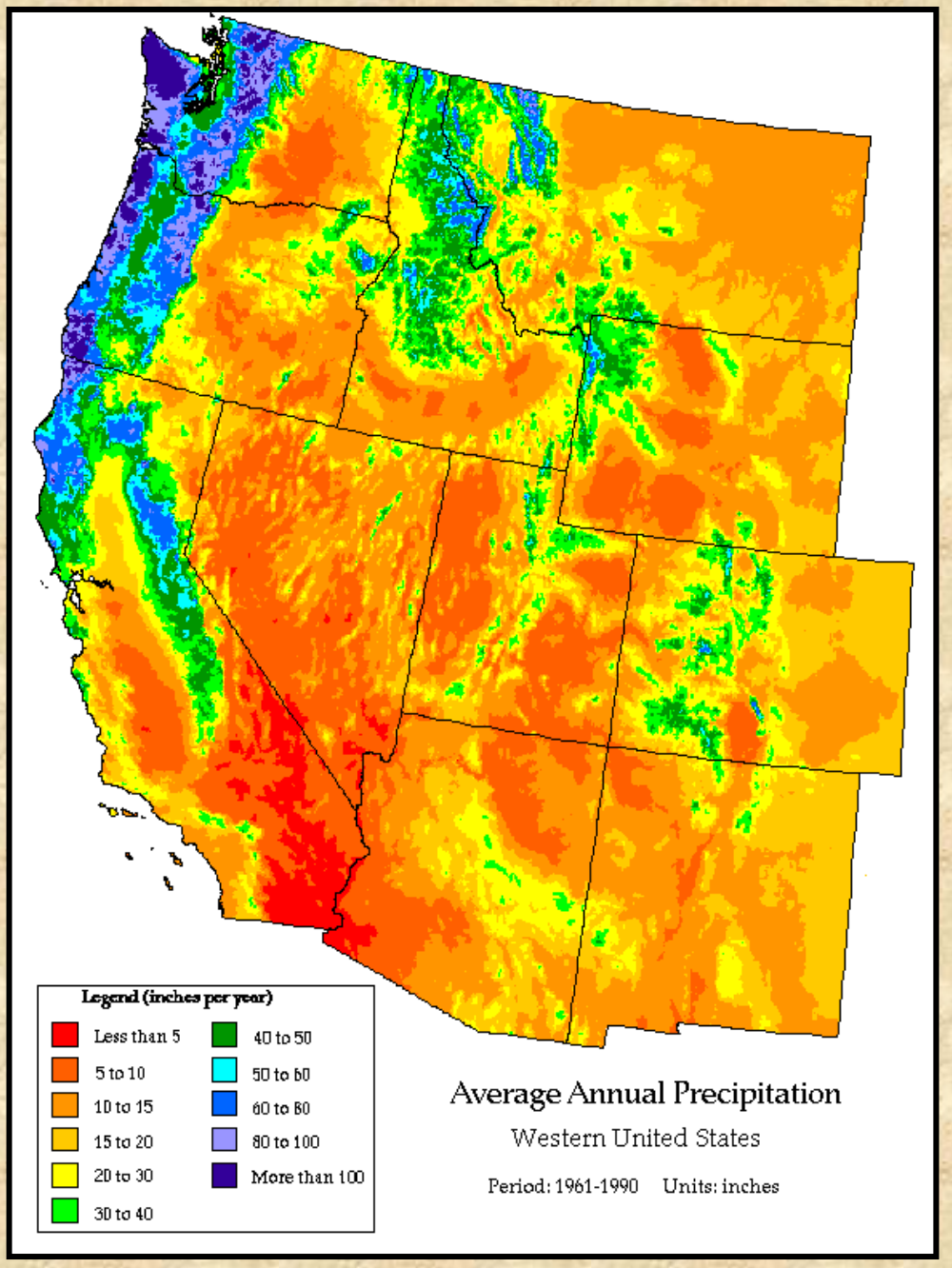
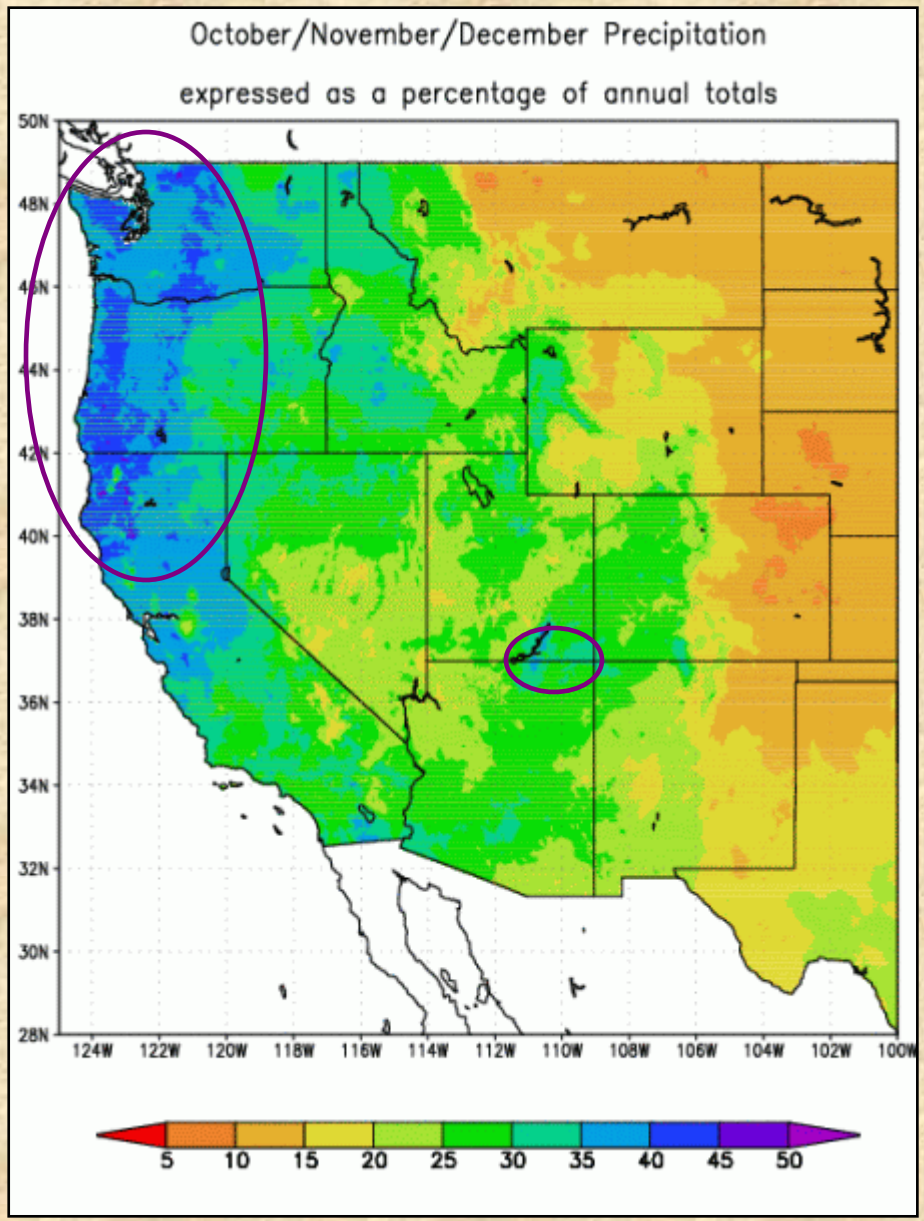
Kudos to Joe Barsugli and Jon Eischeid

