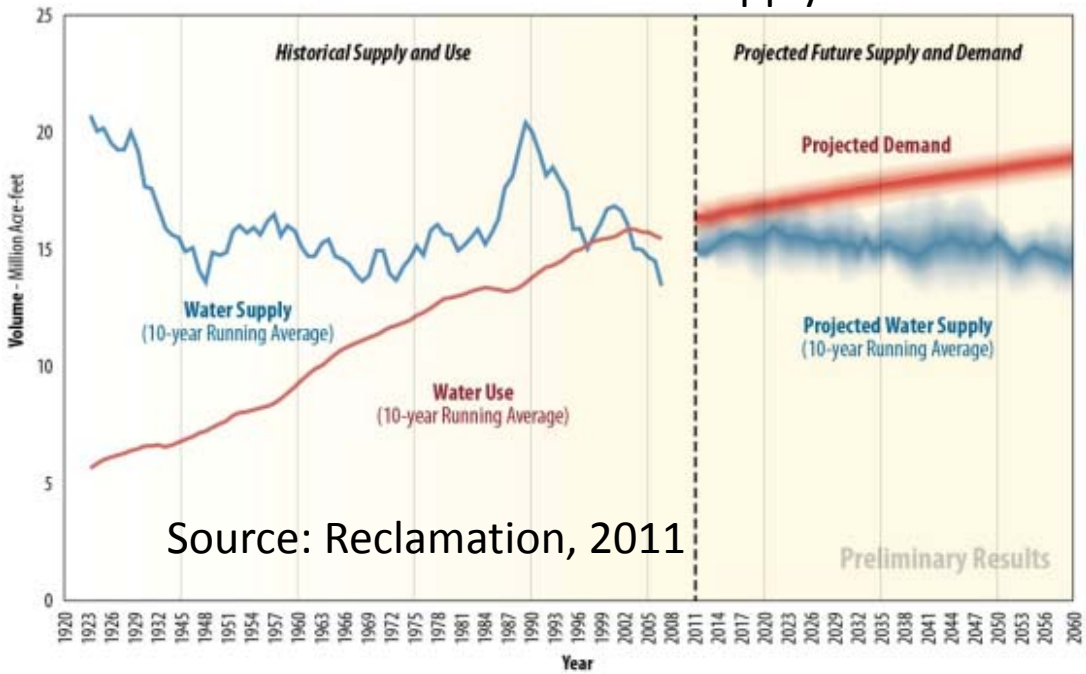
NPS Scenario Planning Workshop – Climate Background

Historic and Future Colorado River Supply and Demand



Source: Reclamation, 2011

Brad Udall - bradley.udall@colorado.edu

Western Water Assessment

CIRES, University of Colorado

Western Water Assessment

Climate Change in Colorado

A Synthesis to Support Water Resources Management and Adaptation

A REPORT FOR THE COLORADO WATER CONSERVATION BOARD

Colorado
University of Colorado at Boulder

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globalchange.gov/usimpacts

This report summarizes the science and impacts of climate change in the U.S.

Plain language, authoritative

US Global Change Research Program report, led by NOAA

Extensive review: public reviews (2), blue ribbon expert review, federal agency (GCRP) review

Draws from all previous assessments, global and national (IPCC, CCSP etc)

Author team was 31-members and included federal, academic and private sector experts

United States Global Change Research Program

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, N.J. 08540

(Manuscript received 6 June 1974, in revised form 8 August 1974)

ABSTRACT

An attempt is made to estimate the temperature changes resulting from doubling the present CO_2 concentration by the use of a simplified three-dimensional general circulation model. This model contains the following simplifications: a limited computational domain, an idealized topography, no heat transport by ocean currents, and fixed cloudiness. Despite these limitations, the results from this computation yield some indication of how the increase of CO_2 concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO_2 increase raises the temperature of the model troposphere, whereas it lowers that of the model stratosphere. The tropospheric warming is somewhat larger than that expected from a radiative-convective equilibrium model. In particular, the increase of surface temperature in higher latitudes is magnified due to the recession of the snow boundary and the thermal stability of the lower troposphere which limits convective heating to the lowest layer. It is also shown that the doubling of carbon dioxide significantly increases the intensity of the hydrologic cycle of the model.

Western Water Assessment

The water cycle will change in fundamental ways

- The water cycle is a primary mechanism by which the Earth moves heat from areas with too much to areas with too little.

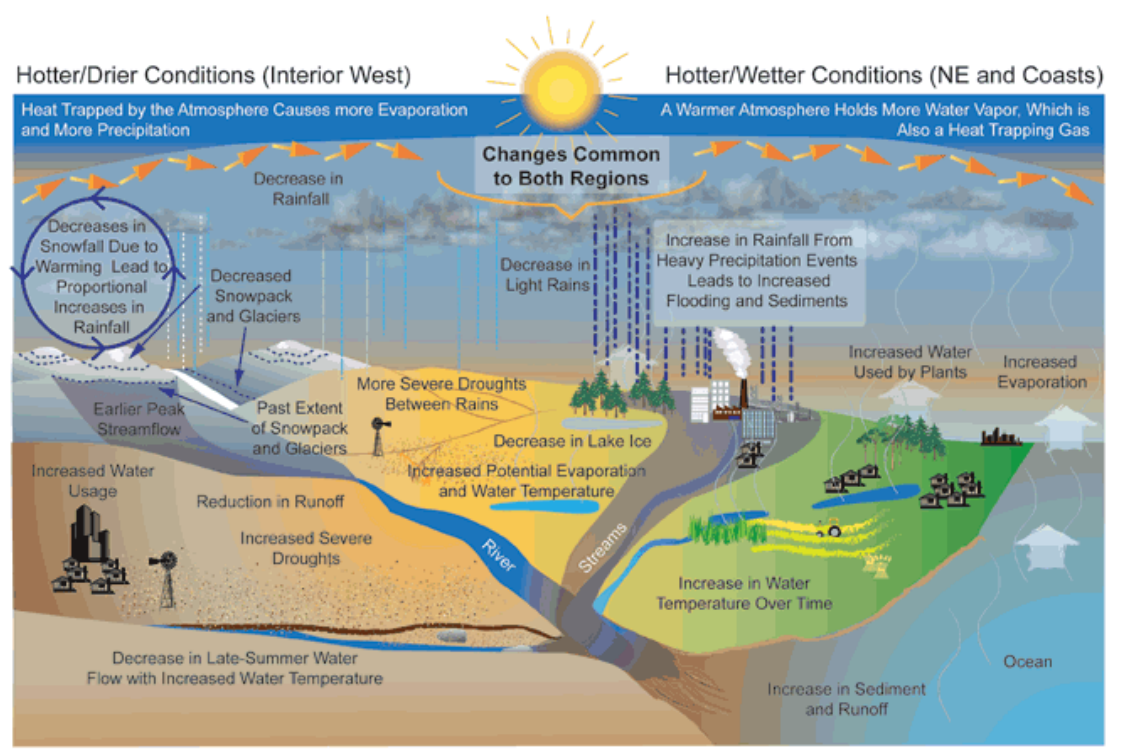
- A warmer climate means more water vapor in the atmosphere - every 1F increase means 4% increase in moisture holding.

- A warmer climate also means more evaporation, more precipitation GLOBALLY but regional losers.

- Storm tracks expected to move northward.

- Wet gets Wetter, Dry gets Drier.

- Admiral Titley Elevator Speech

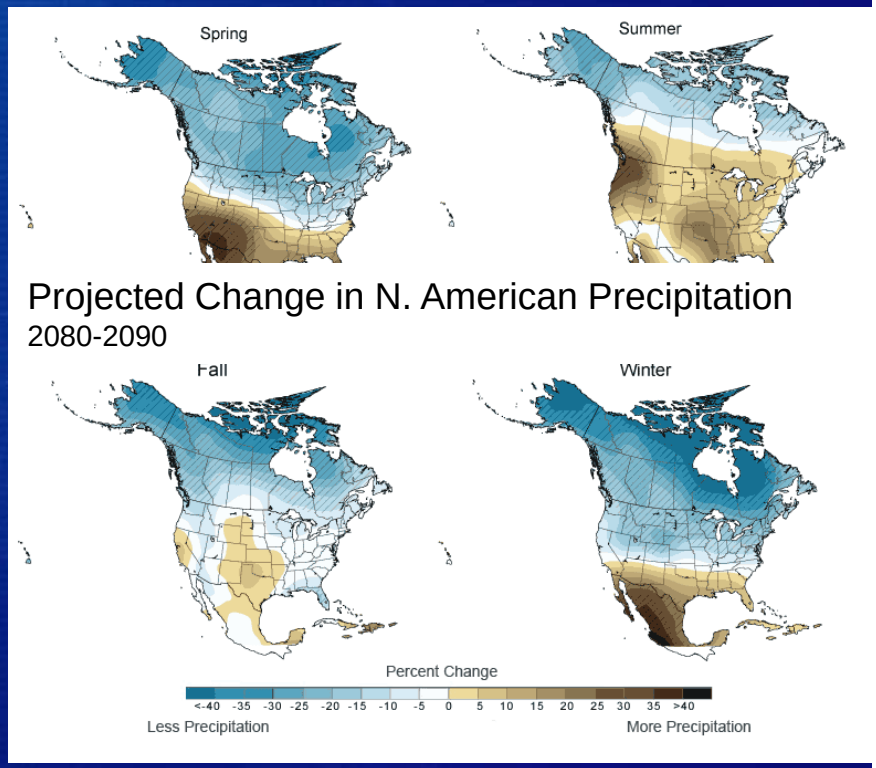


The Water Cycle is already changing

Observed Water-Related Changes During the Last Century[142]		
Observed Change	**Direction of Change**	**Region Affected**
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska

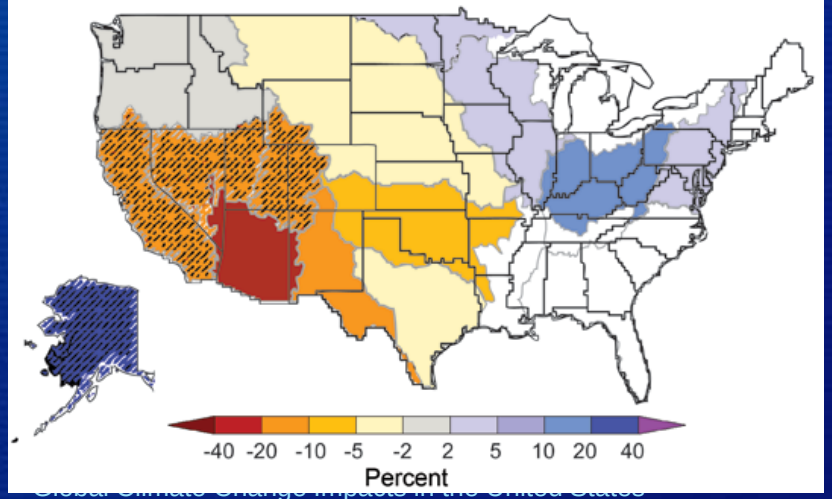
Precipitation and Runoff are projected to change regionally

- Precipitation and Runoff likely to
  - increase in Northeast and Midwest in winter and Spring
  - decrease in West, especially Southwest in spring and summer
- Wet Wetter, Dry Drier
- Summer soil-moisture reductions consistent finding



Projected Change in N. American Precipitation
2080-2090

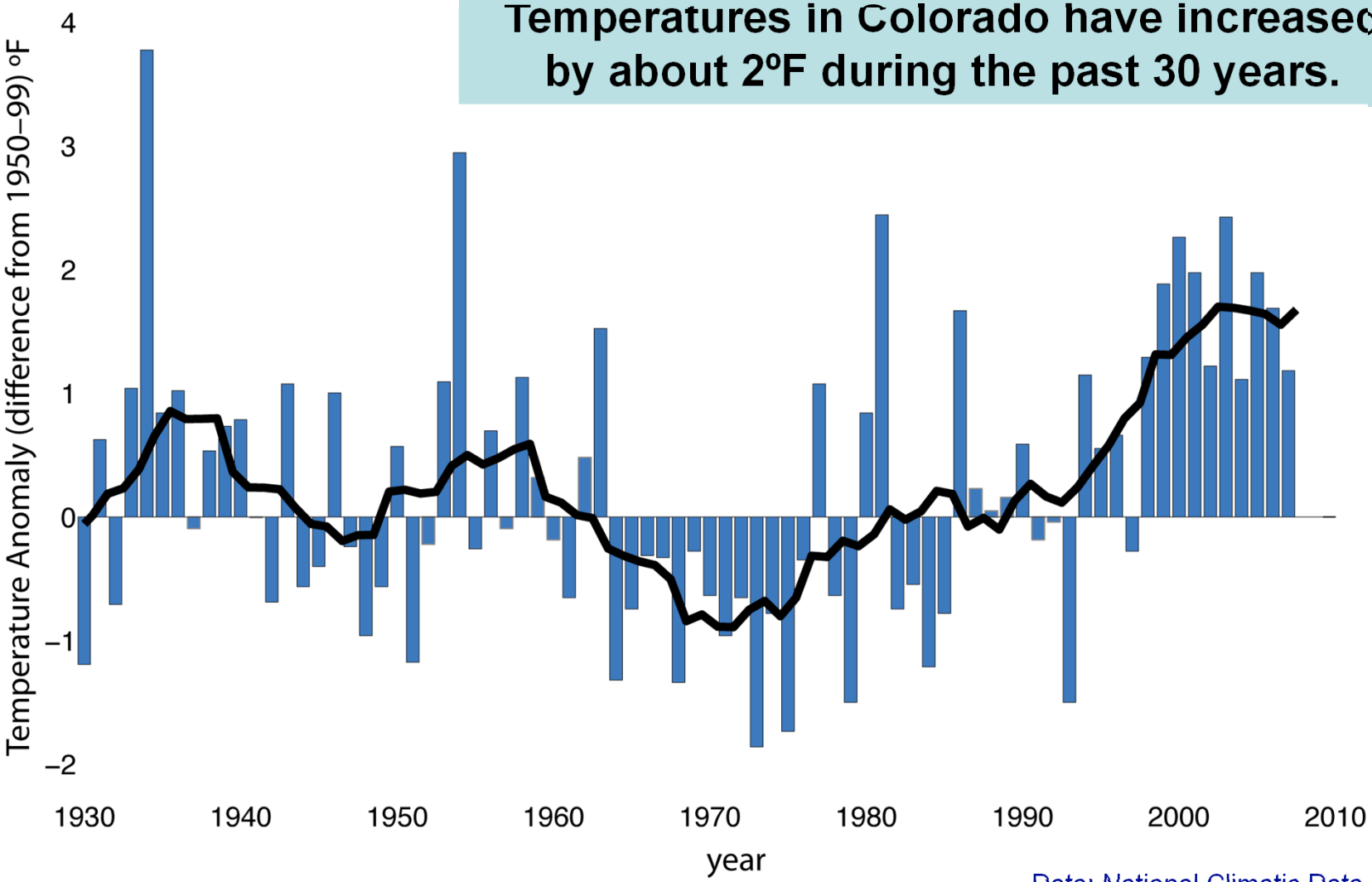
Projected Changes in Annual Runoff
2041-2060



