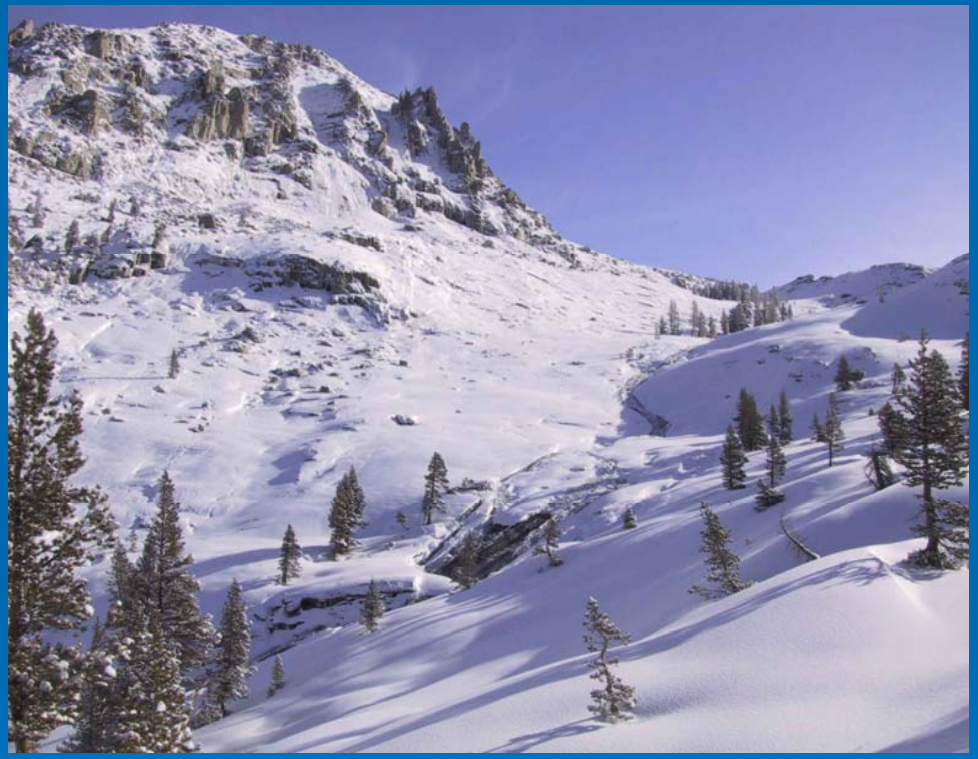
Changes in the timing of snowmelt in Colorado - a response to recent warming



David Clow, U.S. Geological Survey

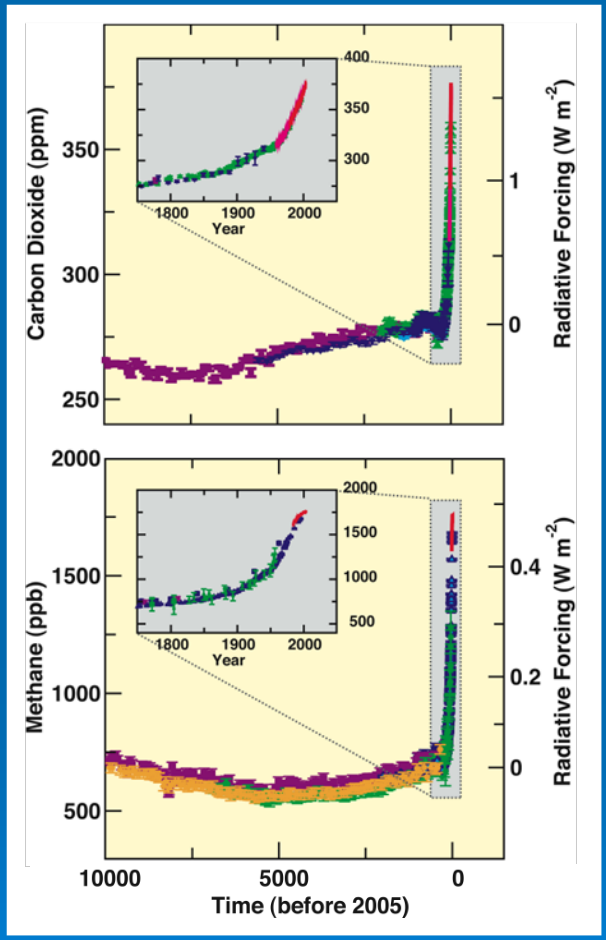
Funding provided by USGS, Colorado Water Conservation Board, Denver Water, Northern Colorado Water Conservancy District, Colorado Spring Utilities, Colorado River Water Conservation District

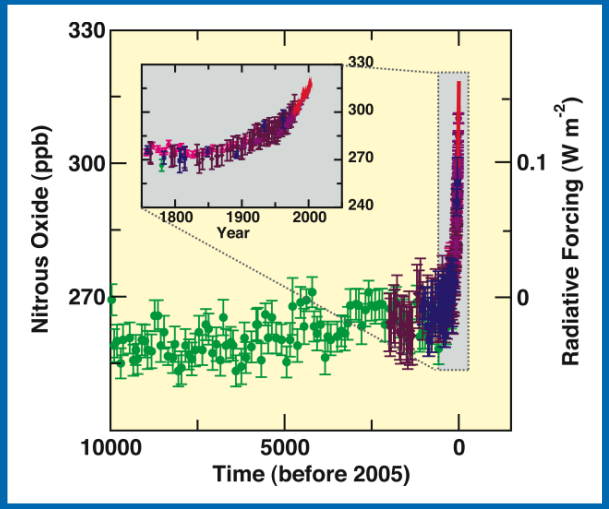
A little context

- Human activities have caused increases in greenhouse gas concentrations in the atmosphere*
- Climate warming is unequivocal
- Recent warming cannot be explained by natural forcings alone

*Intergovernmental Panel on Climate Change (IPCC), 2007

Greenhouse gas concentrations have increased substantially in the last 1000 years