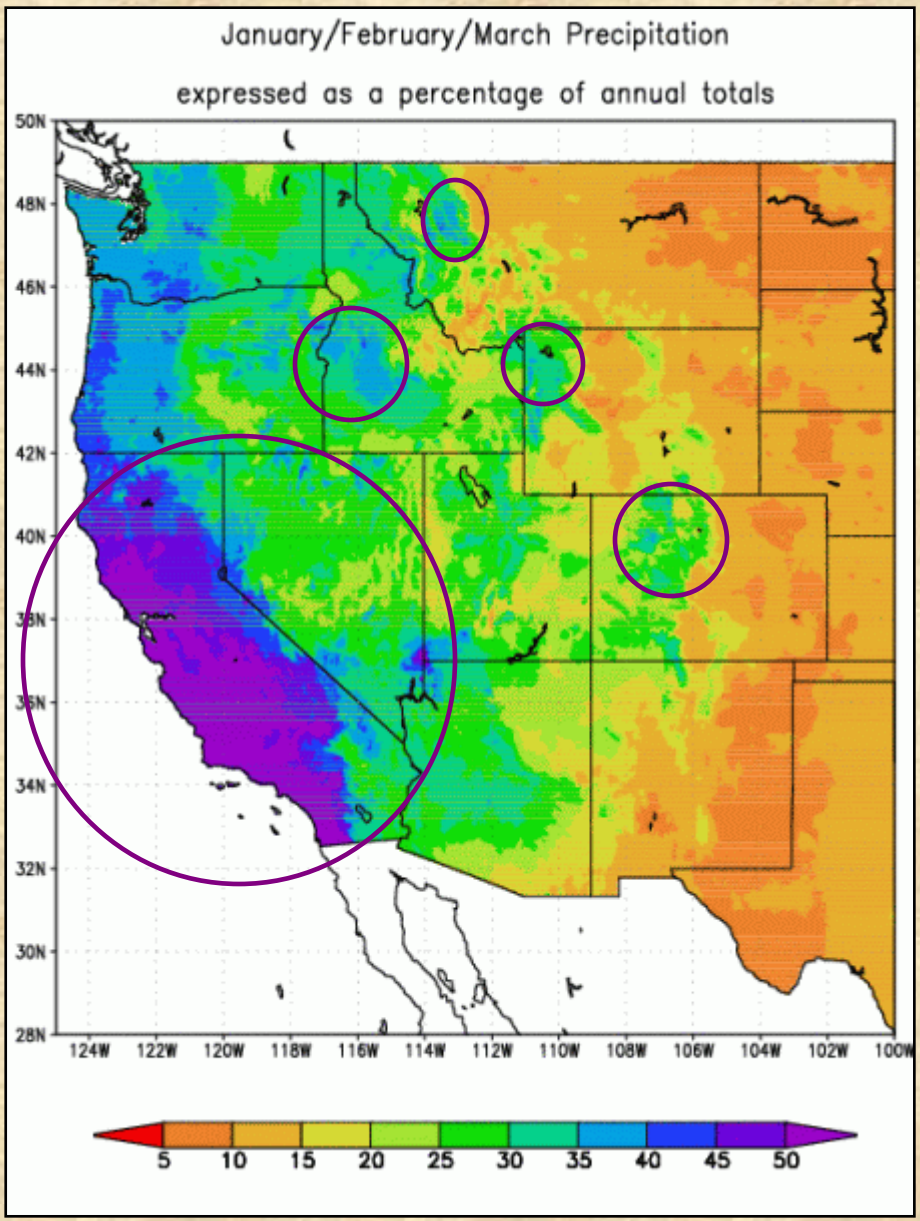
- **Seasonal Precipitation Cycle**
- **ENSO Footprint(s)**
- **Recent Climate Trends**
- **Outlook to Mid-21st Century**

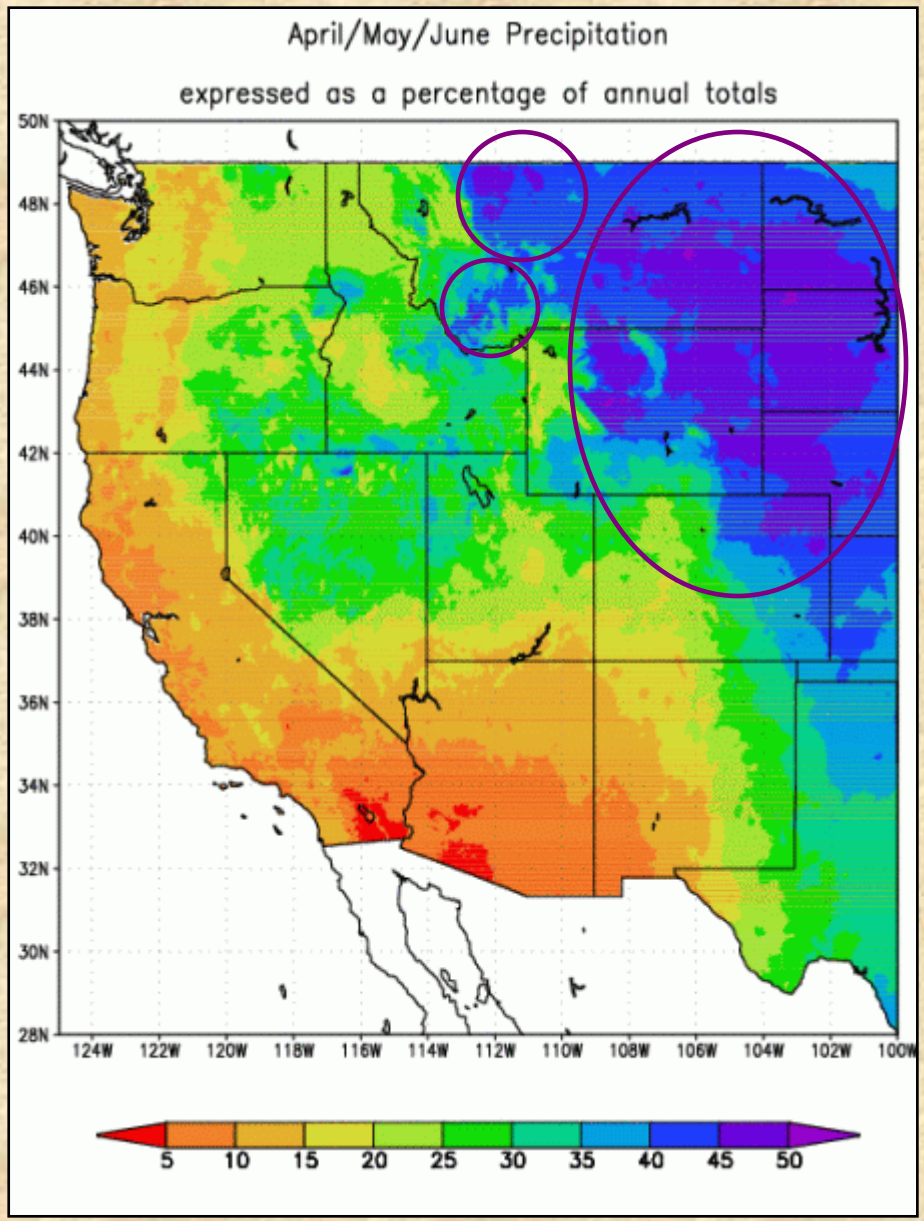


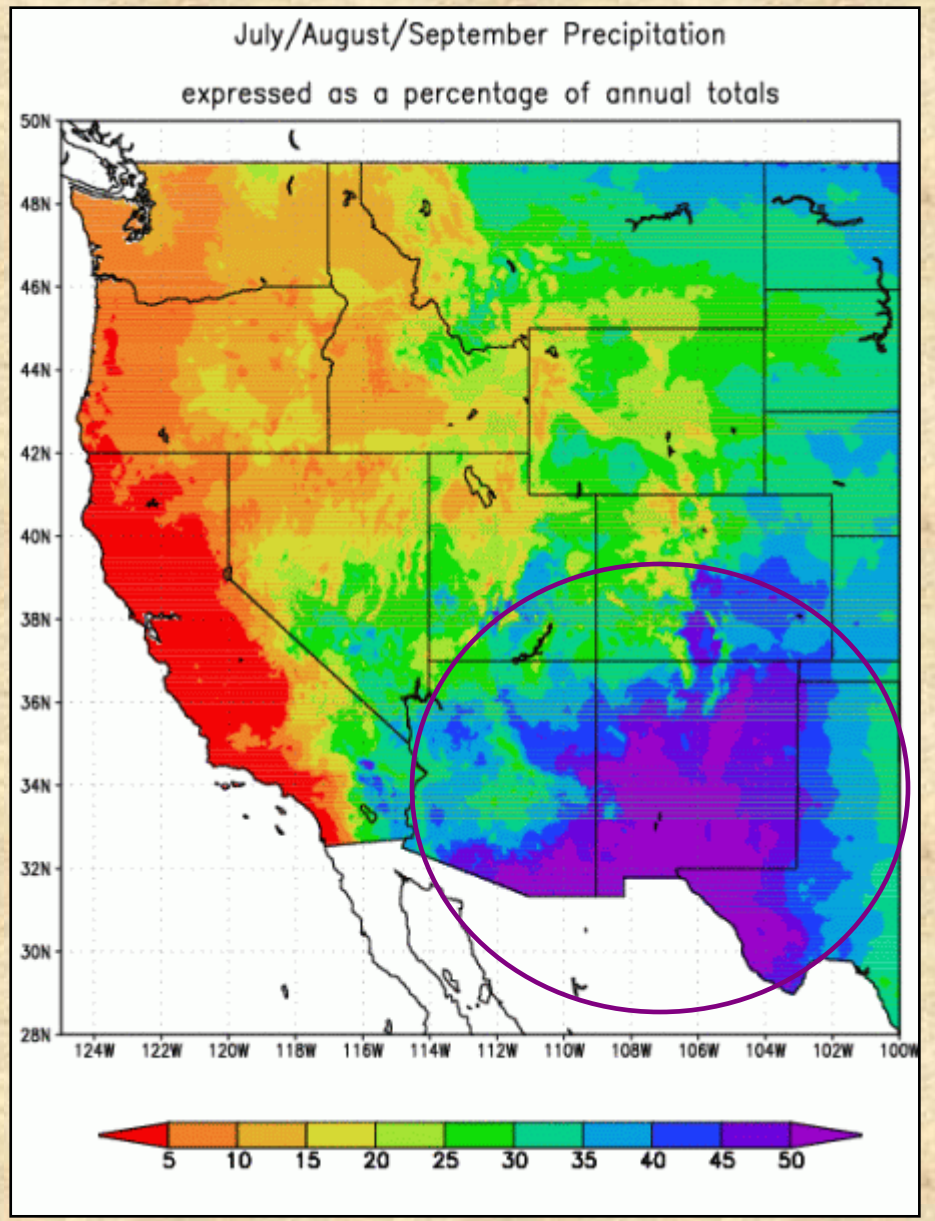
Average Annual Precipitation for the Western U.S.