United States Global Change Research Program

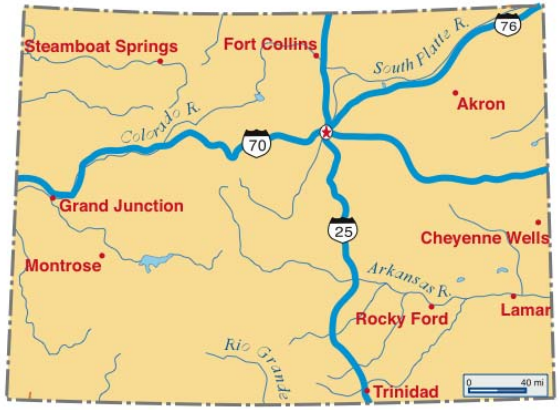
Observations: Statewide Temperature Trend

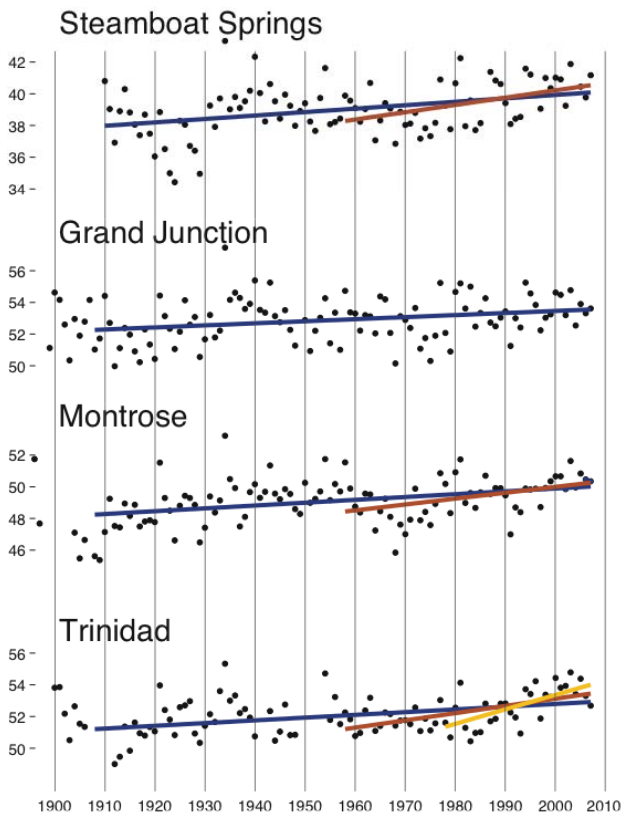
Temperatures in Colorado have increased by about 2ºF during the past 30 years.

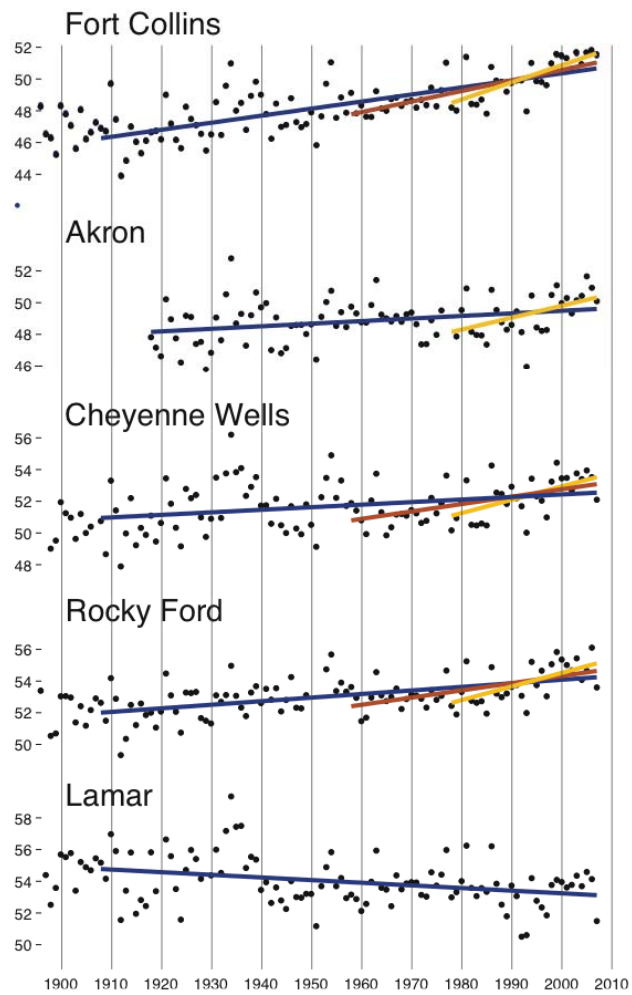


Data: National Climatic Data Center
Graphics: CO Climate Report, 2008

Observations: Temperature







Of 27 temperature trends:

- 19 are increasing
- 1 is decreasing
- 7 were not significant

A trend at a single station is not definitive because of local effects. Look at the big picture!

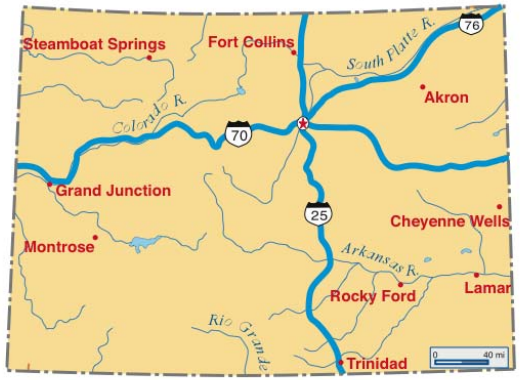
30 year trend

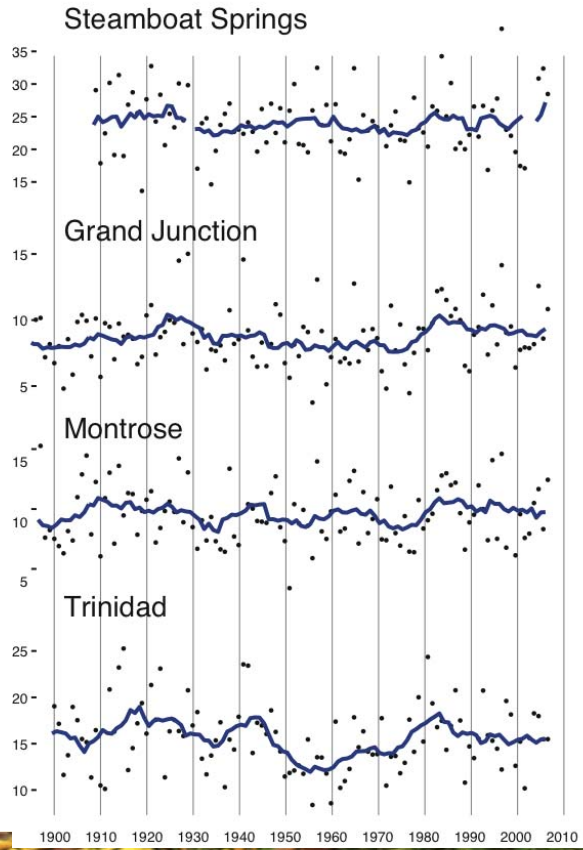
50 year trend

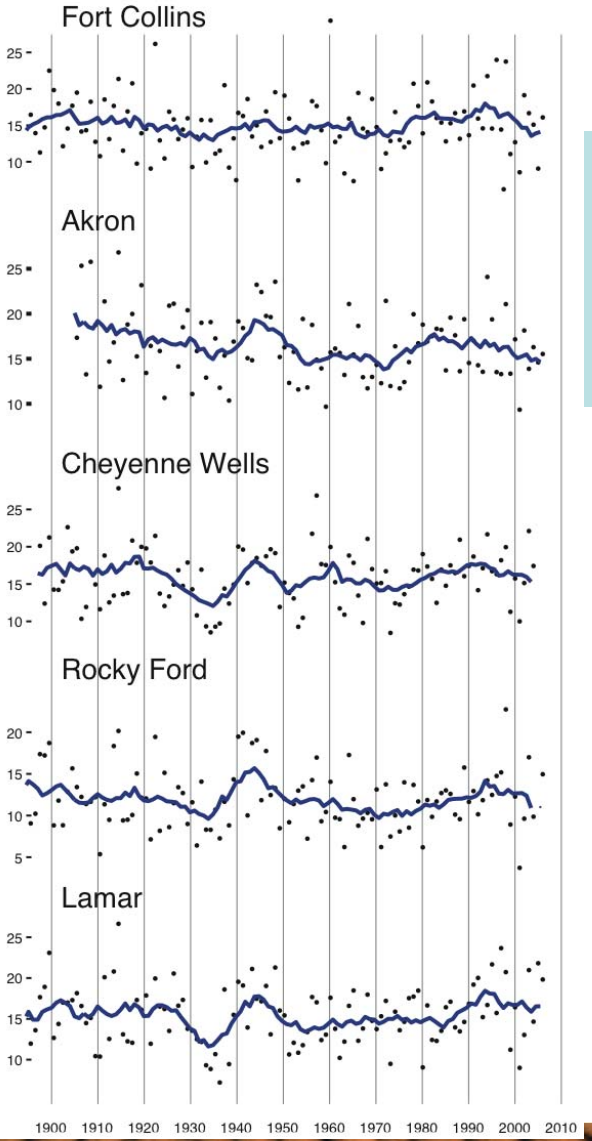
100 year trend

Source: CO Climate Report, 2008

Observations: Precipitation







In all parts of Colorado, no consistent long-term trends in annual precipitation is detected.

Source: CO Climate Report, 2008

Projected Temperature & Precipitation Changes in 2050

Source: CO Climate Report, 2008

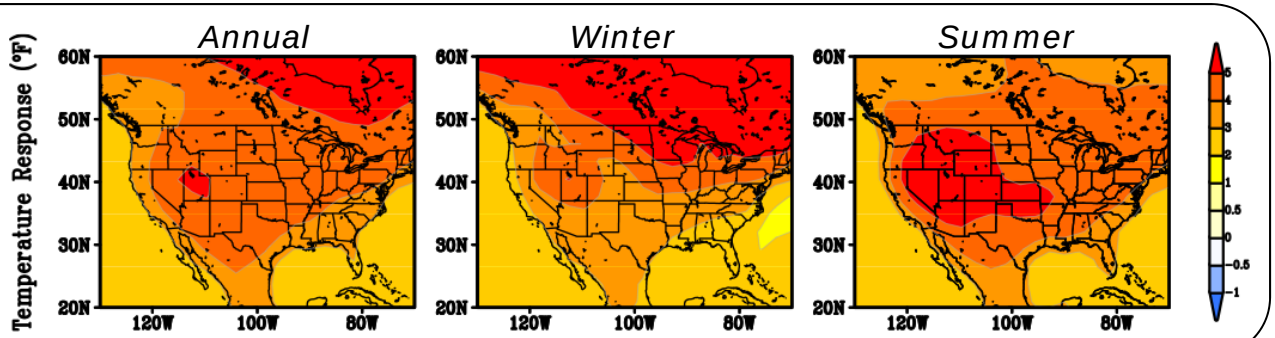
Temperature

Colorado: range

+4°F Annual [2.5-5.5]