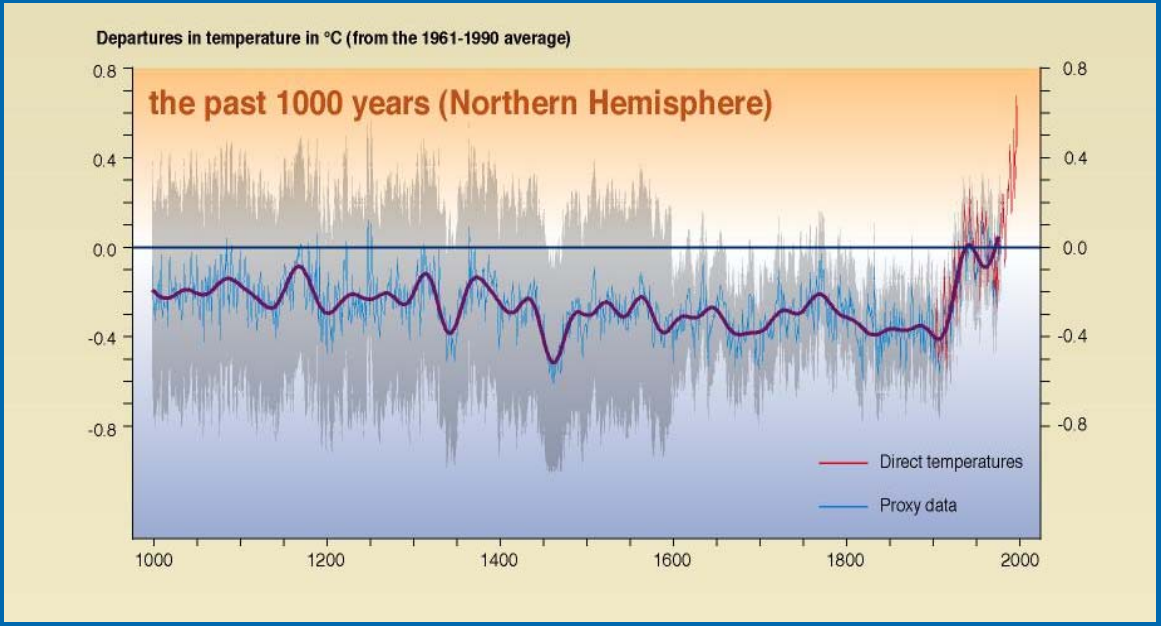




CO_2 concentrations have not been exceeded in at least the past 650,000 years, and probably not during the last 20 million years.

IPCC, 2007

Global air temperatures are warmer than in the last 1000 years

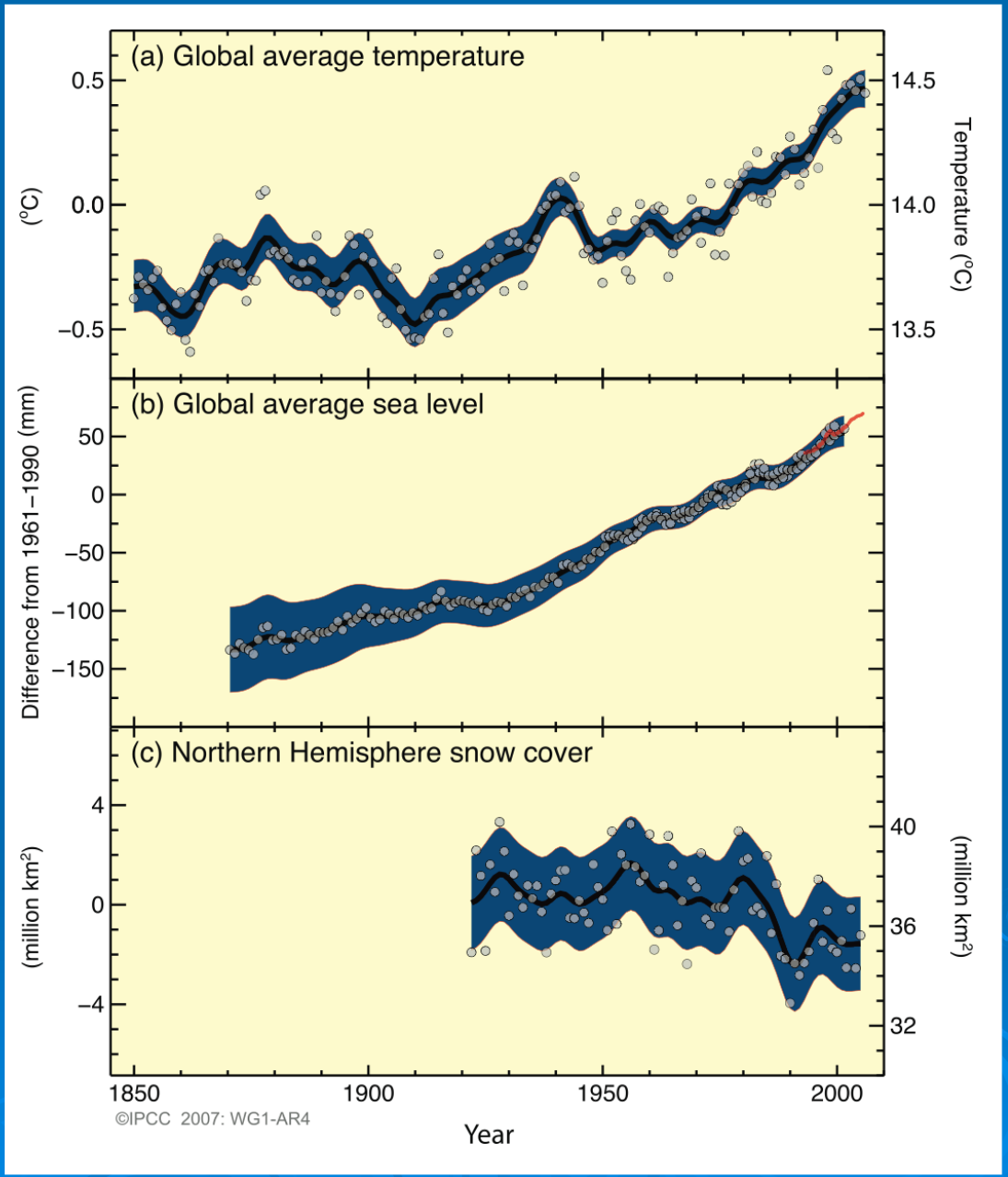


- The rate of warming in the last century was greater than in the last 1000 years
- 11 of the last 12 years were the warmest in the instrumental record