Based on PRISM
OSU/WRCC


October/November/December Precipitation
expressed as a percentage of annual totals
50N
48N
46N
44N
42N
40N
38N
36N
34N
32N
30N
28N
124W
122W
120W
118W
116W
114W
112W
110W
108W
106W
104W
102W
100W
5
10
15
20
25
30
35
40
45
50


January/February/March Precipitation
expressed as a percentage of annual totals
50N
48N
46N
44N
42N
40N
38N
36N
34N
32N
30N
28N
124W
122W
120W
118W
116W
114W
112W
110W
108W
106W
104W
102W
100W
5
10
15
20
25
30
35
40
45
50


April/May/June Precipitation
expressed as a percentage of annual totals
50N
48N
46N
44N
42N
40N
38N
36N
34N
32N
30N
28N
124W
122W
120W
118W
116W
114W
112W
110W
108W
106W
104W
102W
100W
5
10
15
20
25
30
35
40
45
50


July/August/September Precipitation
expressed as a percentage of annual totals
50N
48N
46N
44N
42N
40N
38N
36N
34N
32N
30N
28N
124W
122W
120W
118W
116W
114W
112W
110W
108W
106W
104W
102W
100W
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25
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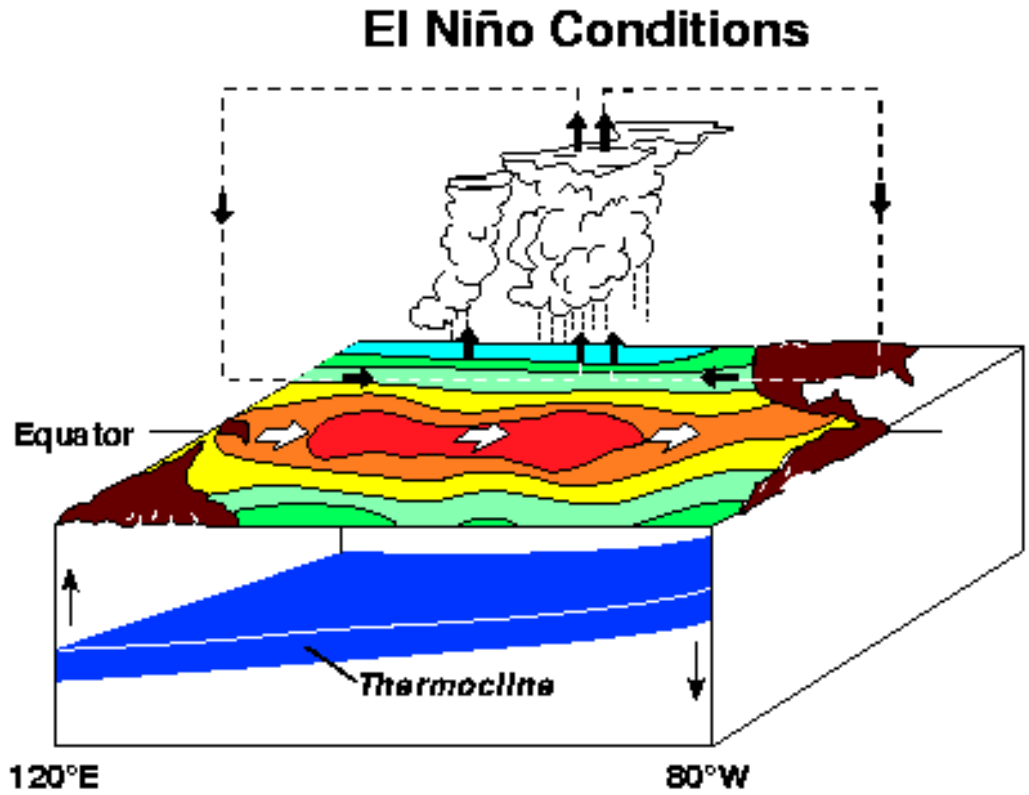
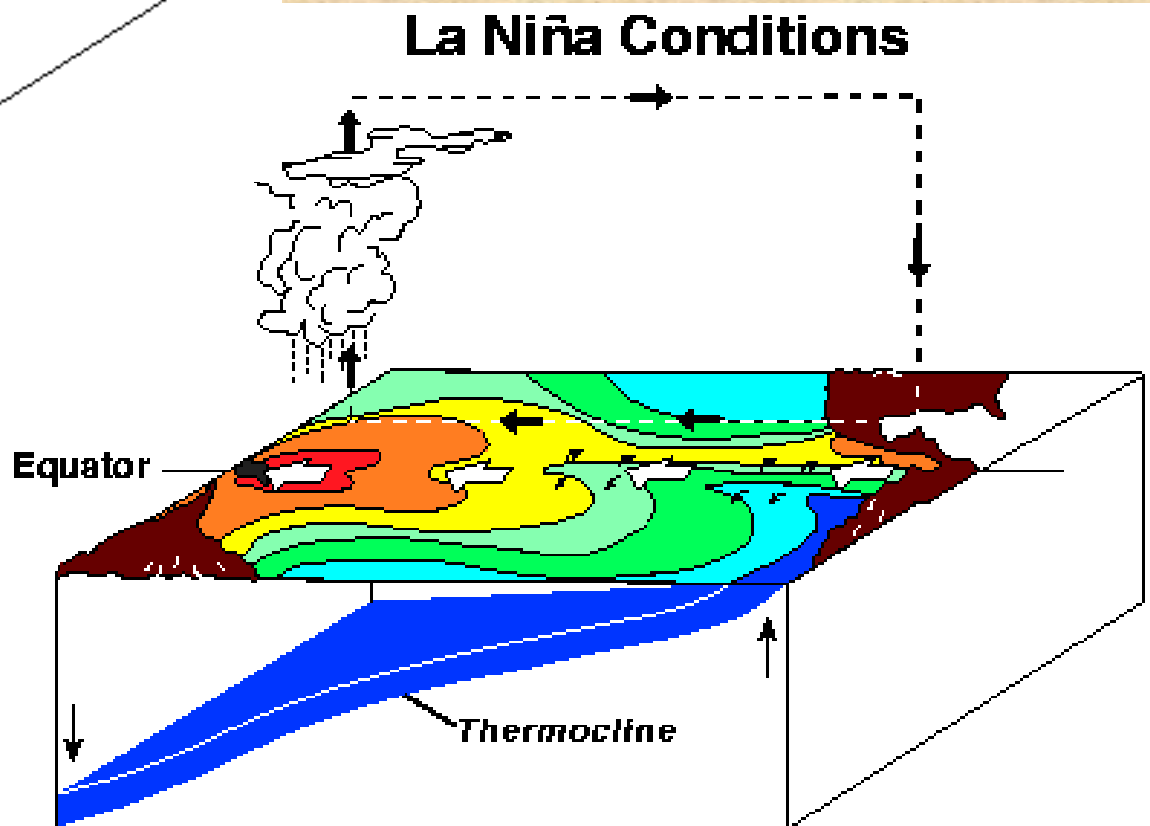
40
45
50