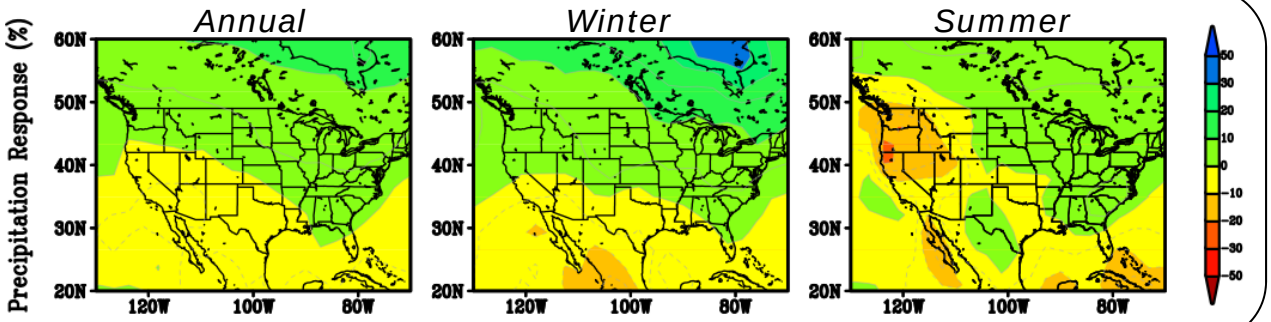
+3°F Winter [2-5]

+5°F Summer [3-7]



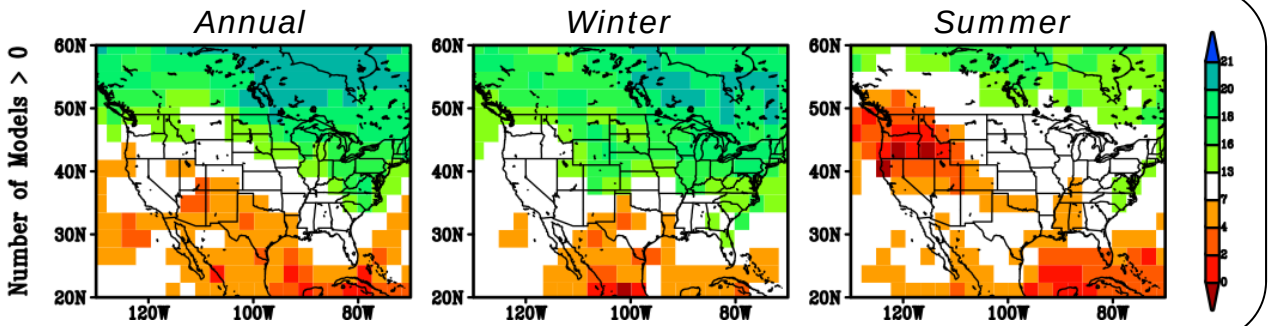
Precipitation

Colorado is in a zone of small precipitation changes

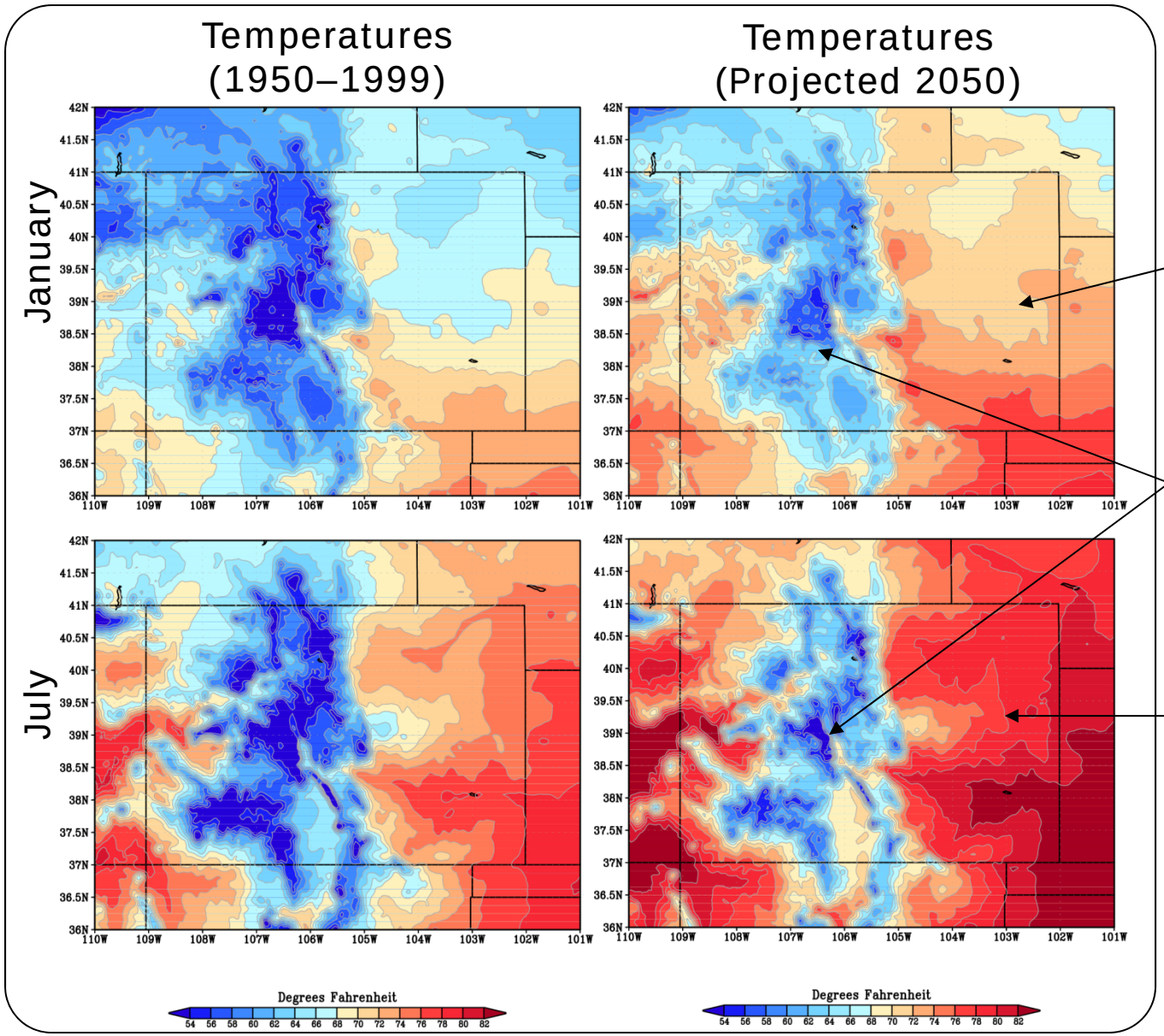


Model Agreement for Precipitation

Colorado is in a region of weak model agreement



Projections: Temperature



What would the projected changes mean for Colorado's varied climate?

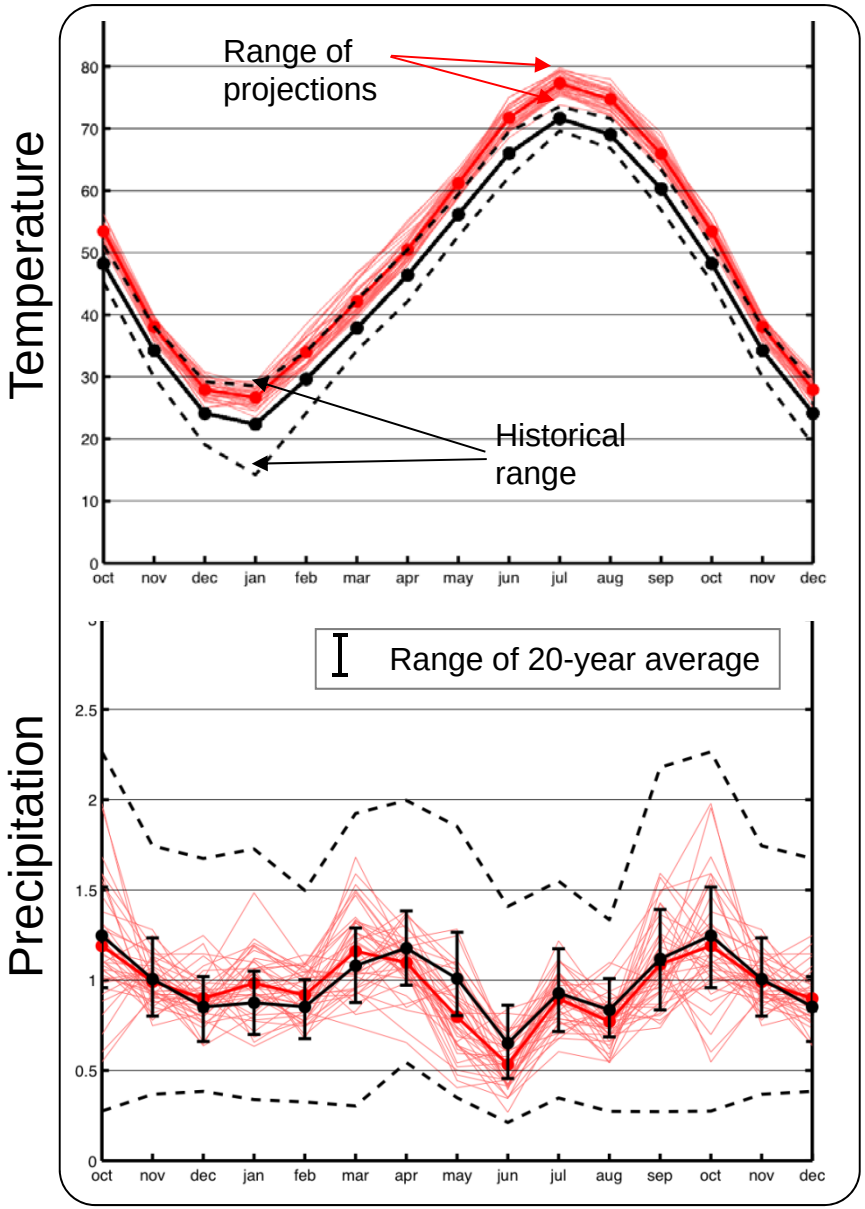
Winter temperatures shift northward on the plains

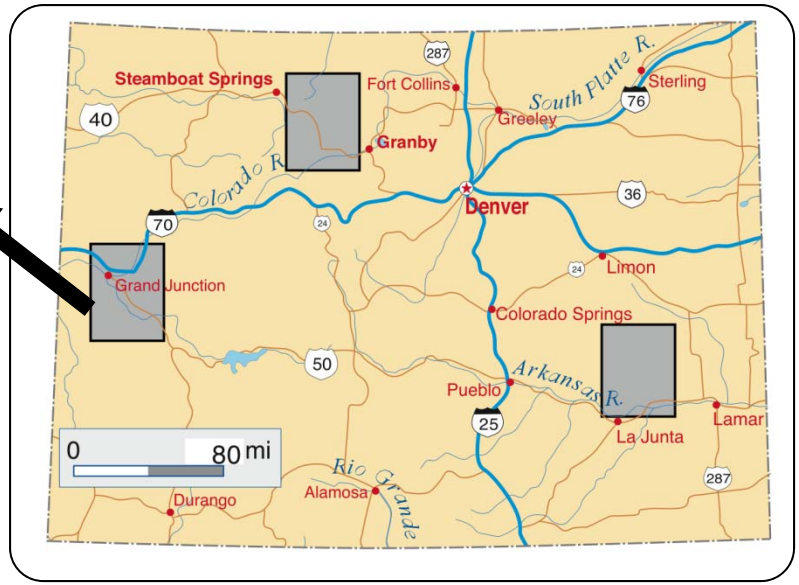
Temperatures creep upwards in the mountains in all seasons

Summer temperatures shift westward on the plains bringing the temperatures of the Kansas border to the Front Range.

Source: CO Climate Report, 2008

Projections: Temperature & Precipitation

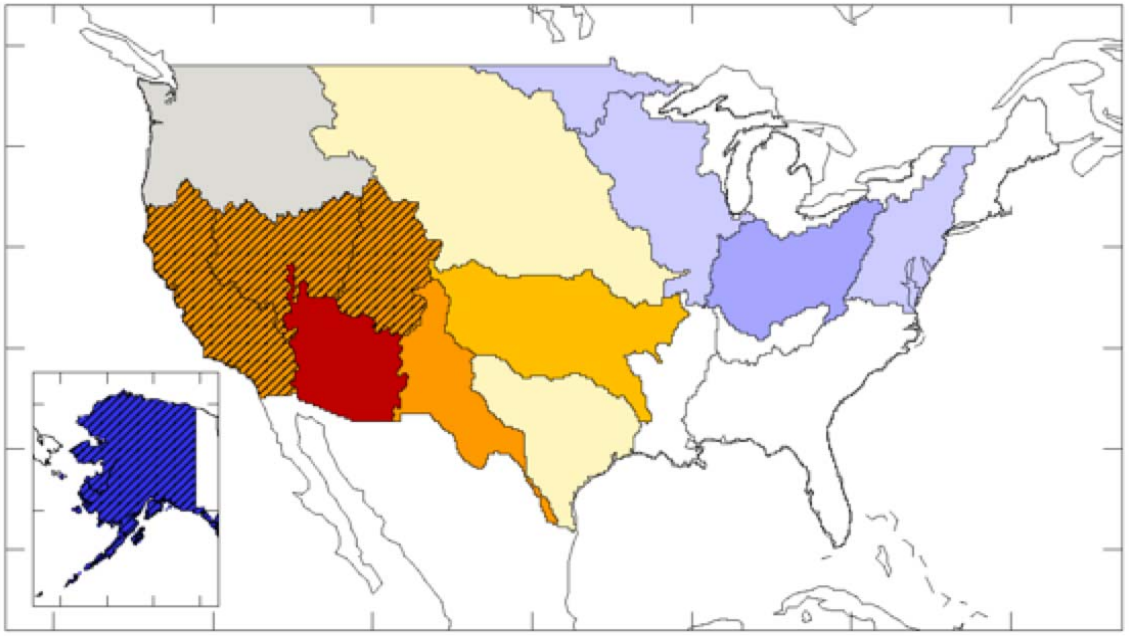




- ***Summers warm more than winters***
- ***Average summer temperatures similar to the hottest months in the past fifty years.***
- ***Heat waves; fewer cold winters***
- ***Projected precipitation trends small compared to the variability.***

Source: CO Climate Report, 2008

Projections: Changes in Annual Runoff



- Trend toward reduced runoff in all Colorado's major river basins
- A warming climate increases the risk to Colorado's water supply even if precipitation remains at historical levels.