IPCC, 2007

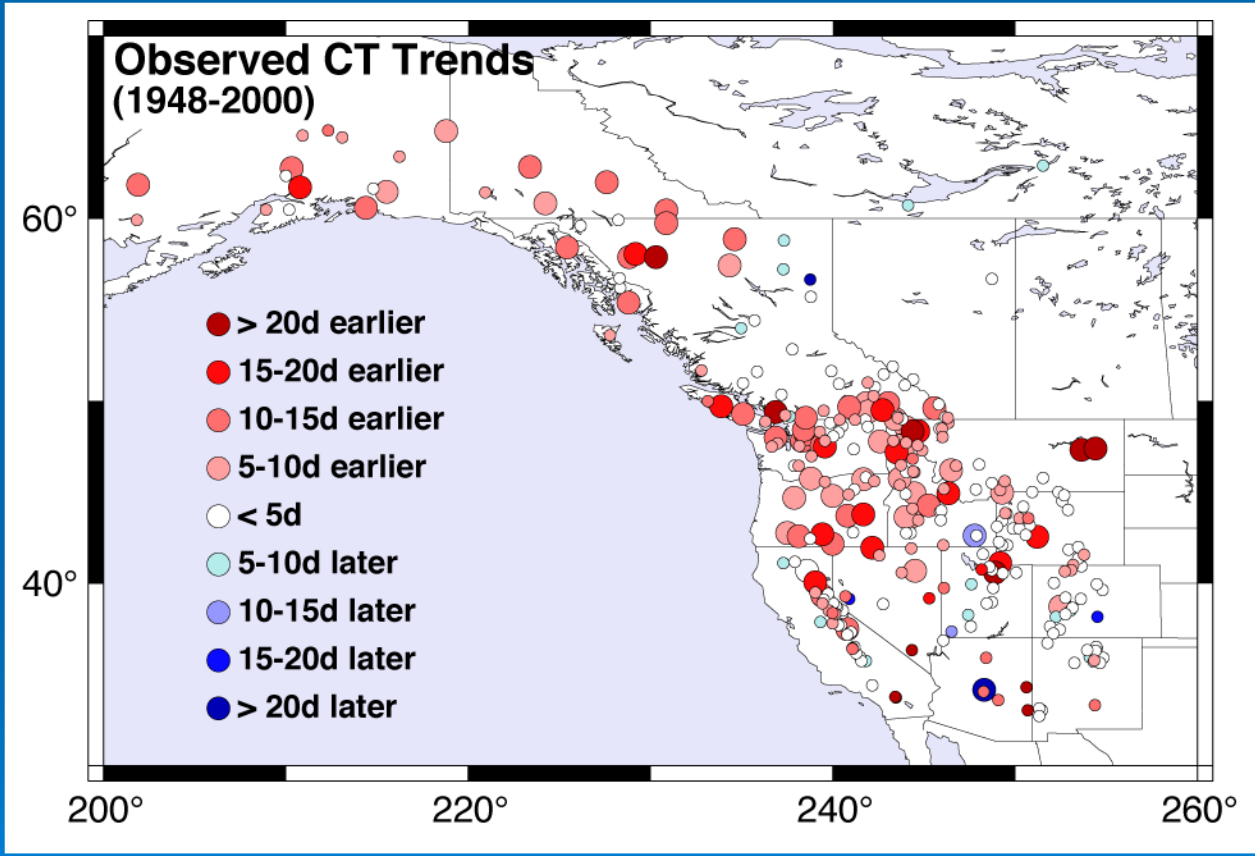
Changes during instrumented period

- Global air temperatures have increased about 0.7°C since 1850
- 80% of the heat is stored in the ocean
- Substantial decrease in Northern Hemisphere snow cover



IPCC, 2007

Snowmelt runoff occurring earlier across most of the west



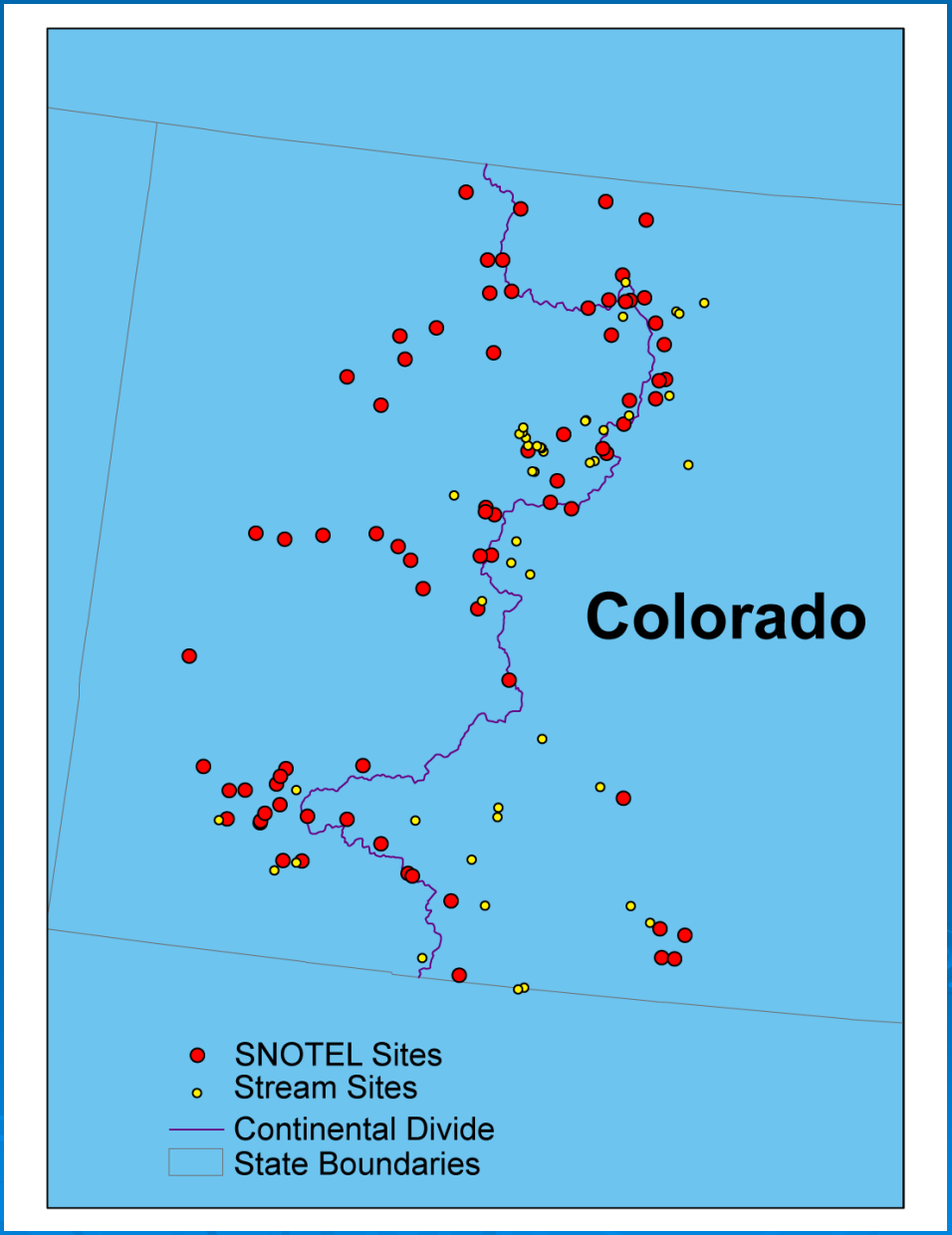
- Largest trend are in the Pacific Northwest
- Not much change indicated in Colorado (!?)