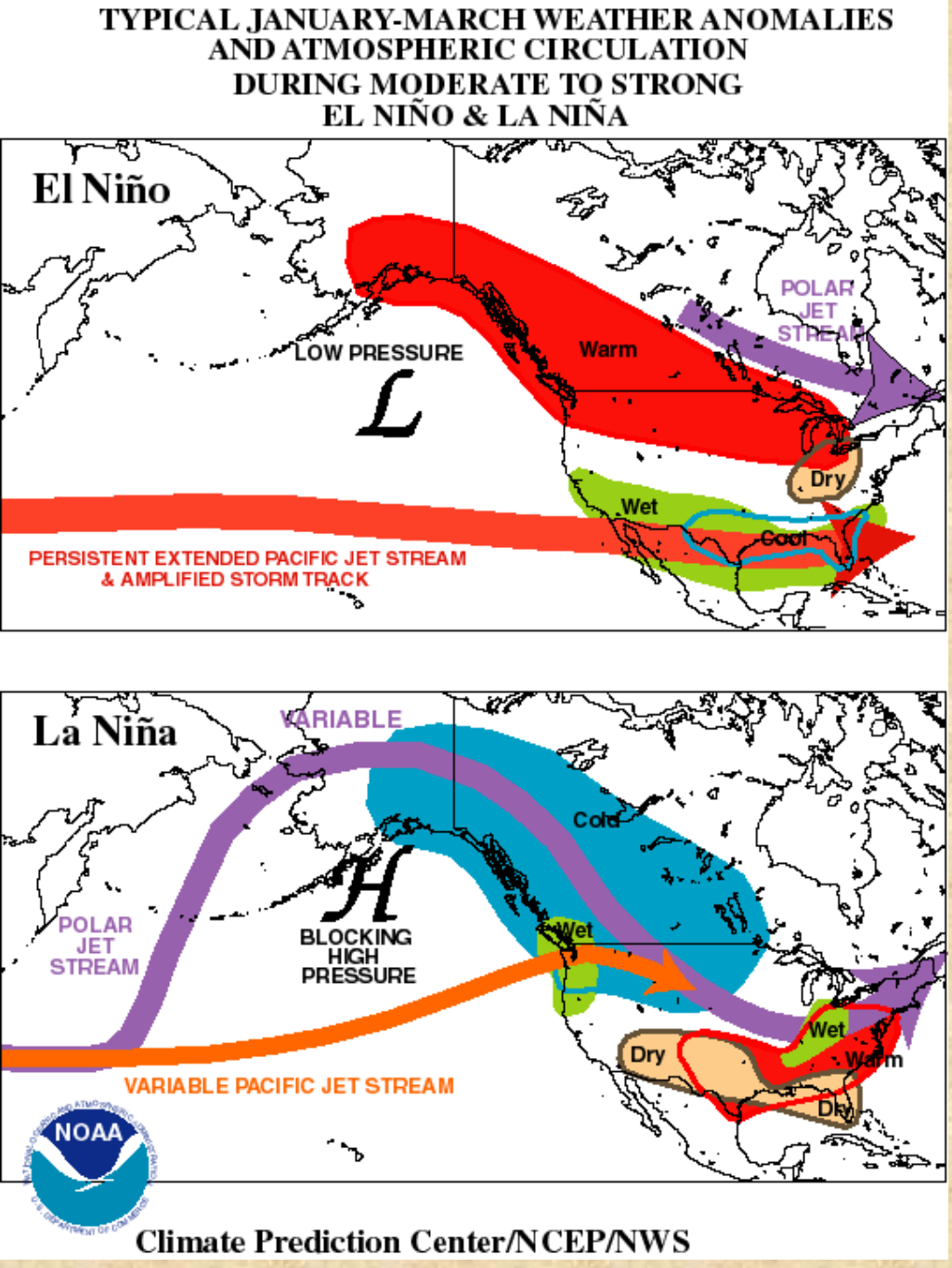
Warm and cold phases of the ENSO (El Niño/ Southern Oscillation) cycle





ENSO is the most thoroughly modeled coupled ocean-atmosphere system, and it is still good for 'surprises'…