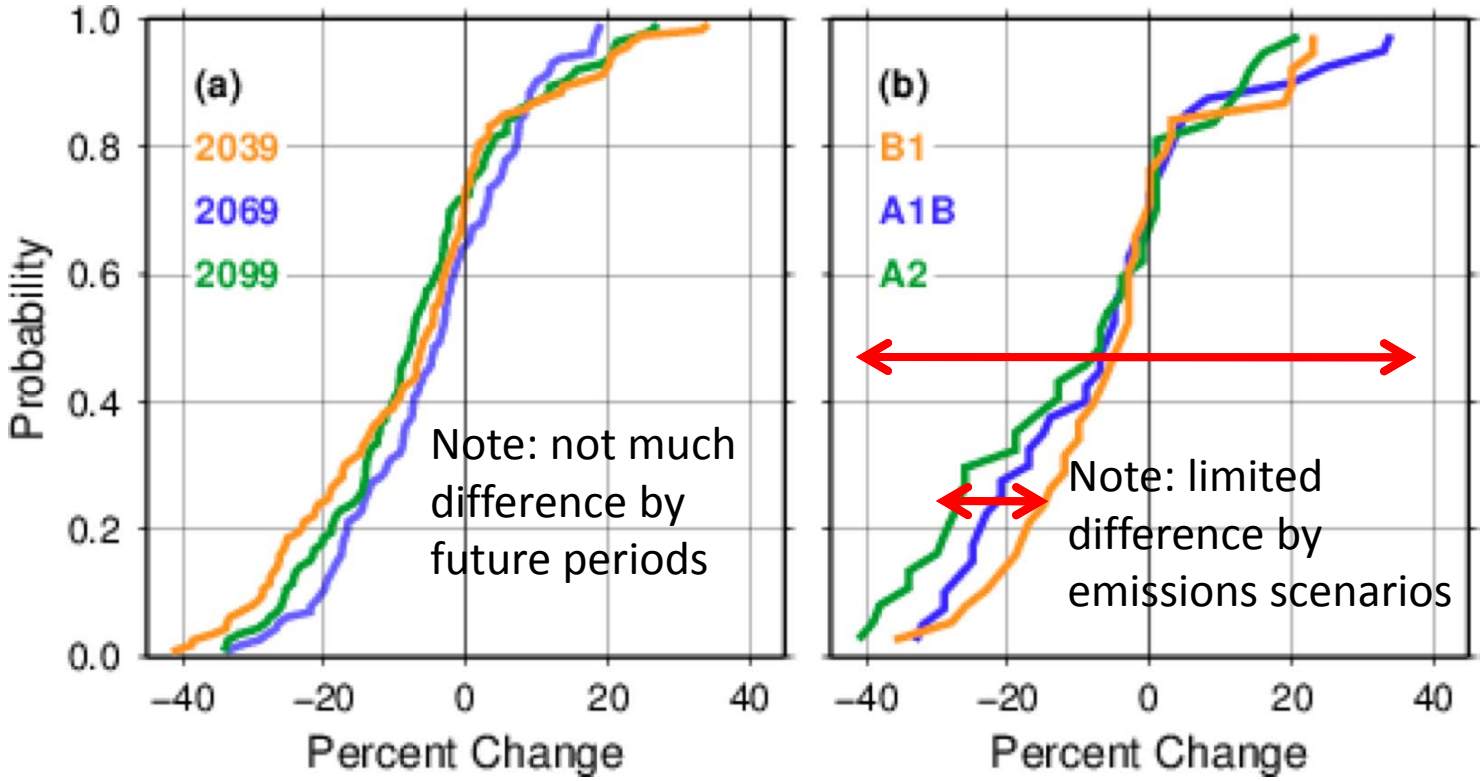
Source: Milly et al. 2005

Alternative Potentially Wet CRB Futures

Rasmussen et al., 2011
Harding et al., 2012

- **Unforced internal model variability and model choice dominate**

empirical CDFs of streamflow change projections



At 3 Future Periods

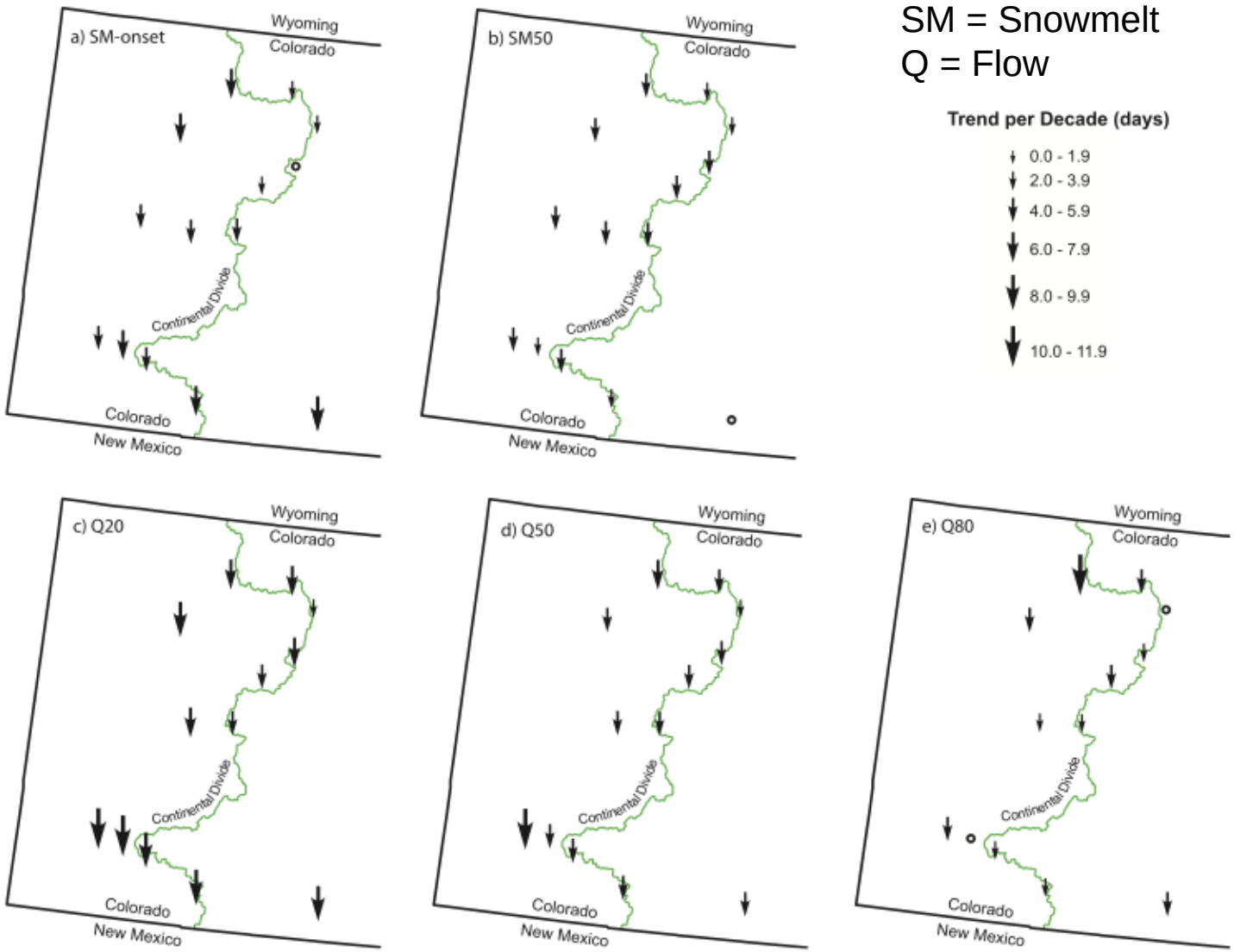
At 2070-2099

Slide from Andy Wood

Western Water Assessment

Changes in Snowmelt and Runoff Timing: Colorado

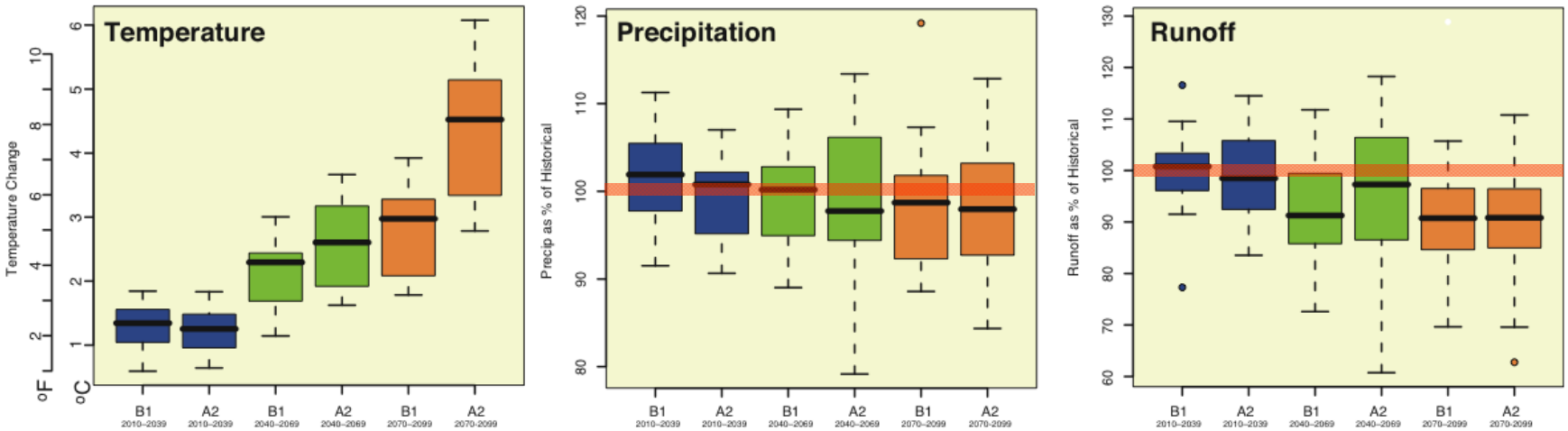
"Strong, Pervasive Trends in snowmelt and streamflow timing"
2-3 week earlier trends over a 29-year period