Stewart et al., Climatic Change 2004

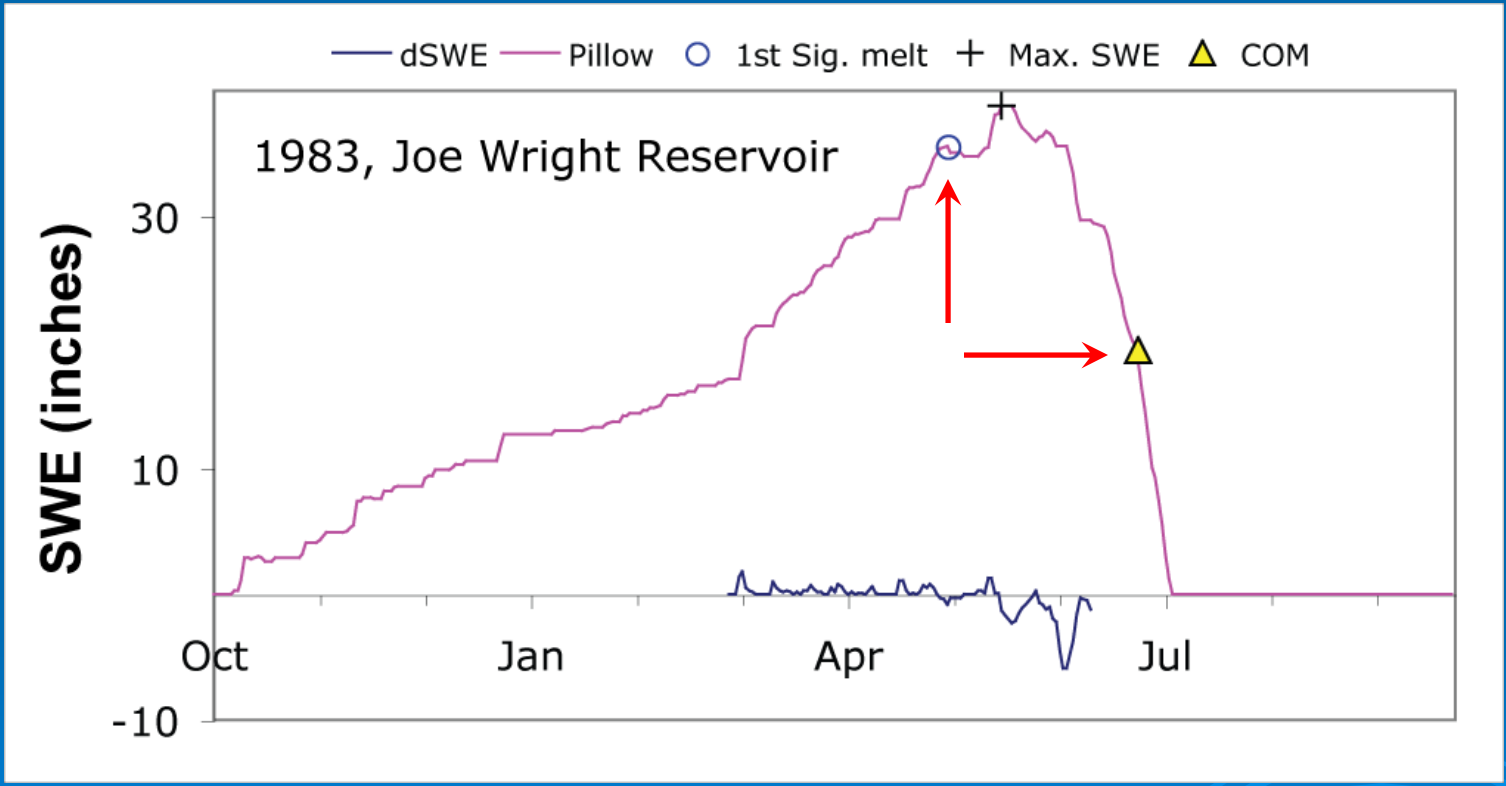
CT is center of streamflow mass (Q50)

Current Study - Objective

- Evaluate changes in Colorado in more detail
- Use daily snowpack data
- Correlation between snowmelt and streamflow timing?
- Correlations with climate?



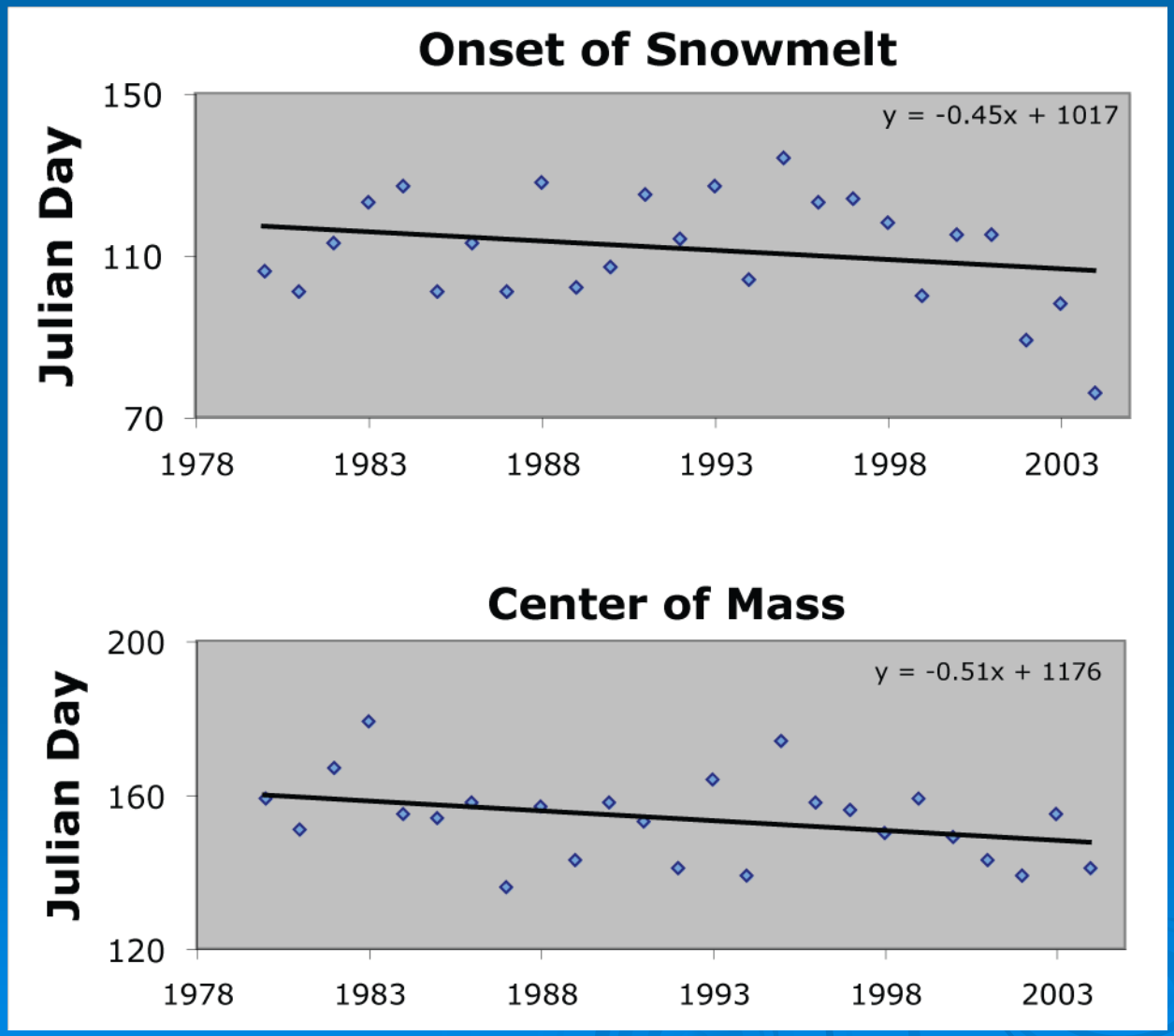
Snowmelt Timing Example



We identified and analyzed trends in:

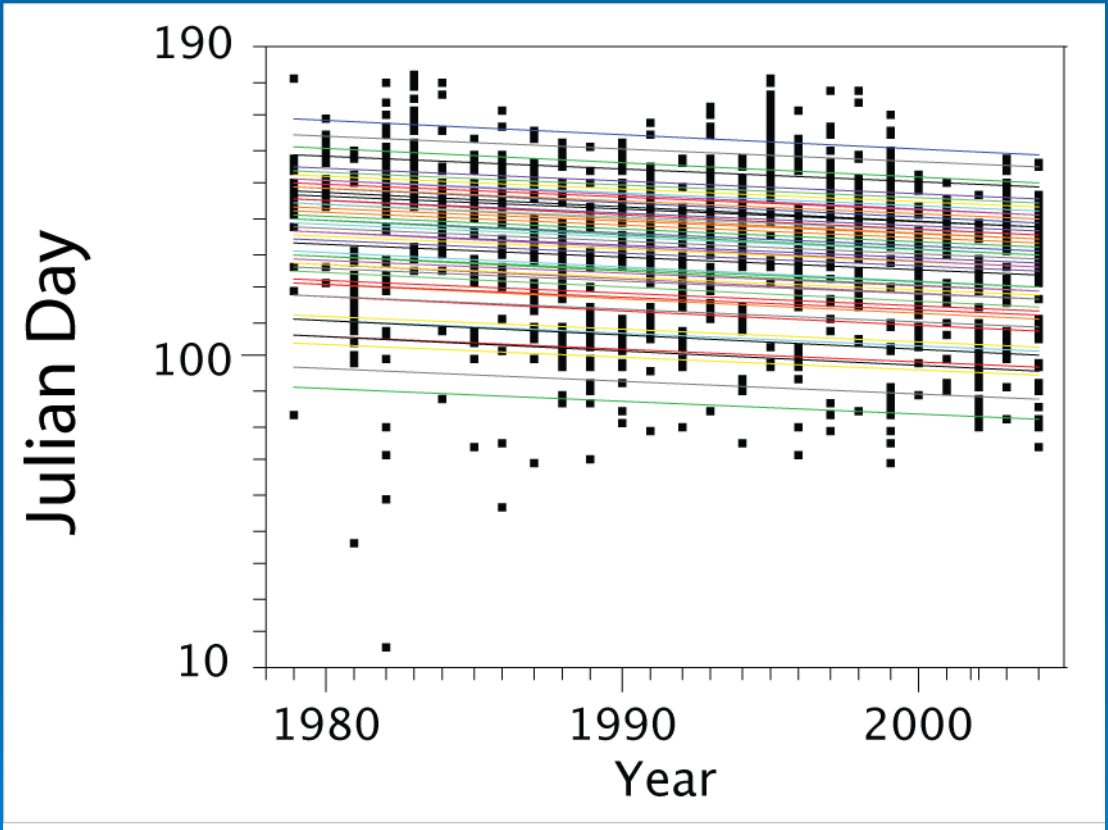
- Snowmelt onset
- Center of Mass (COM)

Trends in snowmelt timing



- Joe Wright SNOTEL site
- Lots of interannual variability and short record makes trend detection difficult

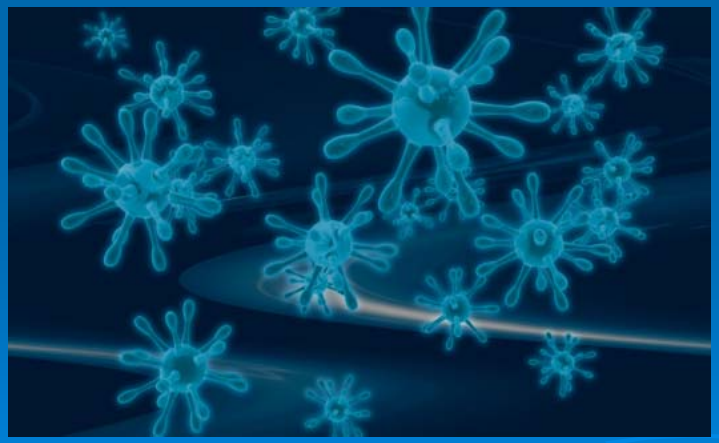
Snowmelt Center of Mass, all sites

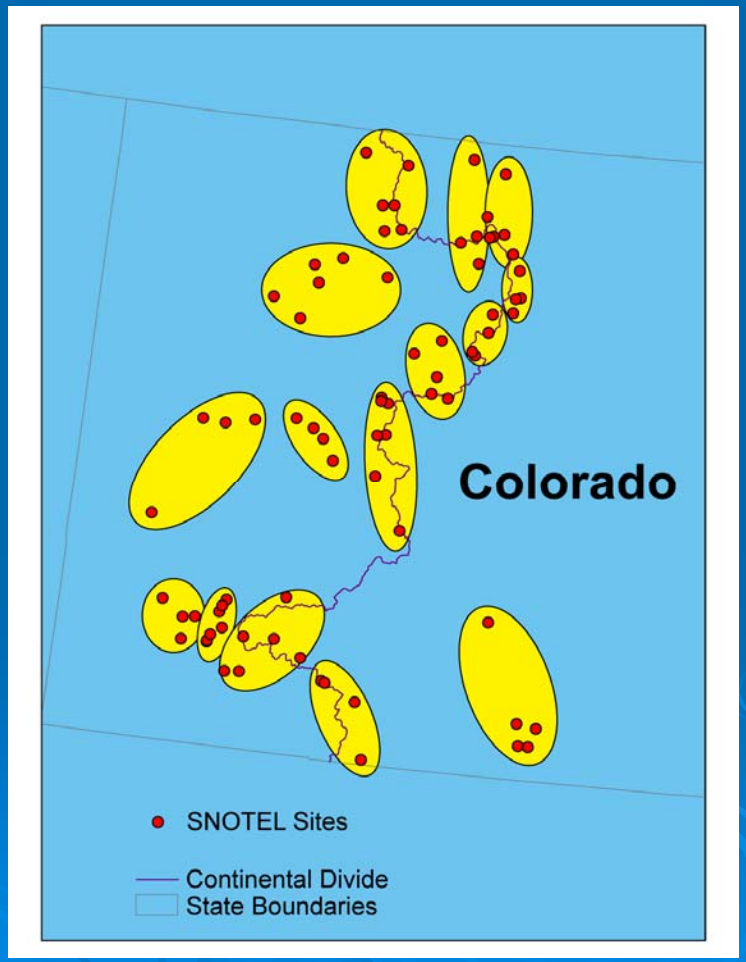


- Few sites showed significant trends by themselves
- But slopes of trend equations were all down
- Grouped trend is down, indicating earlier melt