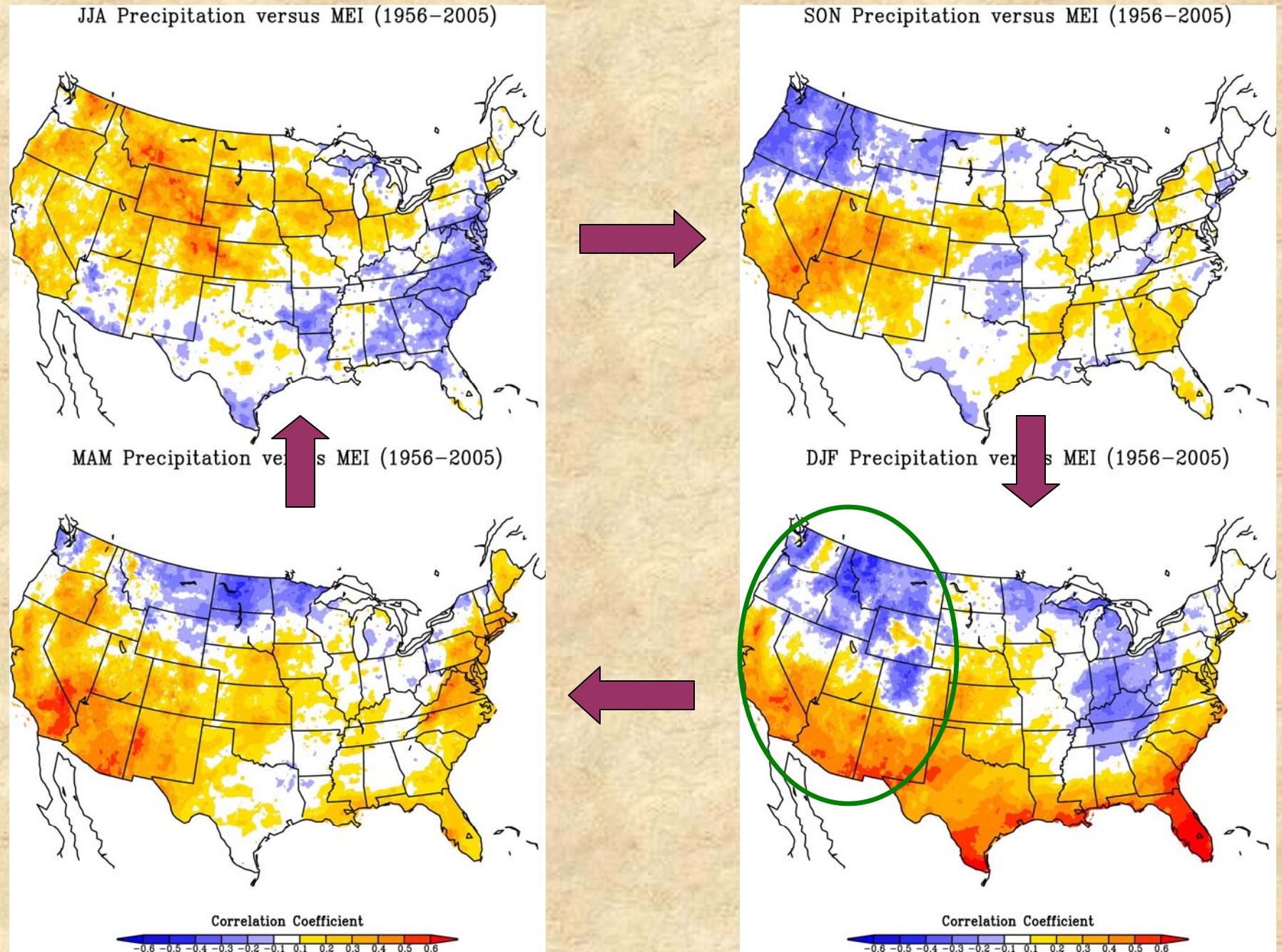
ENSO Impacts on North American Climate



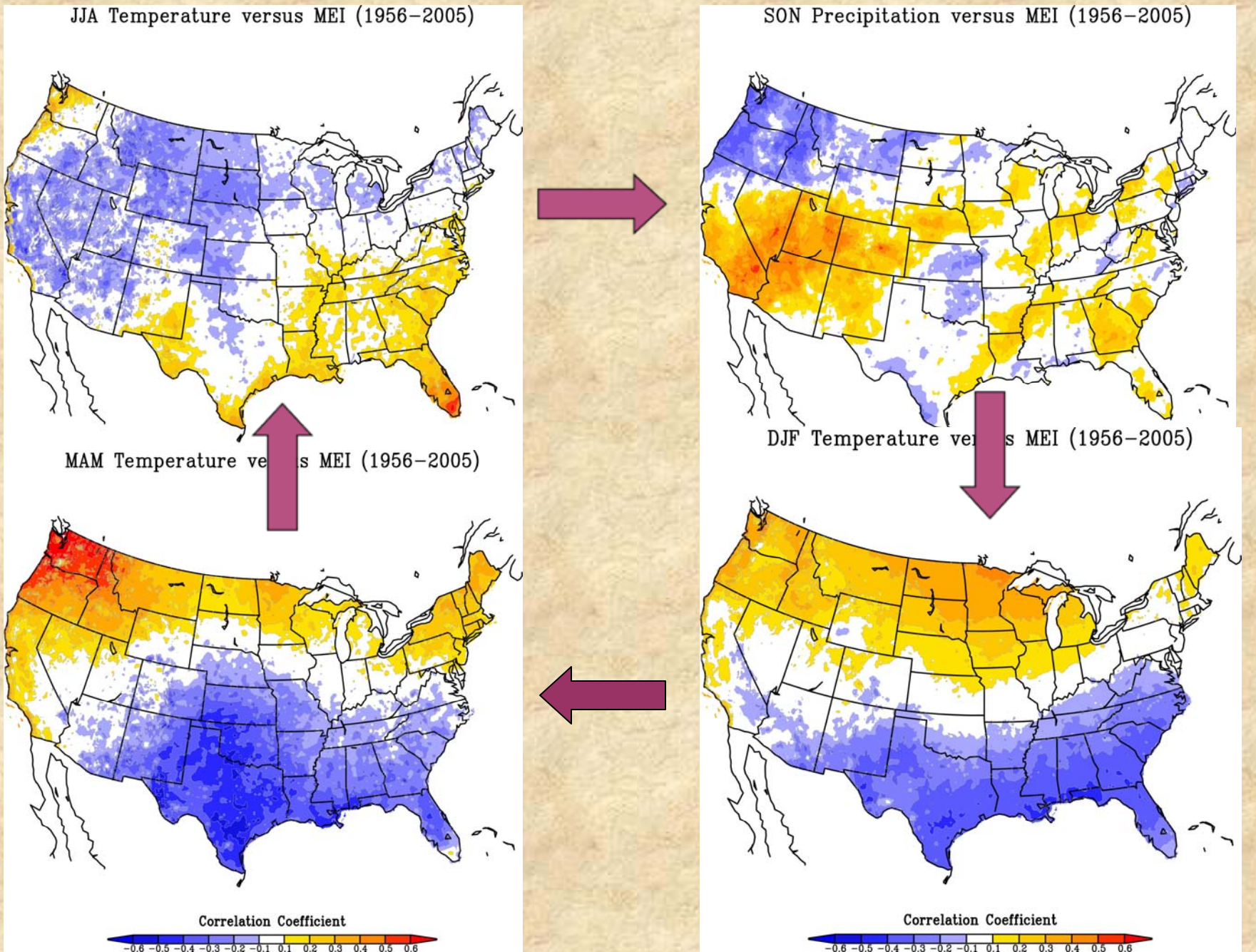
El Niño is often associated with 'split flow' regimes over the Western U.S., leaving Colorado relatively calm.

La Niña is often associated with a strengthened polar jet stream, and tends to give us more frequent wind storms.

Correlations with U.S. precipitation (PRISM; MEI(L))



Correlations with U.S. temperatures (PRISM; MEI(L))



Temperature trends in Colorado, or elsewhere: Caveat emptor!

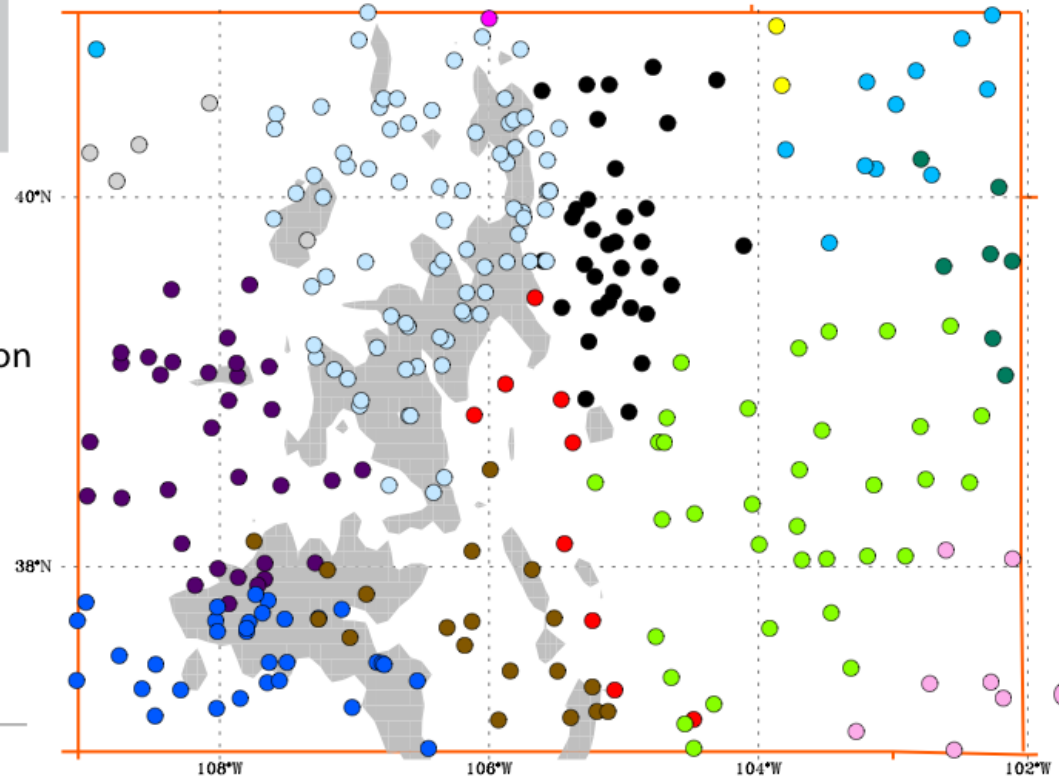
- More so than in other states, Colorado has seen a lot of station location changes, which can easily result in +/-2° F mean temperature changes in orographic regions. *Most of these location changes are well documented…*

- U.S. COOP temperature records are based on once daily full degree Fahrenheit readings of Tmin&Tmax. Many of these are taken in the morning, some in the afternoon, and fewer still at midnight. Observers have been nudged towards a morning observing time which introduces an apparent 'cool' bias for previous afternoon reading stations. Conversion from 'liquid in glass' thermometers to thermistors (MMTS) can give a cool bias of 0.2-0.5° F which may be more than compensated for by placement near electric outlets... *Surprising gaps in metadata…*

- Land-use/land-cover changes are also quite common around here, such as (sub-)urbanization and increased irrigation on eastern plains of the state. *Poorly documented impacts (but: urban heat island, cooler growing seasons in irrigated areas).*

Observations: Regional Temperature Trends

Division	North Central Mountains	North Front Range	Northeast	Grand Junction & Gunnison	Arkansas Valley	Southwest	Lower Arkansas Valley	San Luis Valley	Southern Front Range
1932–2006 75-year trend (°F)	0.8	0.0	0.3	-0.1	0.7	-0.3	-1.3	na	na
1957–2006 50-year trend (°F)	2.6	1.5	0.5	1.6	2.0	0.2	0.5	1.9	0.7
1977–2006 30-year trend (°F)	1.6	2.5	1.8	1.2	1.8	2.0	-0.1	2.4	1.1



Source: CO Climate Report, 2008
Online at:
http://cwcb.state.co.us/

More remarks on climate variability&trends

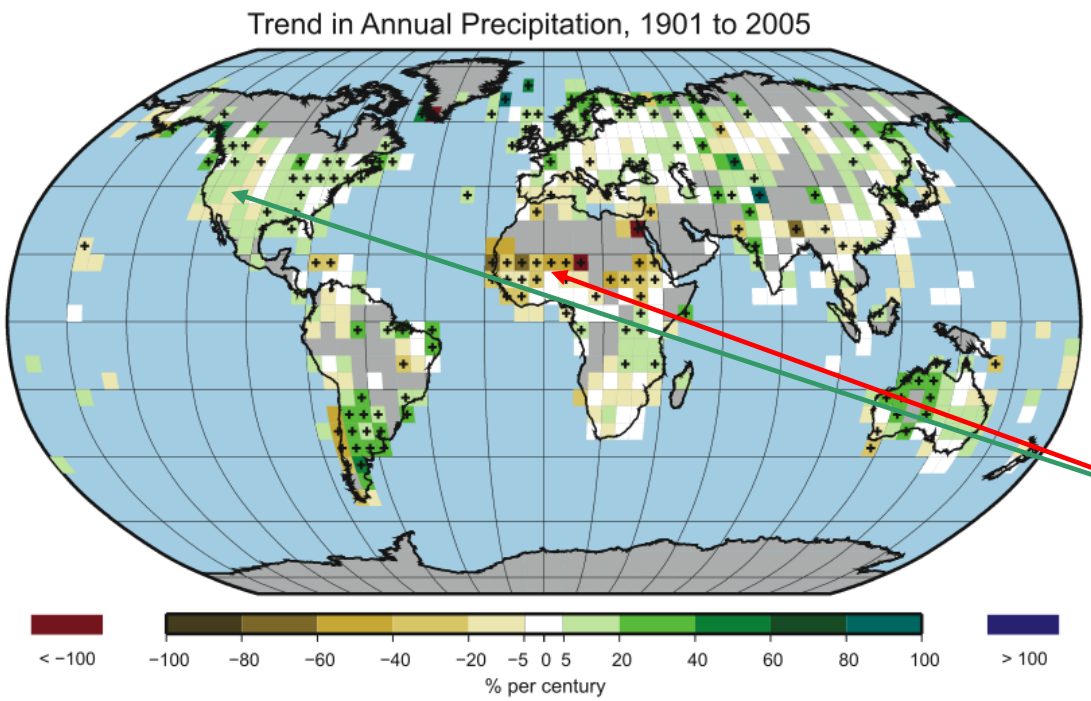
Climate = GHG + 'Natural Variability'+ Surface Changes + Noise