SM = Snowmelt
Q = Flow

Clow 2010

Projections: Upper Colorado River Basin

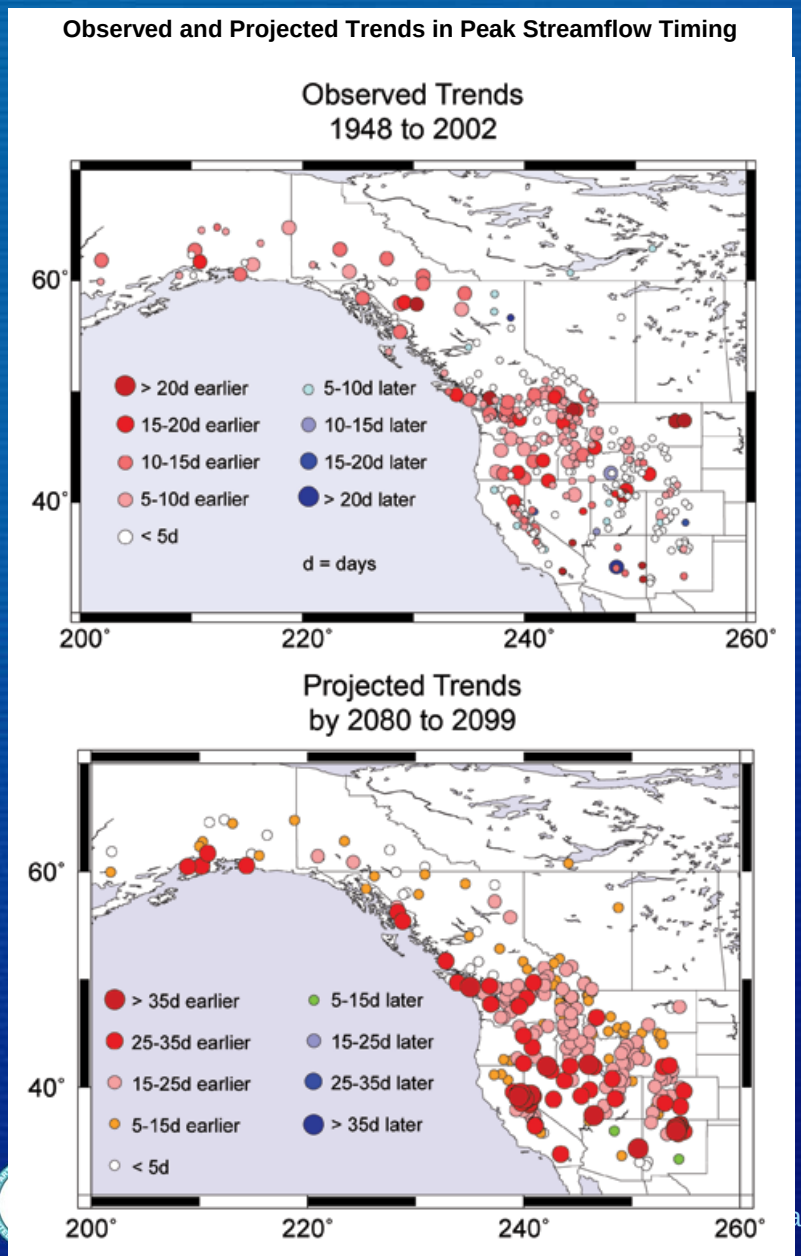


2025 2055 2085 2025 2055 2085 2025 2055 2085

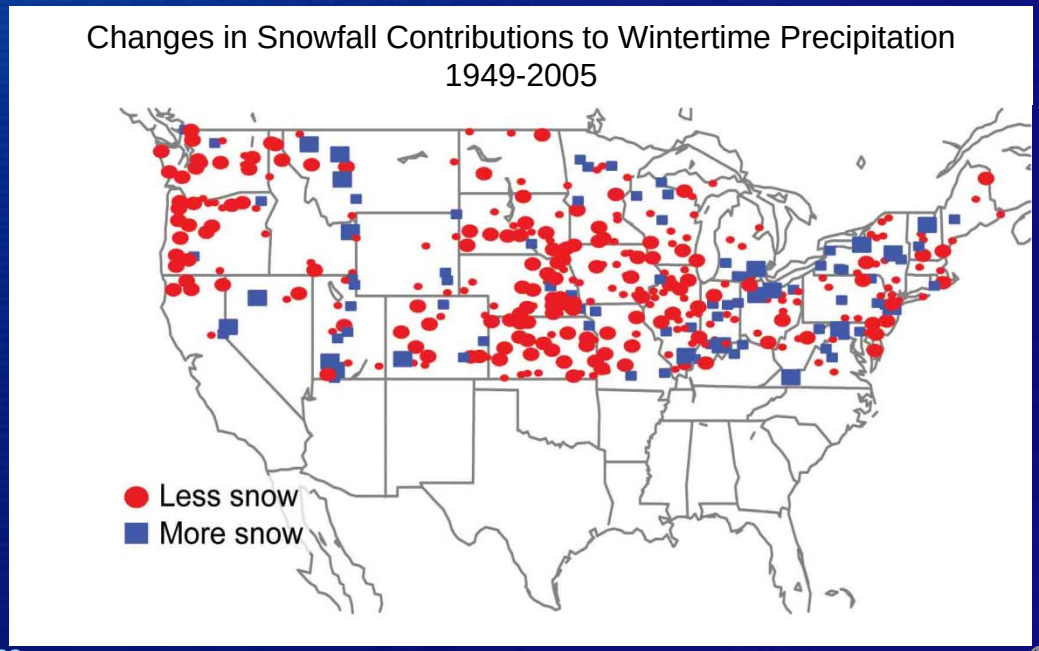
- Range of projections for the Colorado River (multi-model average): -6% to -20%
- Range of projections for a single 20-year period within a single study can be large due to different climate model drivers and natural variability.
- A warming climate increases the risk to Colorado's water supply even if precipitation remains at historical levels.

Data: Christensen and Lettenmeier, 2007
Graphics: Climate Change in CO, 2008

Snow-dominated areas will experience changes



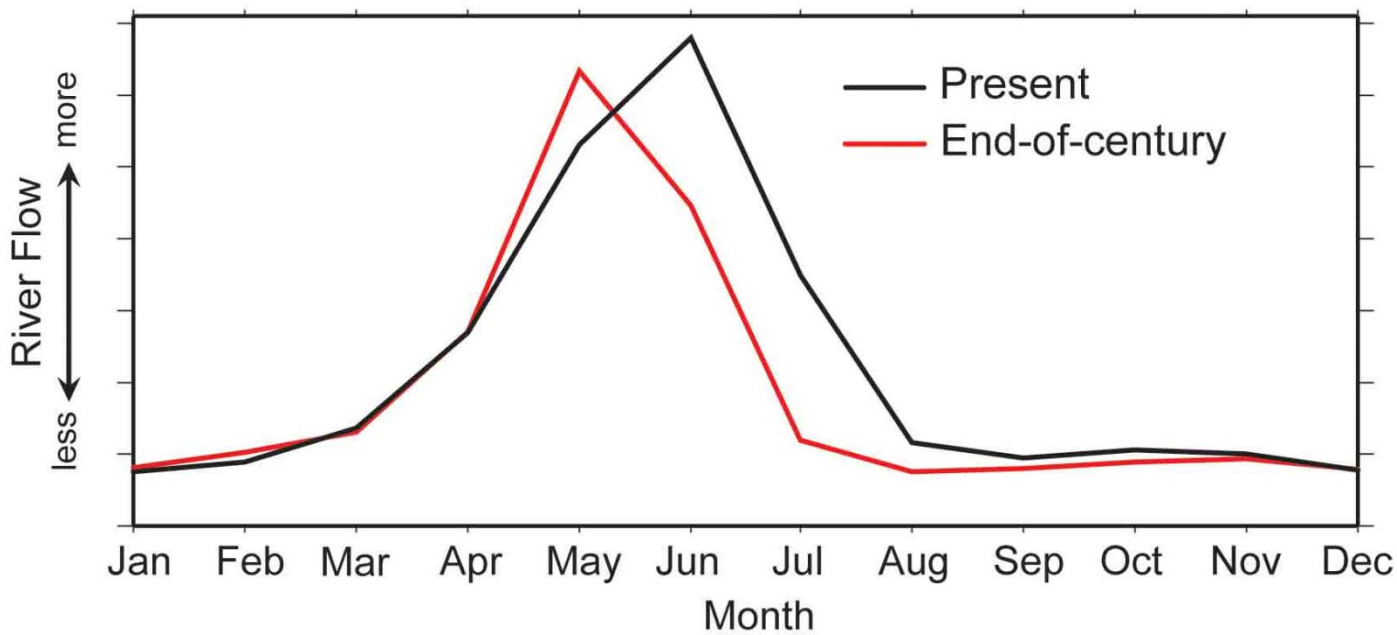
- Snow is a natural reservoir
- Snowpack reductions in West and Northeast already occurring at low elevations
- More rain and less snow in winter
- Advances in Runoff Timing in West (20 days) and NE (14 days) already
- Runoff timing projections are for up to 60-day advance in West, 14-day in East



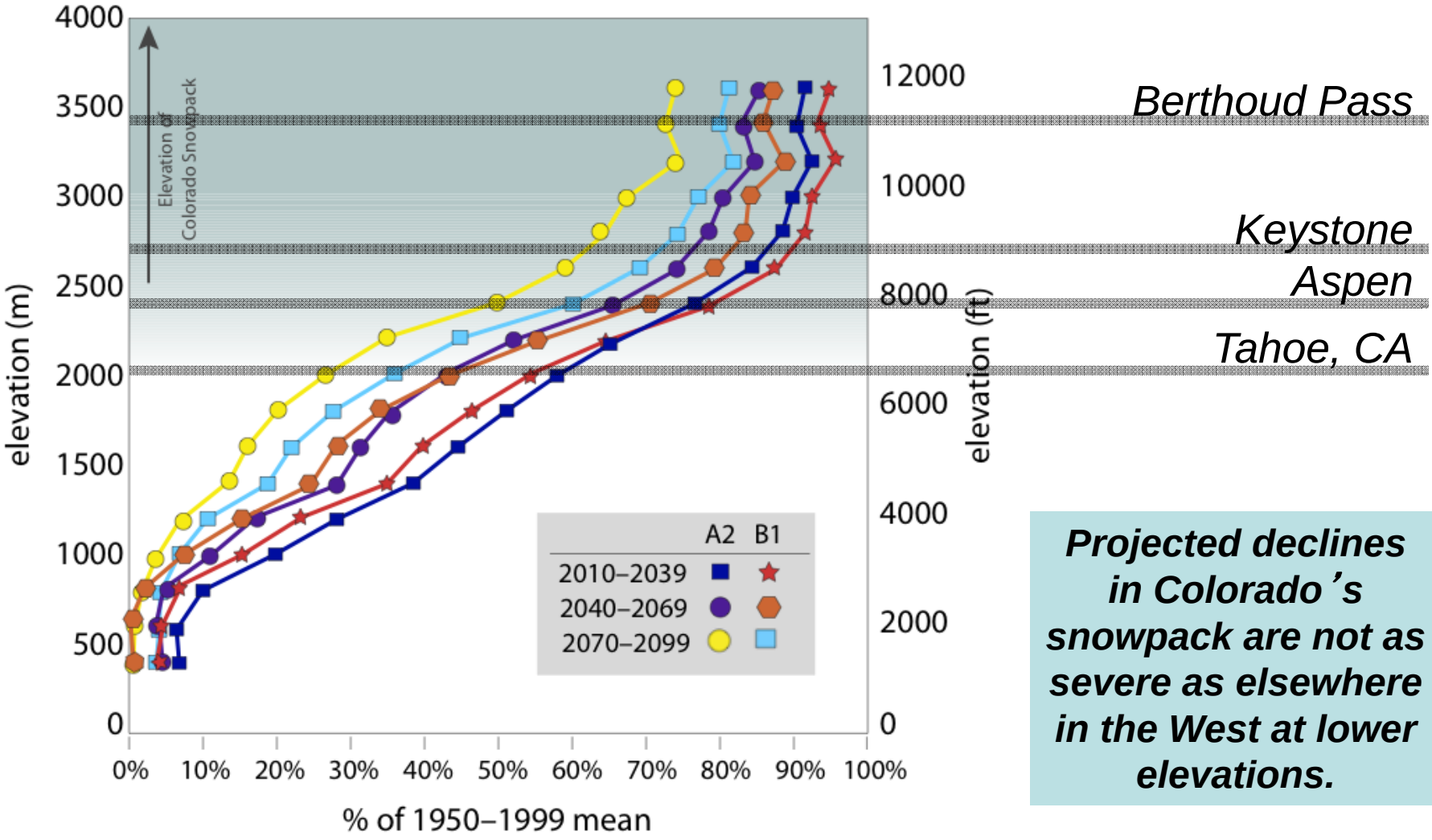
Snow-dominated areas will experience changes

- Annual Runoff Pattern will change
  - Runoff will occur earlier (previous slide)
  - Lower and Warmer Flows in late summer
  - Some regions will see annual declines in flow (previous slide)

Green River, A Tributary of the Colorado River



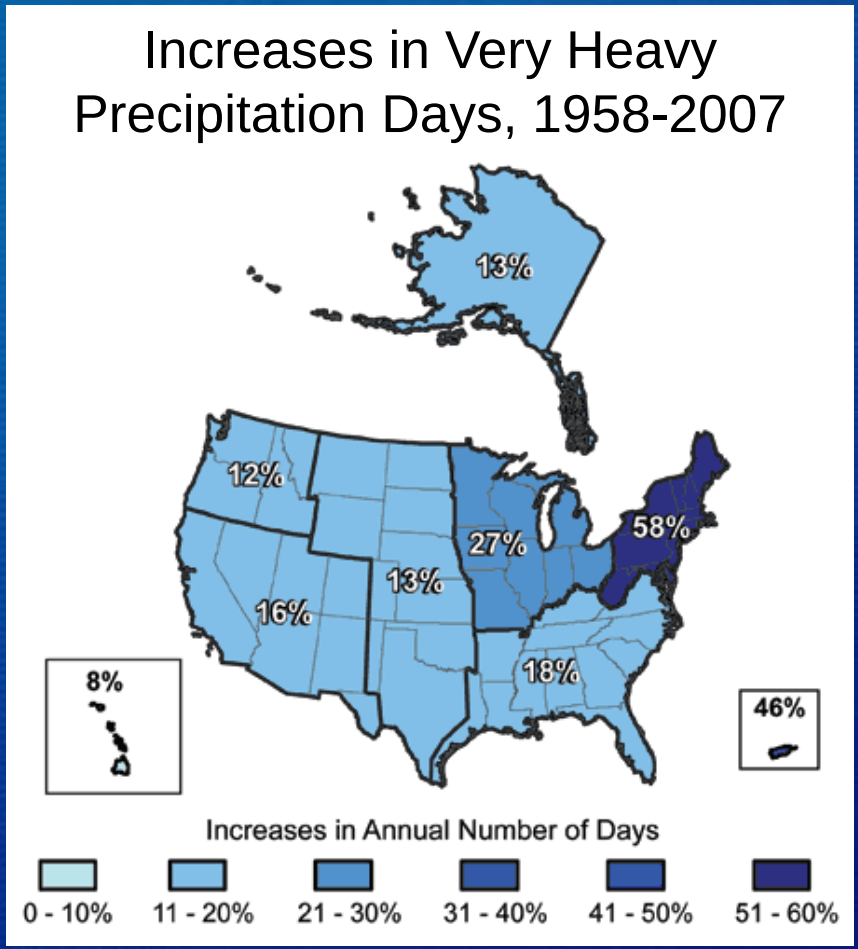
Projections: Colorado River Basin Snowpack

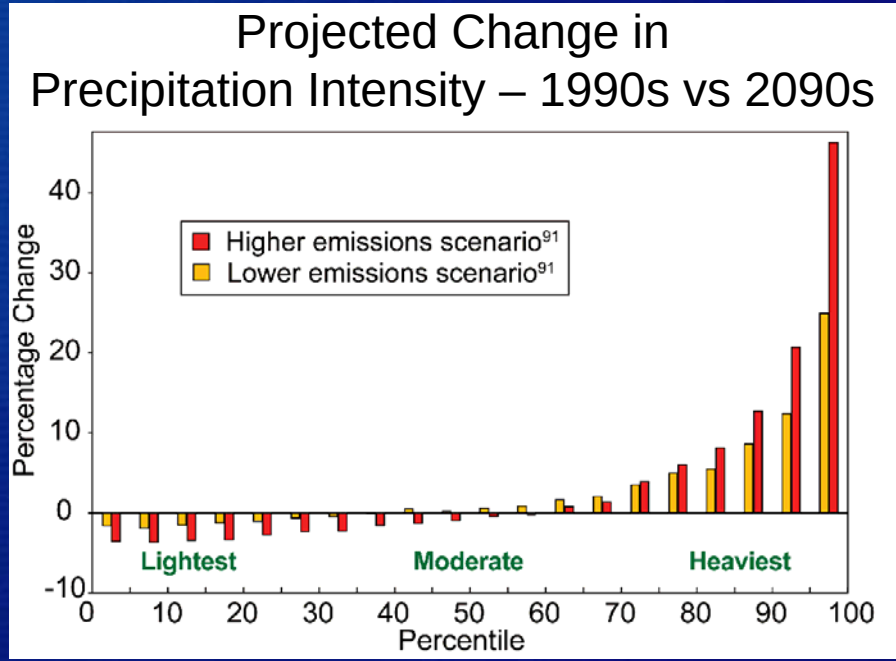


Projected declines in Colorado's snowpack are not as severe as elsewhere in the West at lower elevations.