Regional Kendall Test

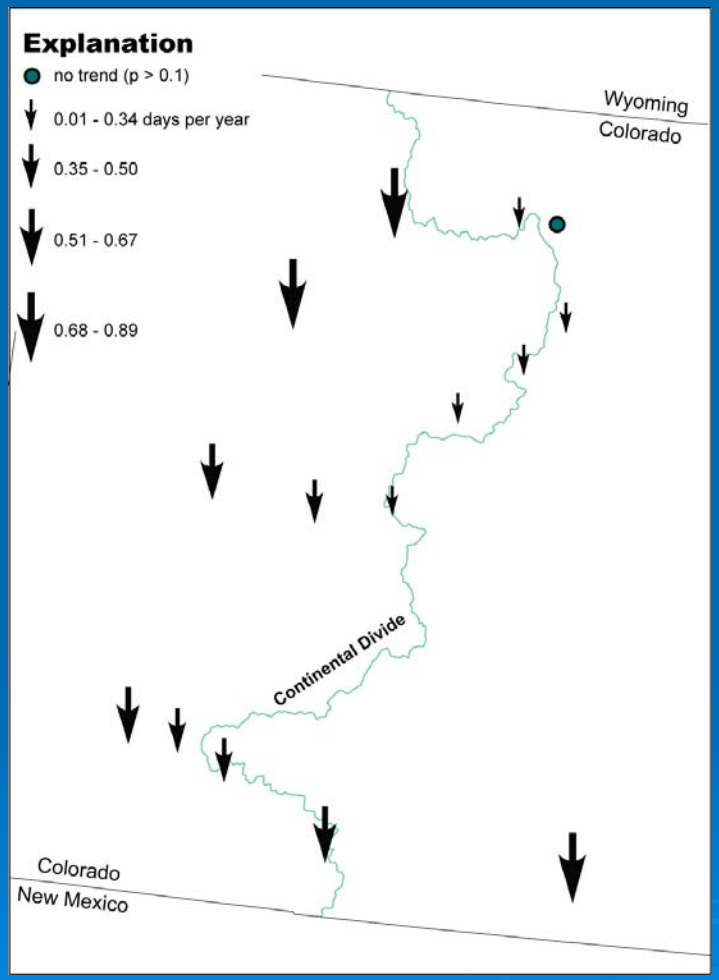
- New statistical technique that provides more power for trend detection by grouping the data





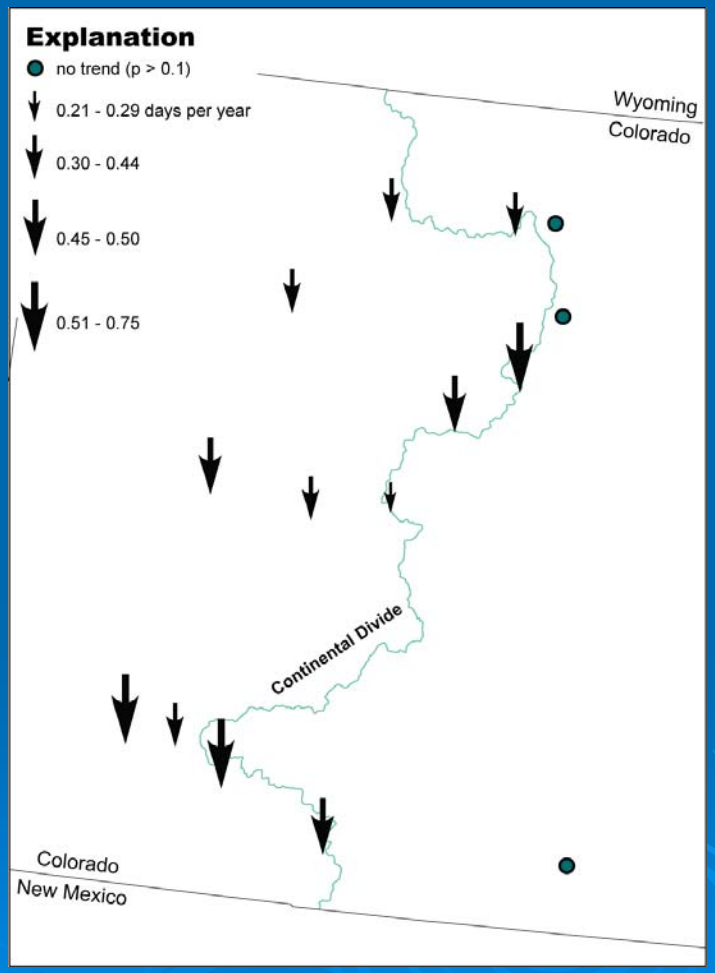
Snowmelt is occurring earlier

Snowmelt Onset



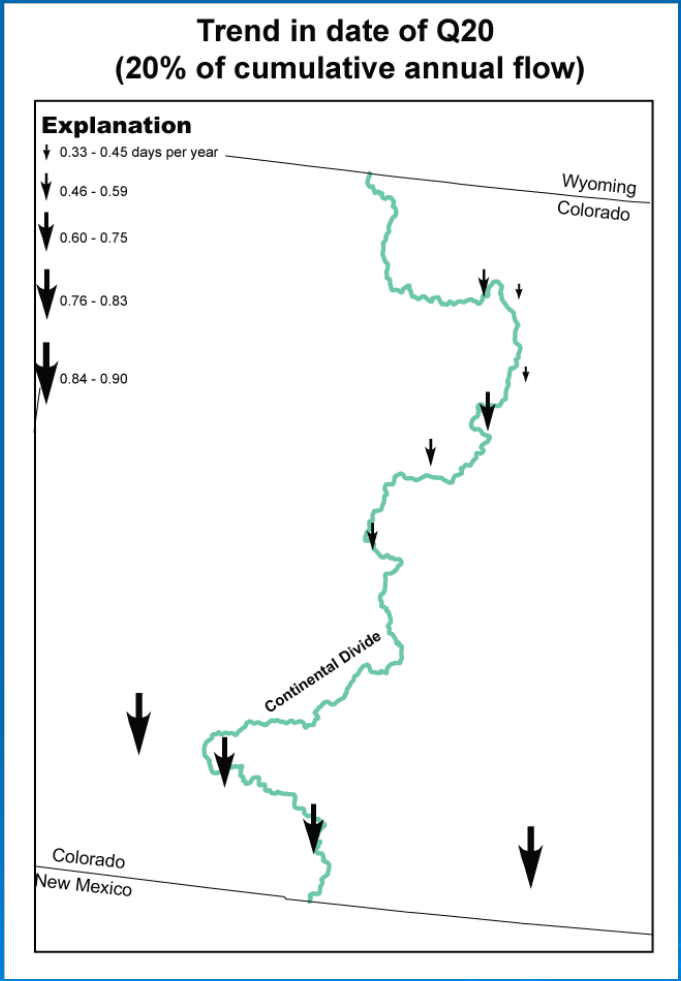
Average change = 0.5 days/year
Or two weeks over study period