GHG:	**Greenhouse-gas-related 'Global Change'**
Natural Variability:	**Decadal (PDO,…); Interannual (ENSO, …)**
Surface Changes:	**Land-use/ land-cover changes (vegetation+irrigation), Urban Heat Island, station siting, …**
Noise:	**Instrument errors, observer errors,…**

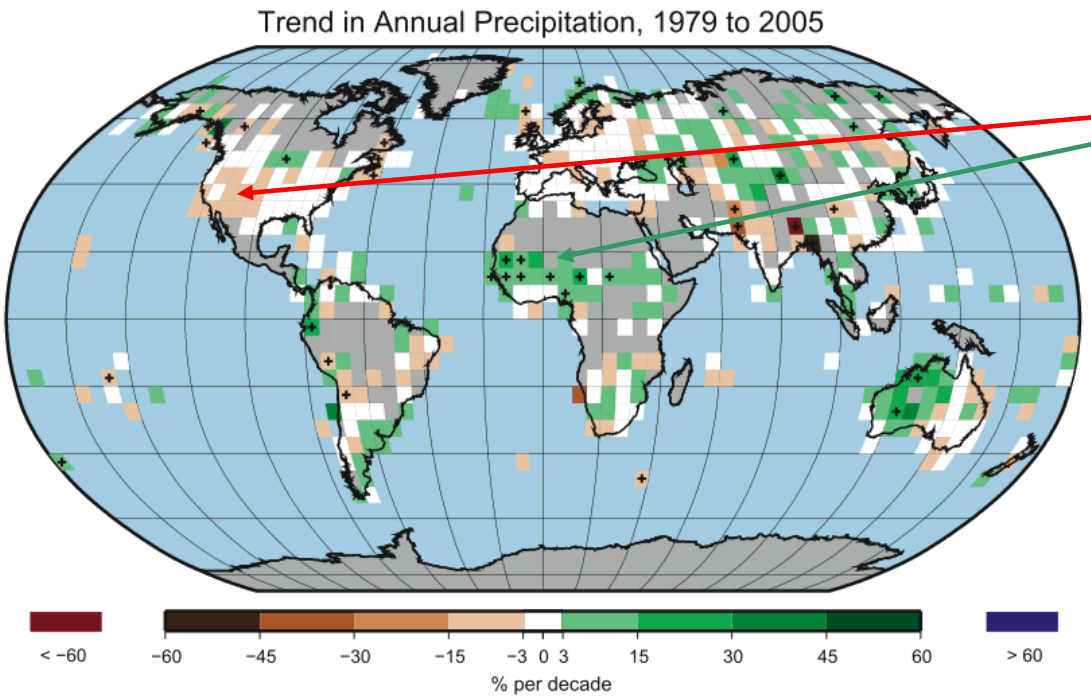
We do NOT fully understand all of the above components of the climate system, leaving room for surprises!

Lemma: Not every weather&climate 'wiggle' is greenhouse-gas-related, nor will it ever be & don't underestimate the "noise" = our (in-)ability to measure correctly!

Observed Trends In Precipitation



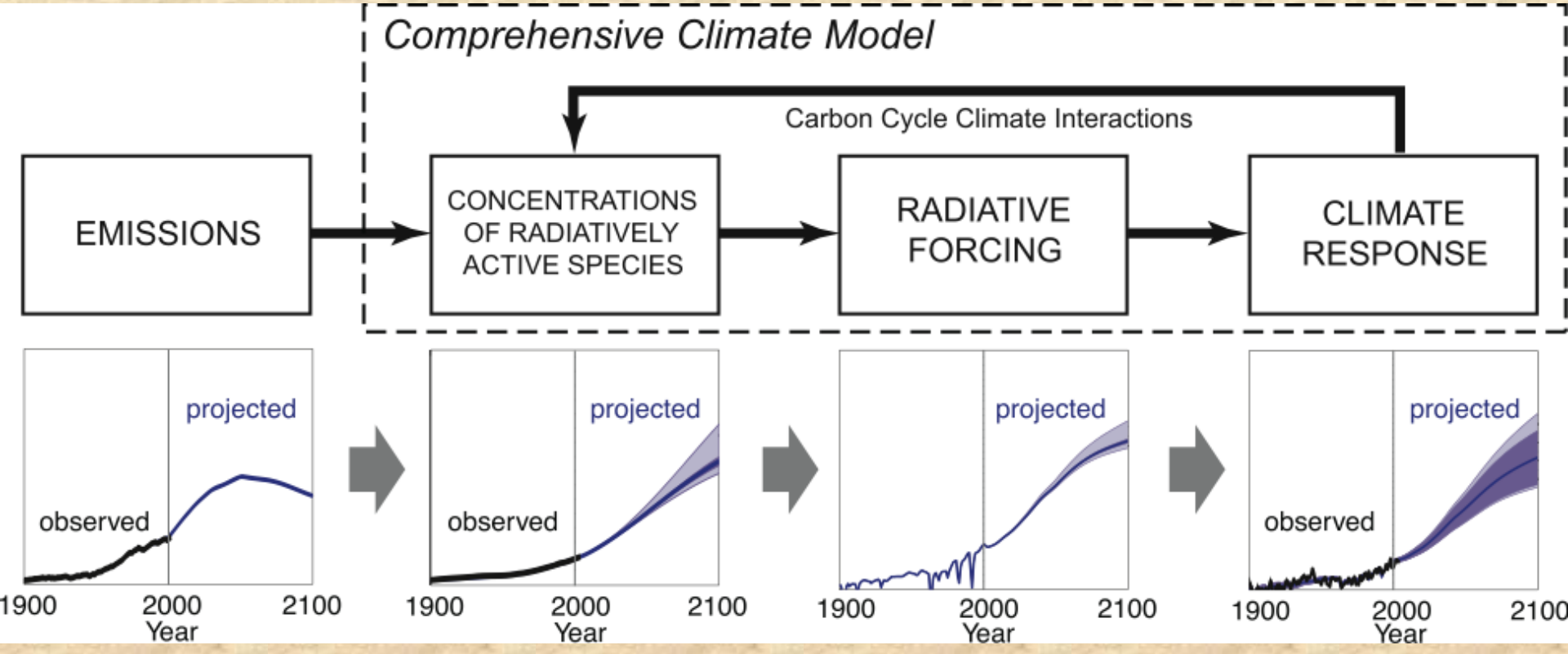
Since 1901



Since 1979

IPCC, 2007: Fig. 3.13
- note contrast between two periods in Western U.S. and Sahel!