Data: Christensen and Lettenmeier, 2007
Graphics: Climate Change in CO, 2008

Floods and Droughts will become more common



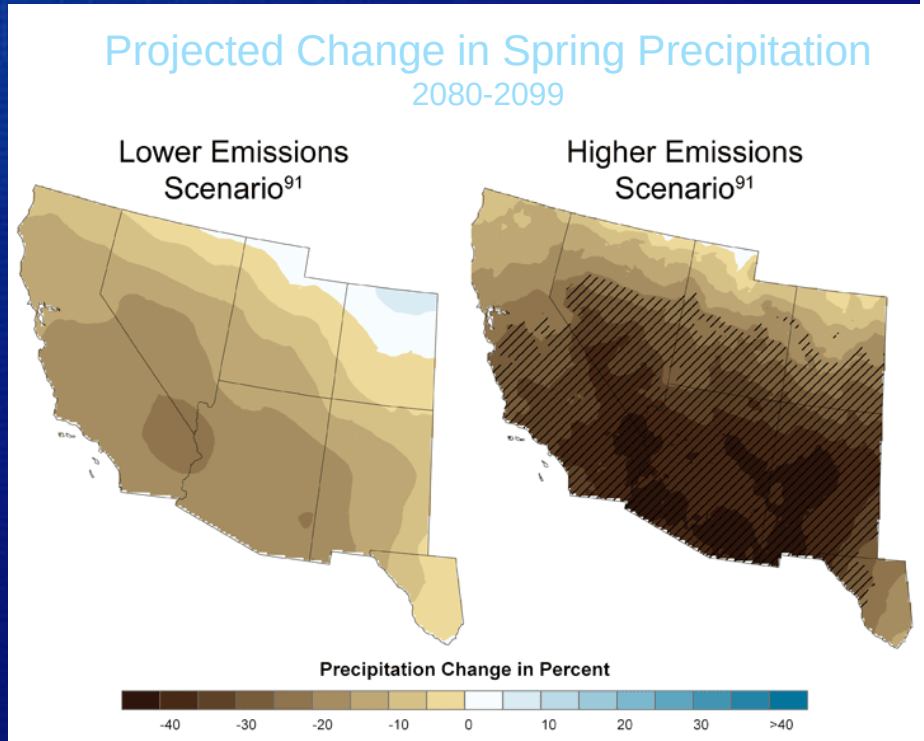


Floods and Droughts will become more common

- No clear national drought trend, but increasing temperatures have made droughts more severe.

- Projections show longer dry periods between precipitation, especially in arid areas, mid continent and Southwest.

- Northward shift in winter and spring storm tracks will reduce precipitation in some regions.

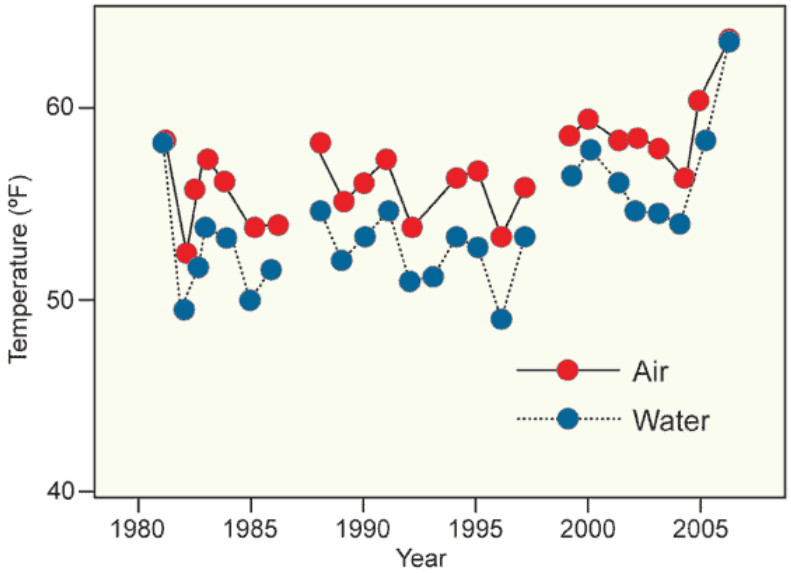


Water quality and groundwater will change

Water Quality Changes

- Higher air temps = higher water temps
- Higher water temps = less dissolved oxygen = higher metabolic rates
- Longer periods of summer lake stratification with no mixing of top and bottom waters
- Pollution generally made worse by higher temps and lower flows
- Heavy Downpours = sediments and pathogens

Lake Superior Air and Water Temperatures, 1979-2006



Western Water Assessment

Challenging Times for Water Managers!

Specific vulnerabilities and impacts were not included in the CO Report

Issues	Observed and/or Projected Change
Water demands for agriculture and outdoor waterin g	Increasing temperatures raise evapotranspiration by plants, lower soil moisture, alter growing seasons, and thus increase water demand .
Water supply infrastructure	Changes in snowpack, streamflow timing, and hydrograph evolution may affect reservoir operations including flood control and storage. Changes in the timing and magnitude of runoff may affect functioning of diversion, storage, and conveyance structures .
Legal water system s	Earlier runoff may complicate prior appropriation systems and interstate water compacts, affecting which rights holders receive water and operations plans for reservoirs .
Water quality	Although other factors have a large impact, “water quality is sensitive both to increased water temperatures and changes in patterns of precipitation” (CCSP SAP 4.3, p. 149). For example, changes in the timing and hydrograph may affect sediment load and pollution, impacting human health .
Energy demand and operating cos t s	Warmer air temperatures may place higher demands on hydropower reservoirs for peaking power. Warmer lake and stream temperatures may affect water use by cooling power plants and in other industries .
Mountain habitat s	Increasing temperature and soil moisture changes may shift mountain habitats toward higher elevation.
Interplay among forests, hydrology, wildfires, and pests	Changes in air, water, and soil temperatures may affect the relationships between forests, surface and ground water, wildfire, and insect pests. Water-stressed trees, for example, may be more vulnerable to pest s.
Riparian habitats and fisheries	Stream temperatures are expected to increase as the climate warms, which could have direct and indirect effects on aquatic ecosystems (CCSP SAP 4.3), including the spread of in-stream non-native species and diseases to higher elevations, and the potential for non-native plant species to invade riparian areas. Changes in streamflow intensity and timing may also affect riparian ecosystems.
Water- and snow-based recreation	Changes in reservoir storage affect lake and river recreation activities; changes in streamflow intensity and timing will continue to affect rafting directly and trout fishing indirectly. Changes in the character and timing of snowpack and the ratio of snowfall to rainfall will continue to influence winter recreational activities and tourism.
Groundwater resources	Changes in long-term precipitation and soil moisture can affect groundwater recharge rates; coupled with demand issues, this may mean greater pressures on groundwater resources.

Closing Thoughts About Communication of Science

Does annual focus, long term means hide important changes?

- is a +3C world with 0% runoff change the same as now?
- What happens to water demand?

We must show Full Range of Futures and Associated Risks

- Our credibility is on the line
- But not all futures have the same risk

Do we imply greater knowledge and certainty than really exists with our studies?

- Are we being overly deterministic and precise?
- We trap ourselves with our own science
- Are we conflicted? – how can we take $ to say we don't know?
- "**The first principle is that you must not fool yourself, and you are the easiest person to fool." ~ Richard Feynman**

Easy to dump on models, not so easy to define a healthy relationship

- Best outputs from models are counter-intuitive findings and mechanisms, not results

We are headed towards a very different and disturbing world with respect to our water supplies and our inability to precisely define these changes should not take away from this critical message.

PREDICTING CLIMATE CHANGE

Vital Details of Global Warming Are Eluding Forecasters

Decision-makers need to know how to prepare for inevitable climate change, but climat researchers are still struggling to sharpen their fuzzy picture of what the future holds

SCIENCE VOL 334 14 OCTOBER 2011

nature

www.nature.com/nature Vol 463 | Issue no. 7283 | 18 February 2010

Validation required

Transparency and quality control are essential in the highly uncertain business of assessing the impact of climate change on a regional scale.

ADAPTATION TO CLIMATE CHANGE

Time to Adapt to a Warming World, But Where's the Science?

With dangerous global warming seemingly inevitable, users of climate information—from water utilities to international aid workers—are turning to climate scientists for guidance. But usable knowledge is in short supply

25 NOVEMBER 2011 VOL 334 SCIENCE

Western Water Assessment

Projected mean UCRB streamflow changes by ~2050 from GCM-based studies: consistent negative outlook

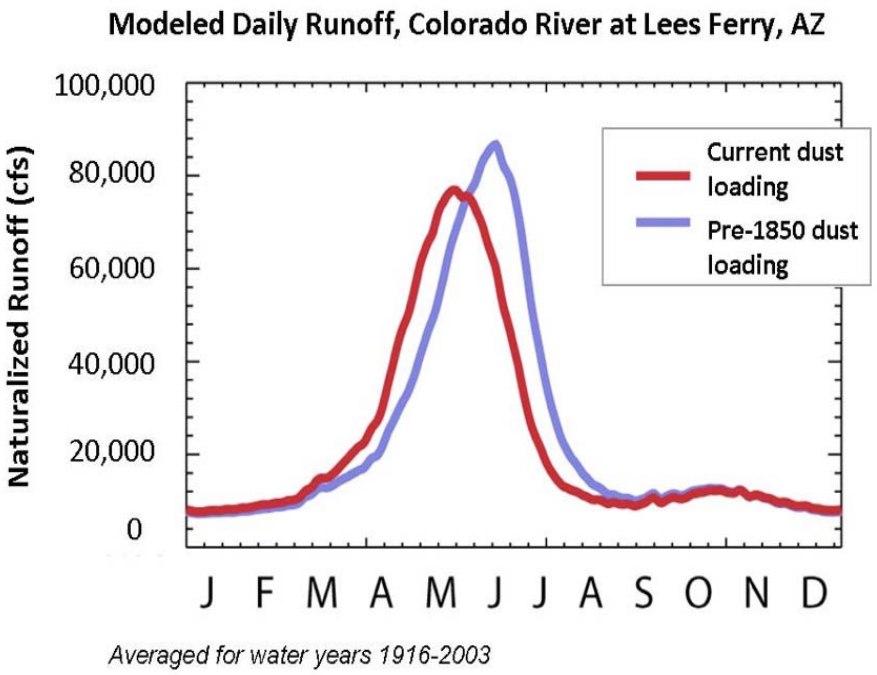
Study	# GCM runs	Hydro model	Annual Temp Δ	Annual Precip Δ	Annual Runoff Δ
Christensen et al. (2004)	3	VIC	+3.1°F	-6%	**-18%**
Christensen and Lettenmaier (2006)	22	VIC	+4.5°F	-1%	**-6%**
CWCB Colo River Water Availability Study (2010)	5 (of 112)	VIC	+3.6°F (2040) +5.8°F (2070)	-2% -2%	**-7%** **-22%**
Joint Front Range Climate Change Vuln Study (2012)	5 (of 112)	Sac. & WEAP	+3.4°F (2040) +5.6°F (2070)	+1% +2%	**-4%** **-10%**
Reclamation WWCRA & Colorado Basin Study (2011)	112	VIC	+3.8°F (2050) +5.1°F (2070)	0% 0%	**-9%** **-7%**