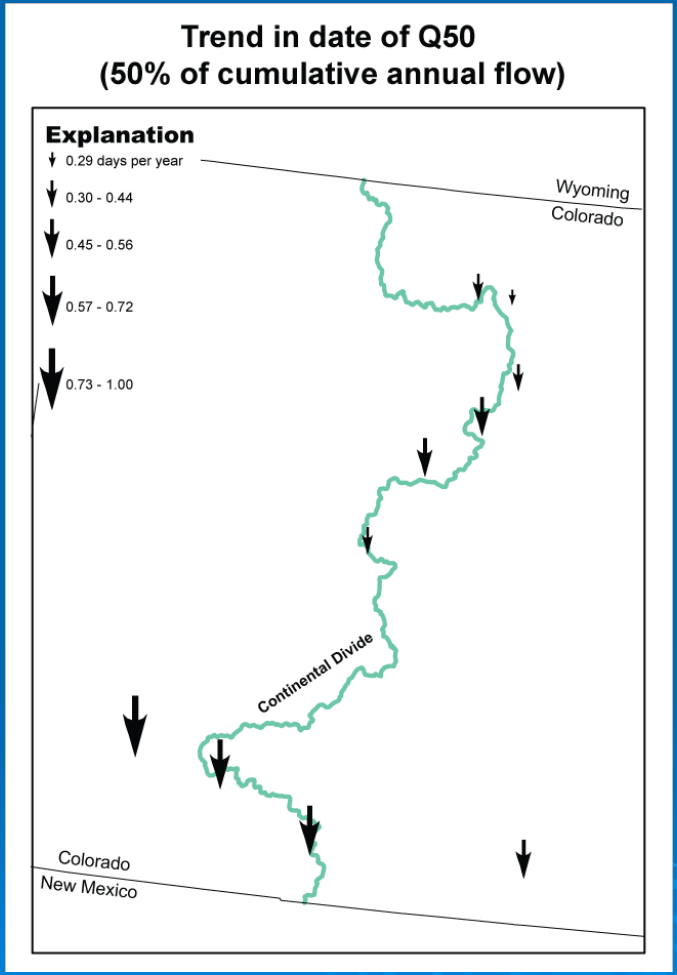
Snowmelt Center of Mass



Average change = 0.4 days/year

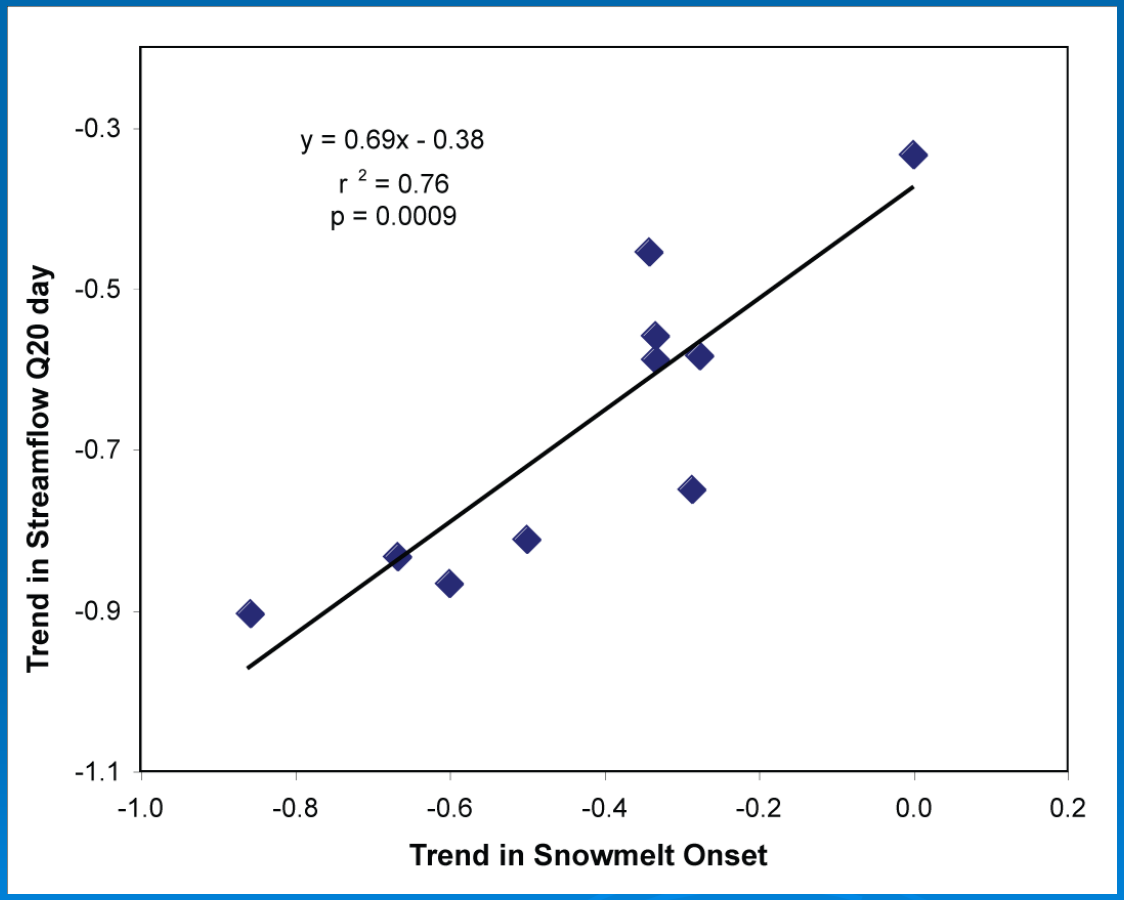
Streamflow is occurring earlier too



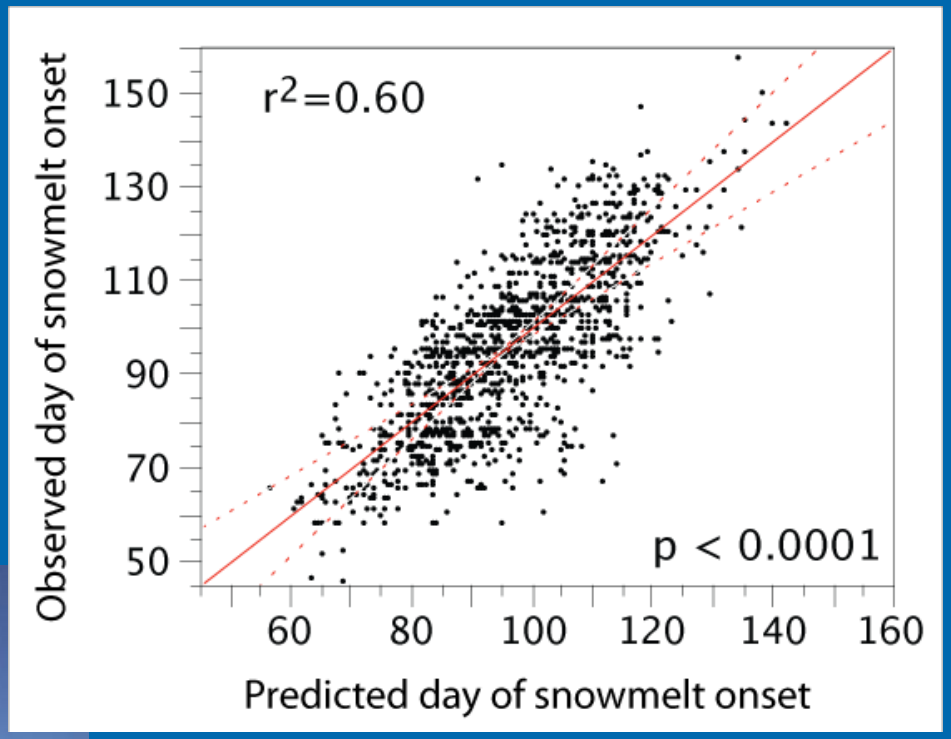


Trends similar in magnitude to snowmelt timing trends

Trends in Snowmelt and Streamflow timing are correlated