IPCC, 2007: Fig. 10.1



Even if emissions drop before 2100 -

Greenhouse gases will keep going up -

Except for Pinatubo-like volcanic eruptions, this means more energy input -

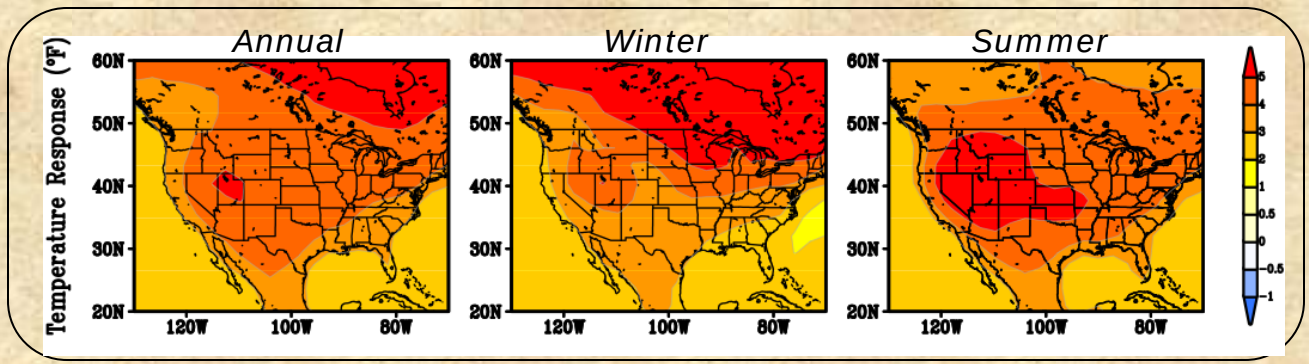
And higher global temperatures

Projected Temperature & Precipitation Changes in 2050

Source: CO Climate Report, 2008

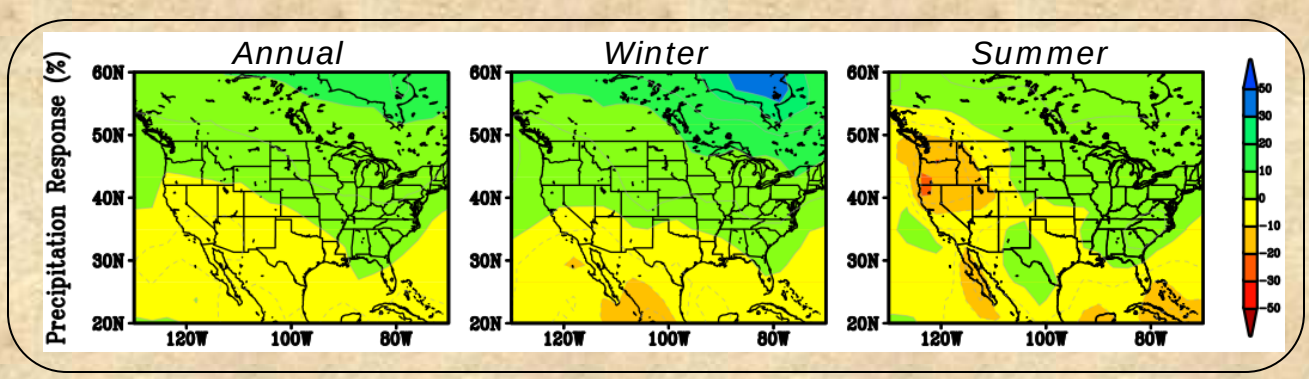
Temperature

Widespread warming



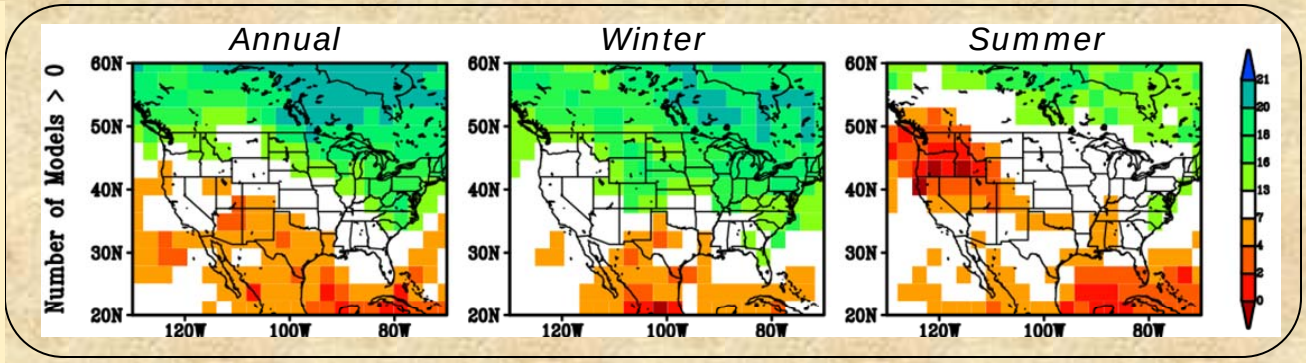
Precipitation

Wet northern tier; dry southwest. Potential seasonal shift in Utah/Colorado region