Western Water Assessment

Dust

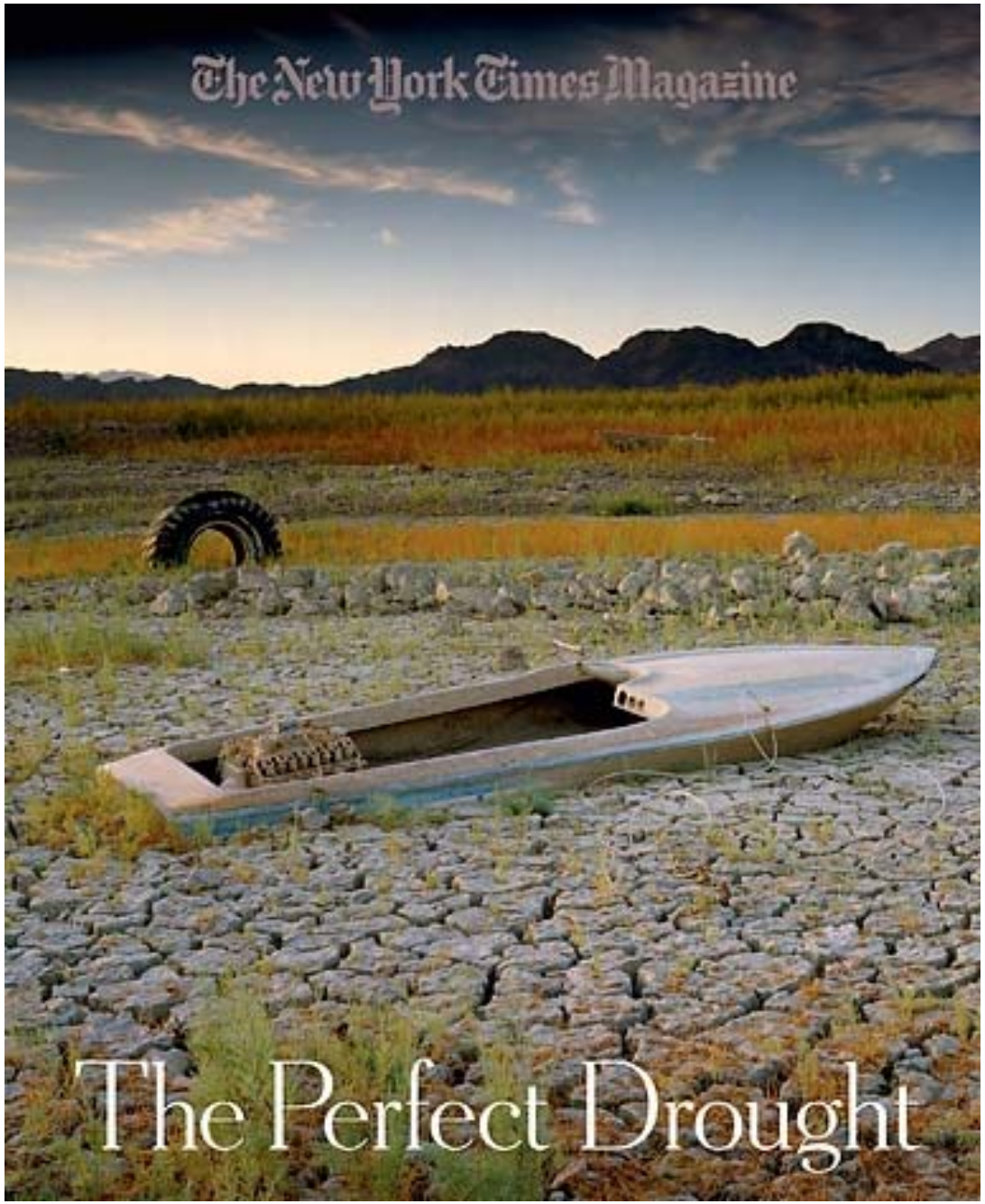
Dust-on-snow – modern dust loading is causing earlier snowmelt and runoff, and may be reducing UCRB flow by ~5% compared to pre-1850 conditions (Painter et al. 2010)