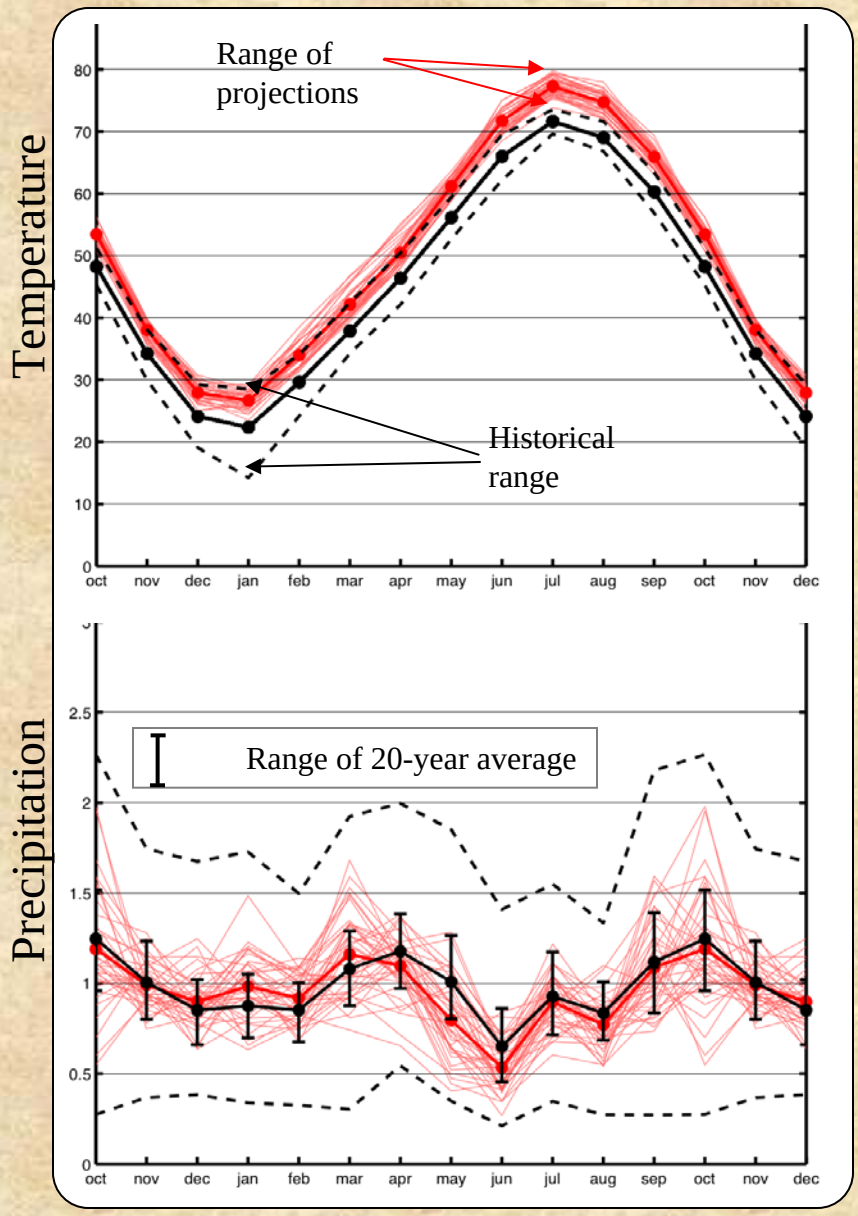
Model Agreement for Precipitation

Colorado/Utah is in a region of weak-to-modest model agreement

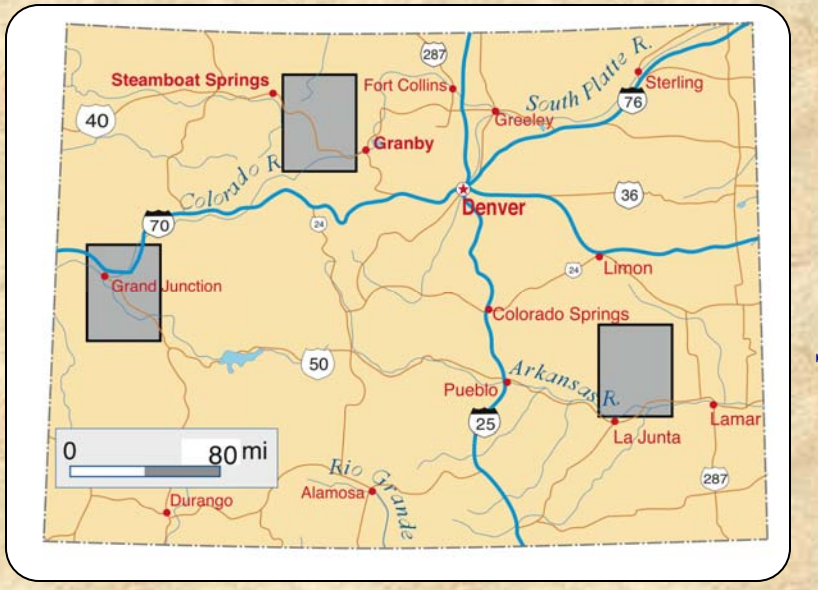


Projections: "2050" from Statistical Downscaling

Grand Junction

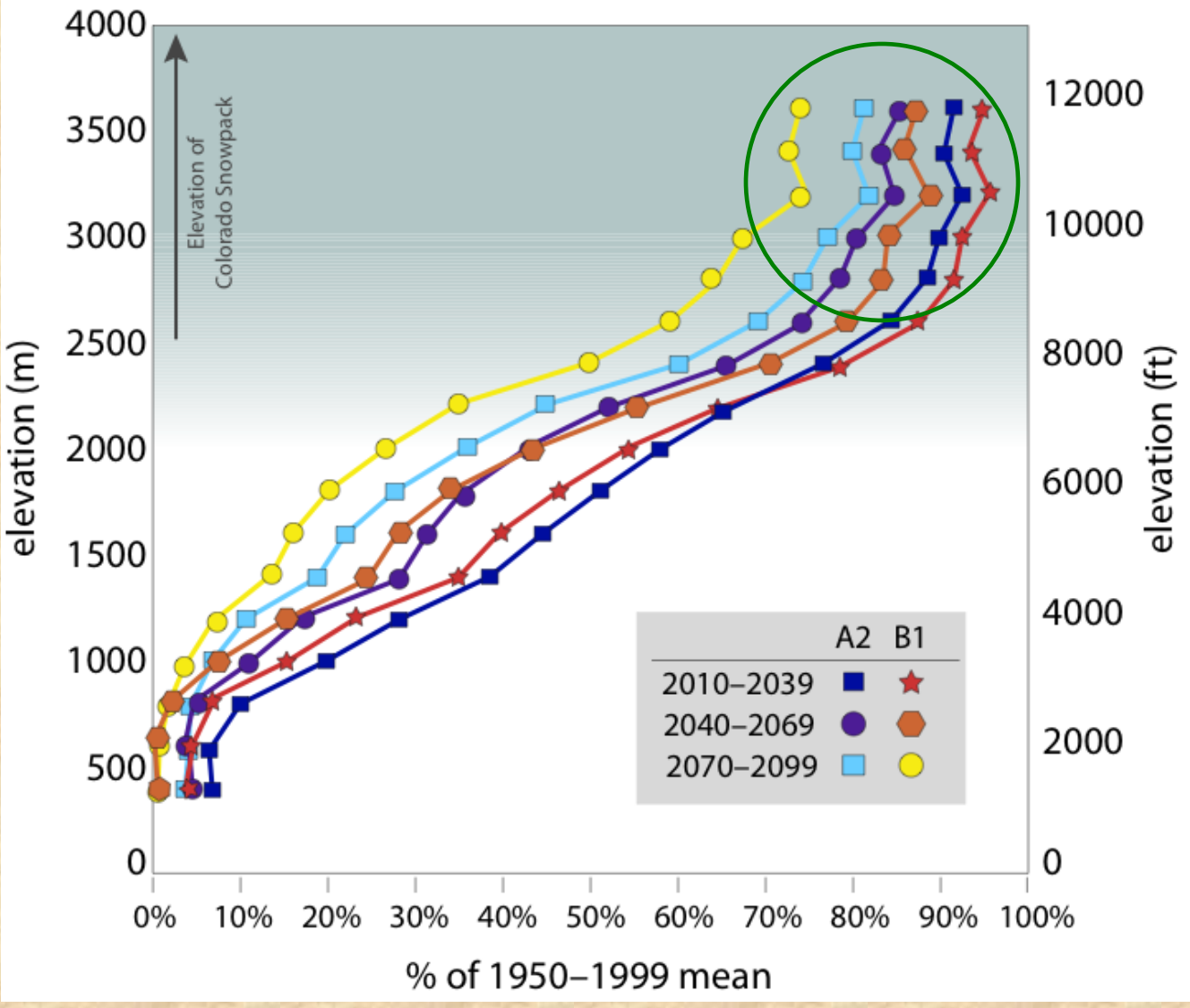


- Summers warm more than winters
- Average summer temperatures similar to the hottest months in the past fifty years.
- Heat waves; fewer cold winters
- Projected precipitation trends small compared to the variability.
- Note: Range includes model differences AND model internal variability.



Source: CO Climate Report, 2008

Projections: Colorado River Basin Snowpack

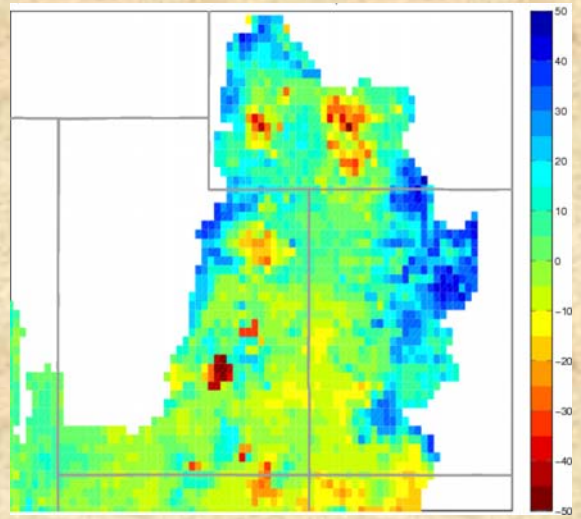


Projected declines in the high mountain snowpack of Colorado and Utah are not as severe as elsewhere in the West at lower elevations.

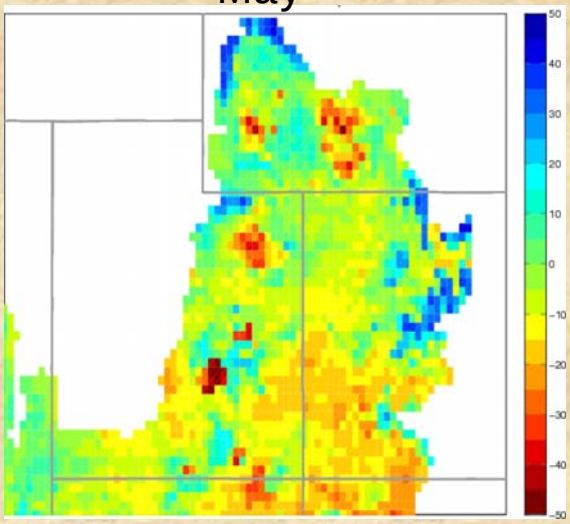
Data: Christensen and Lettenmeier, 2007
Graphics: CO Climate Report, 2008

Projections: Colorado River Basin Soil Moisture "2050"

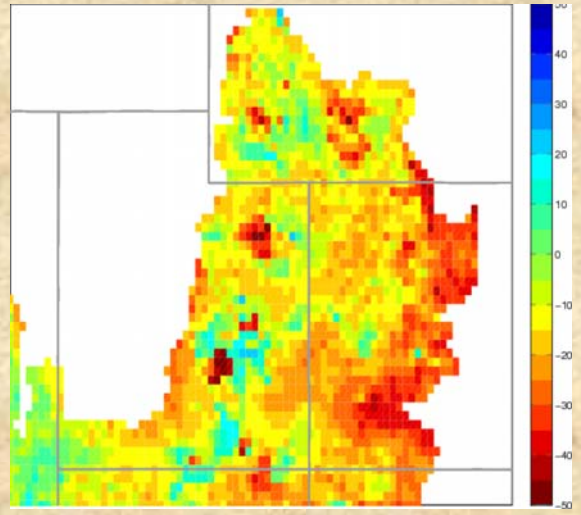
April



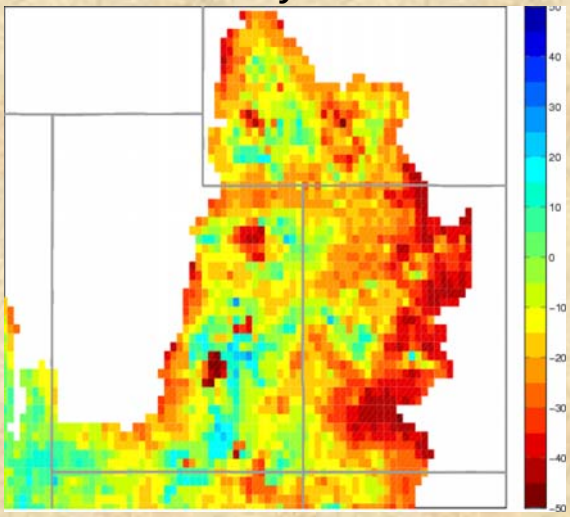
May



June



July



Earlier snowmelt leads to wetter conditions in April, and much drier conditions by summer.

Source: CO Climate Report, 2008
Data: Dennis Lettenmaier, UW

Take-home messages & Key unresolved issues

- **Temperatures have been increasing in Western U.S., and will continue to rise, if not always at the same accelerated pace as recently**
- **Great uncertainty in precipitation projections**
- **In the absence of precipitation changes, temperature increases alone combined with related changes in evaporation and soil moisture lead to a decline in runoff for most of Western U.S. river basins by the mid-21st century in all recent hydrologic projections**

An imcomplete laundry list of unresolved topics:

- ***Need to separate recent impact of drought on snowmelt vs. higher temperatures (how much of that is GHG-related?!)***
- ***Importance of (multi-)decadal 'natural' climate drivers***
- ***Possible changes in monsoon system due to earlier snowmelt versus possibly higher incidence of forest fires***
- ***Causes of drought: role of global oceans versus local forcing (soil moisture)***