Source: Chris Landry, CSAS



Source: Painter et al. (2010), PNAS

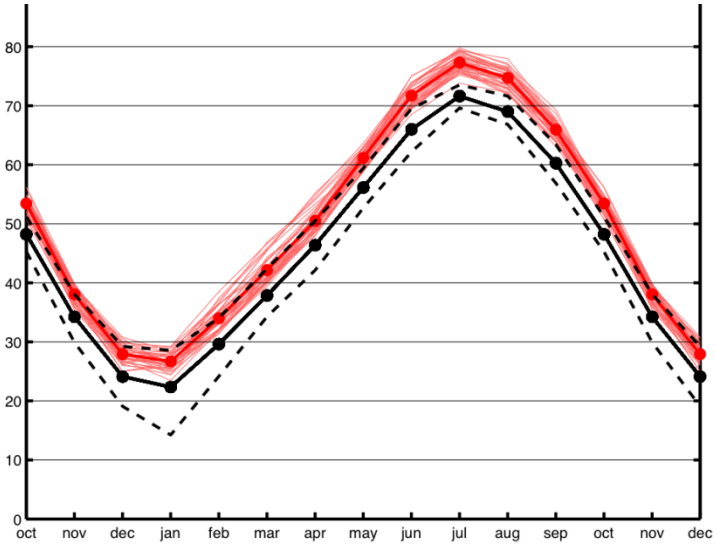
Western Water Assessment

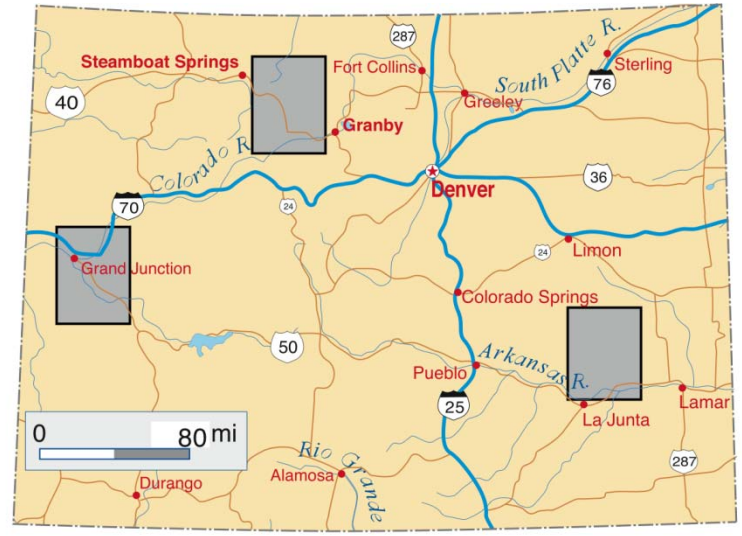


Water will be the delivery mechanism for many of the impacts of climate change

Projections: Temperature

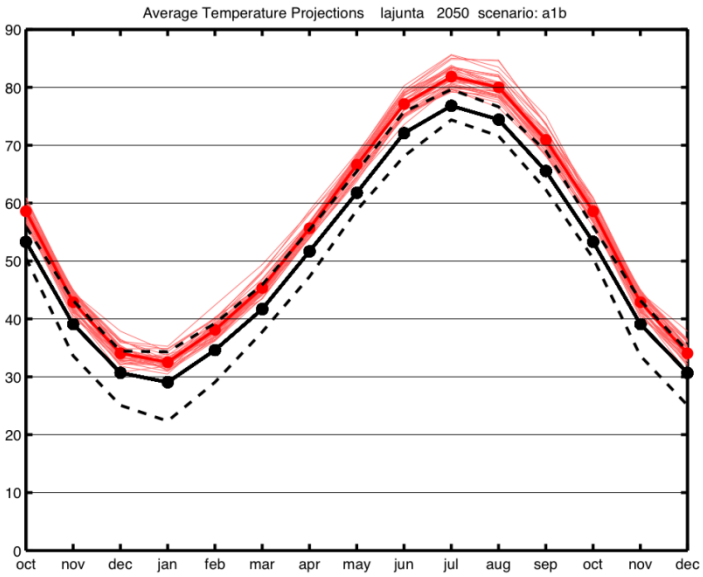
Grand Junction



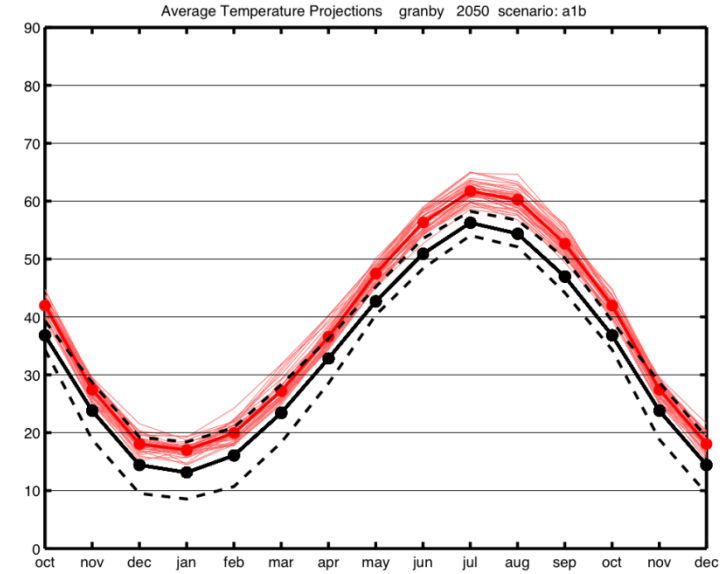


Source: CO Climate Report, 2008

La Junta

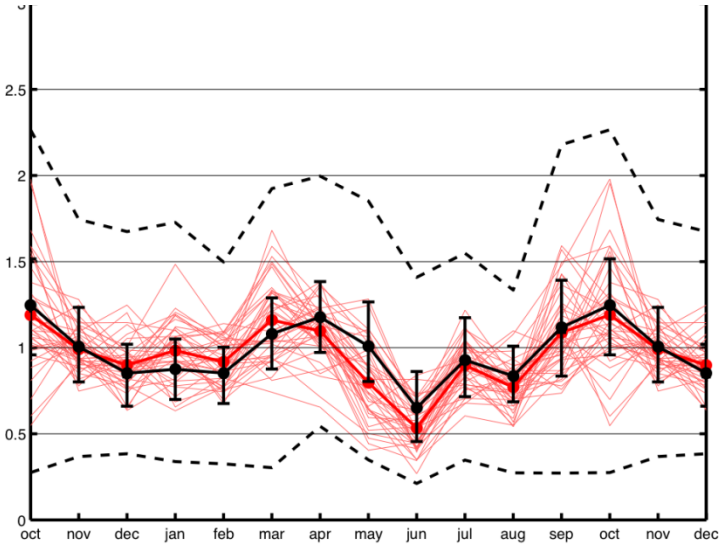


Granby

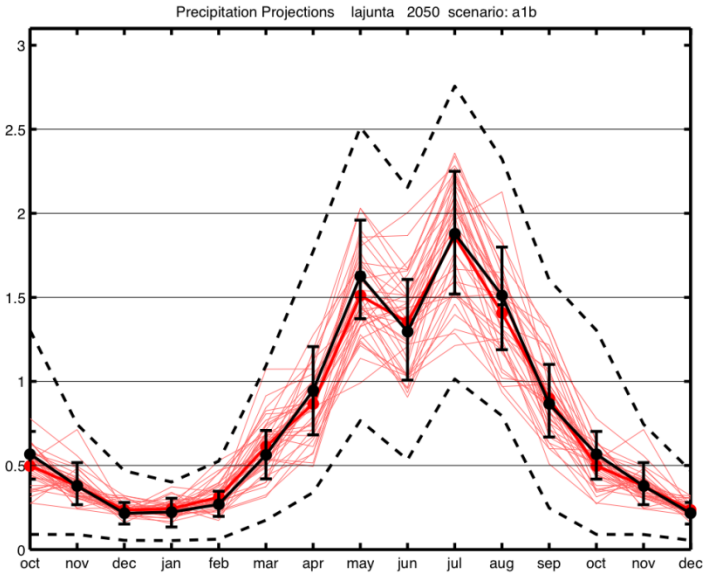


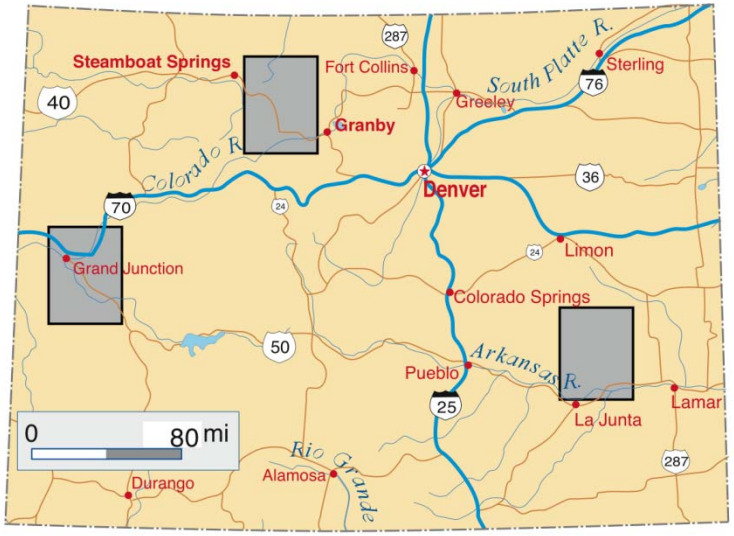
Projections: Precipitation

Grand Junction



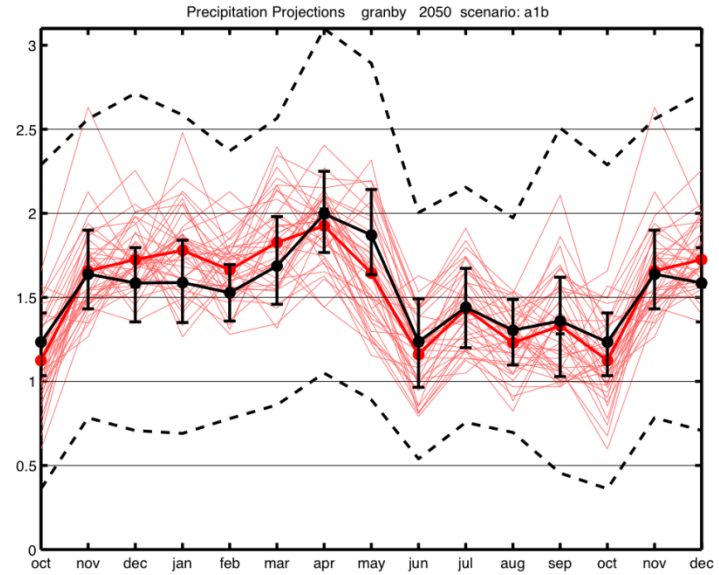
La Junta





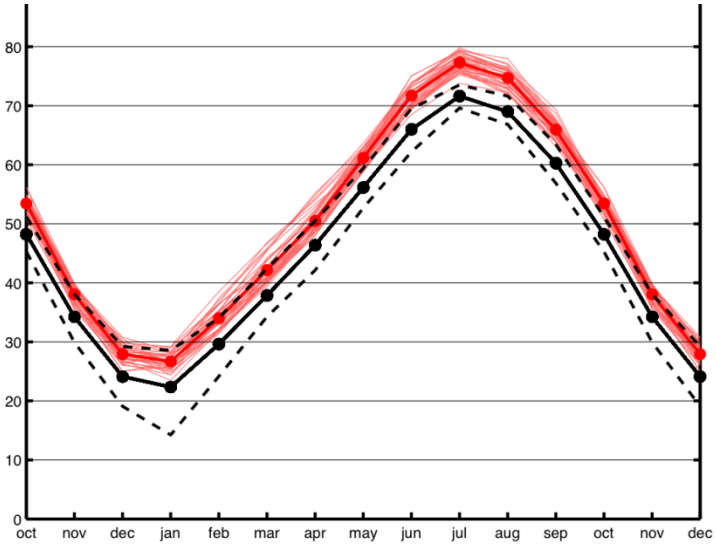
Source: CO Climate Report, 2008

Granby

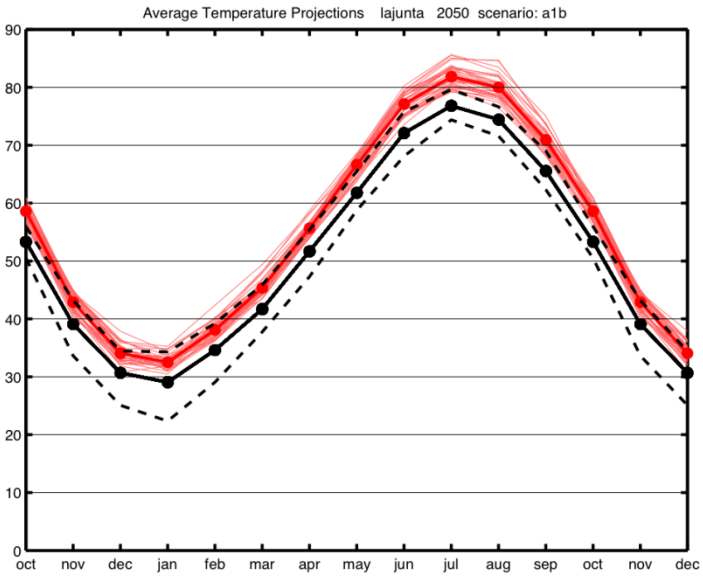


Projections: Temperature

Grand Junction



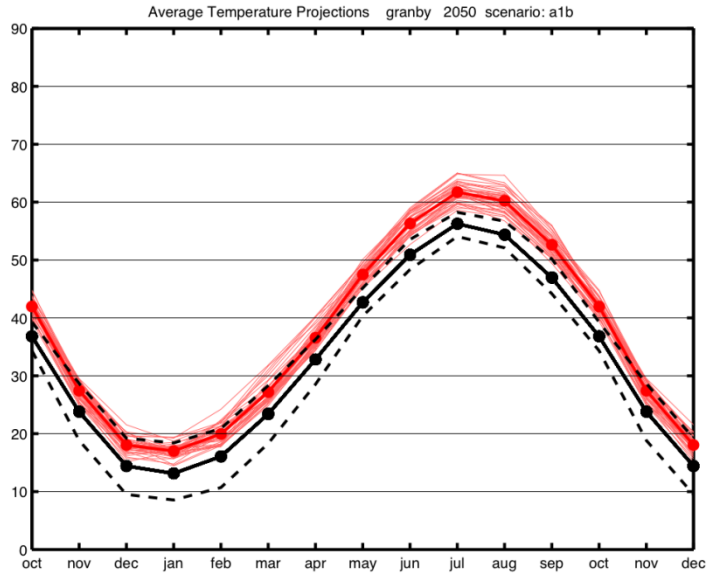
La Junta



Summers warm more than winters

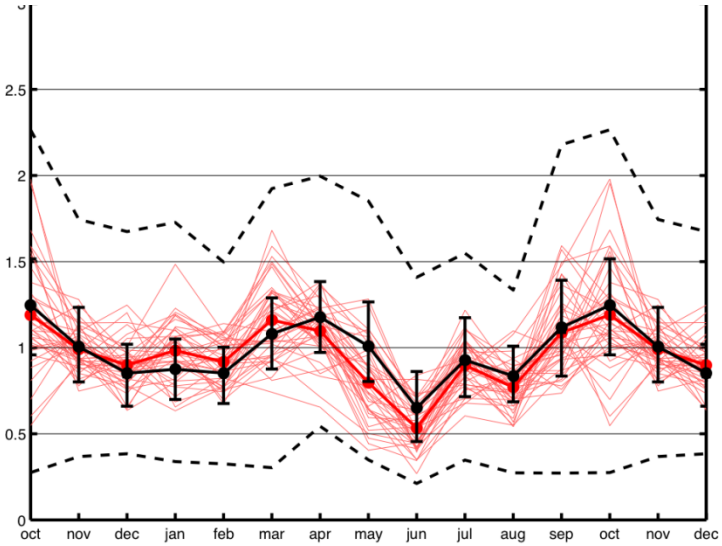
Average summer temperatures similar to the hottest days in the past few years

Granby

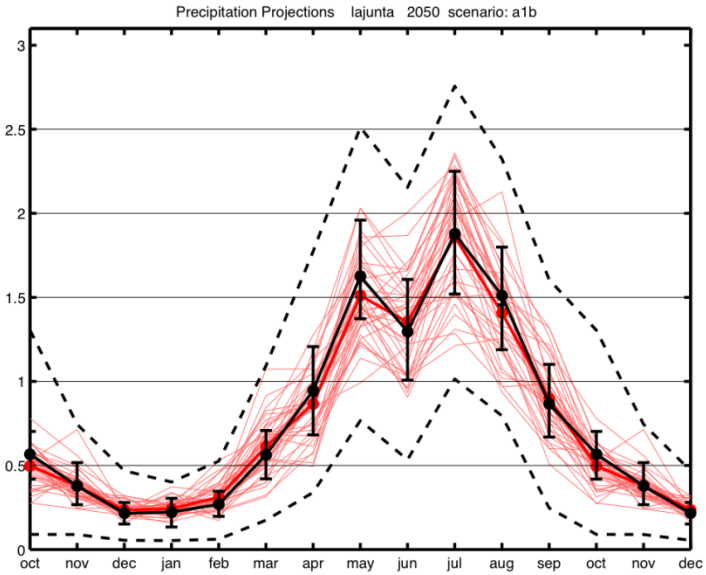


Projections: Precipitation

Grand Junction



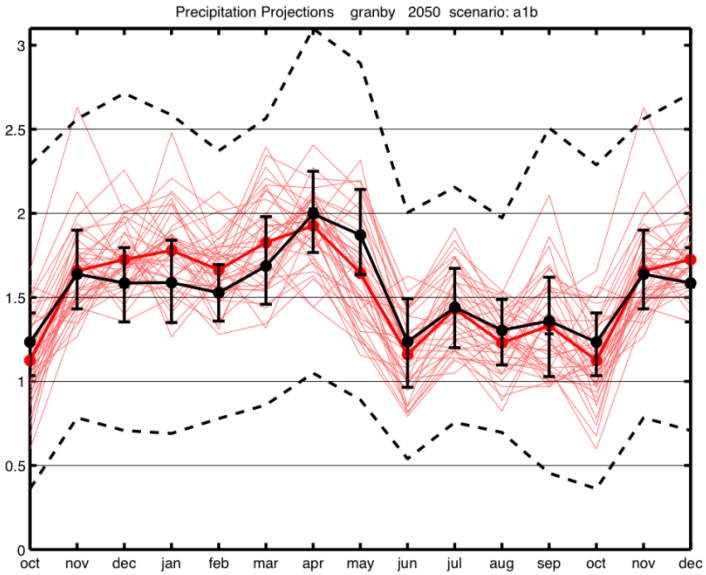
La Junta



Precipitation will continue to be variable

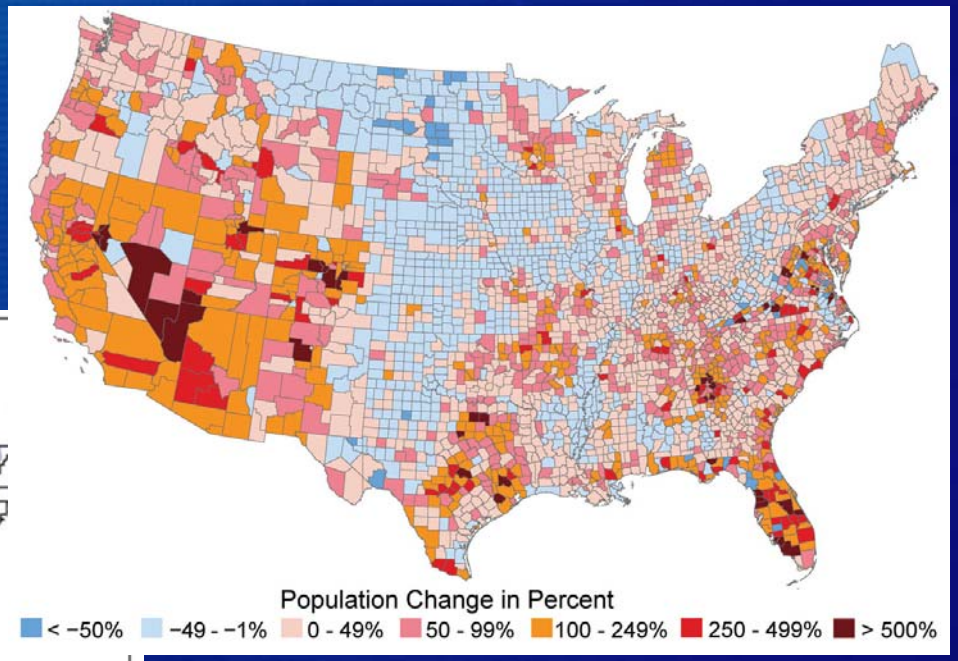
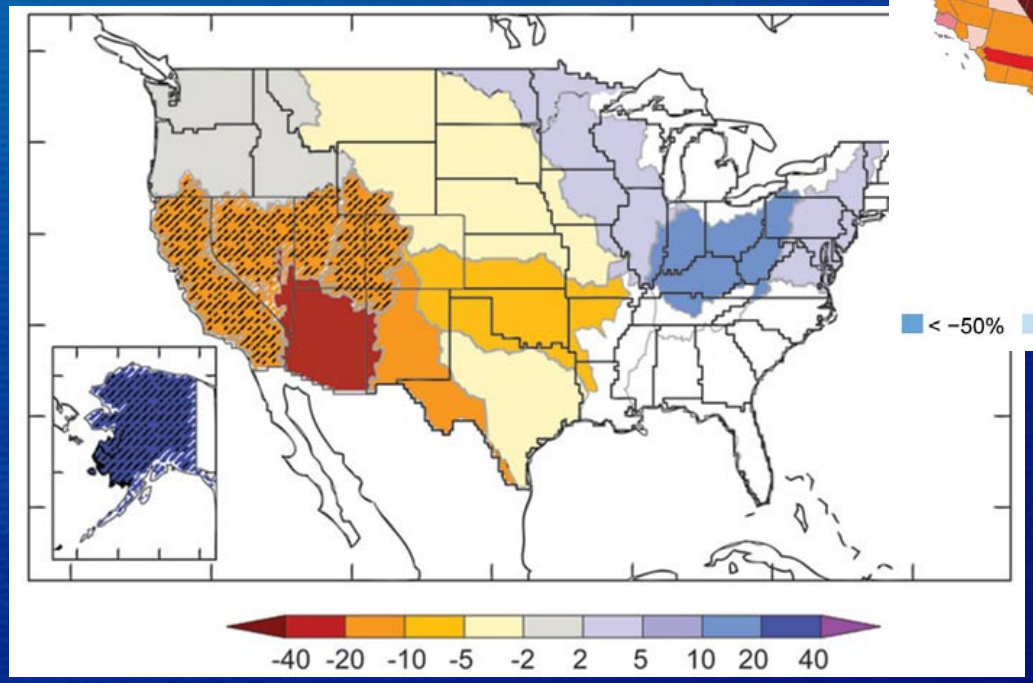
Seasonal shift: more mid-winter precipitation & less in late spring and summer

Granby



Climate change will stress water resources

Change in Population from 1970 to 2008



Projected Changes in Annual Runoff