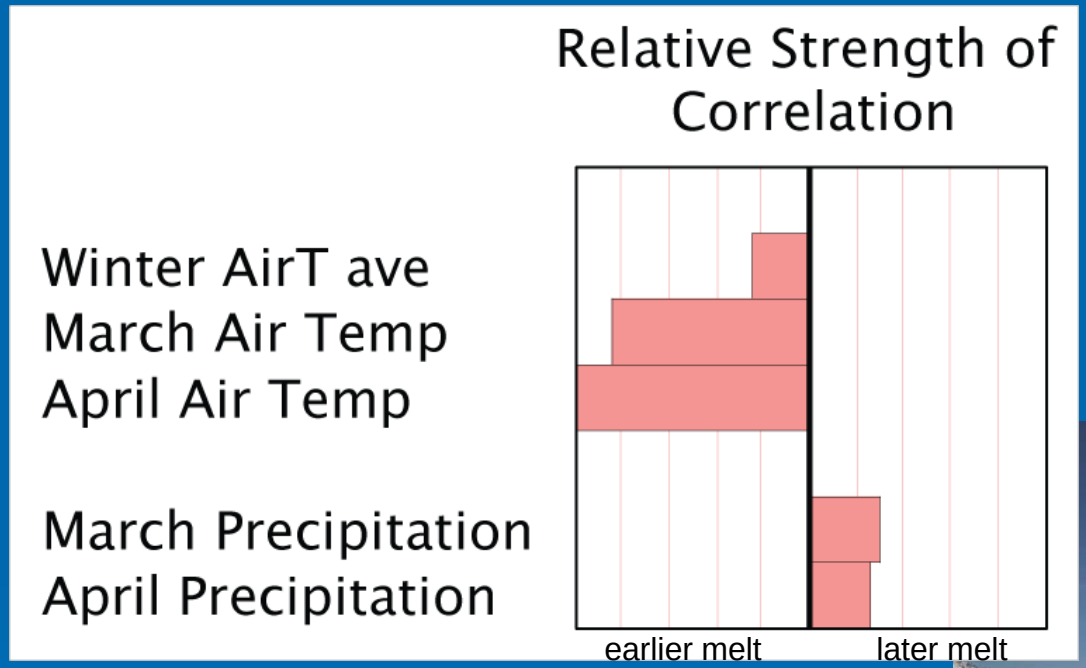


What Controls Snowmelt Timing?



Simple climate variables explain 60% of variance in snowmelt timing

Springtime warming has the biggest influence

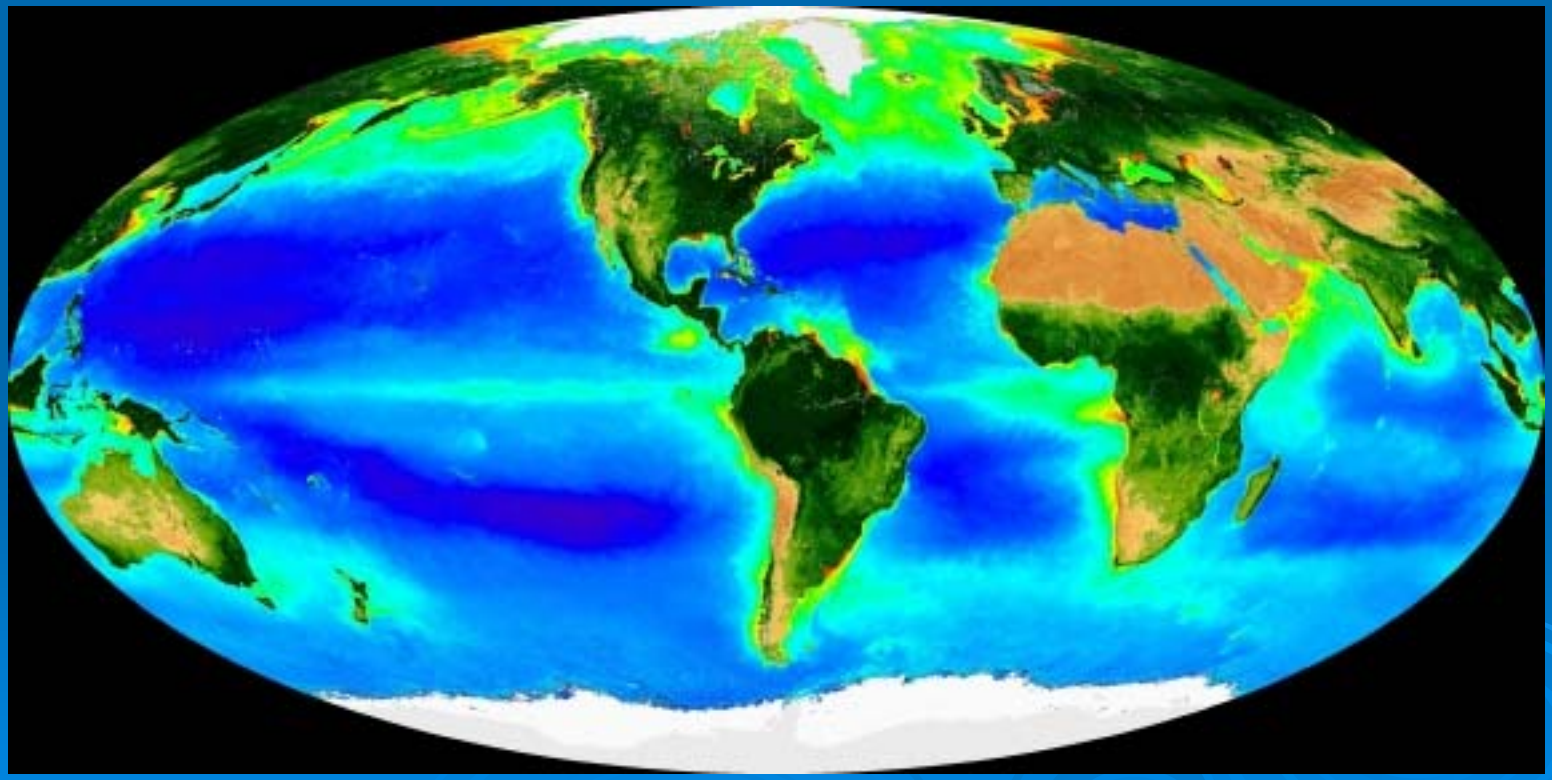


Warm Springtime temperatures cause early melt

Heavy Springtime snowfall delays melt

Back to the global scale

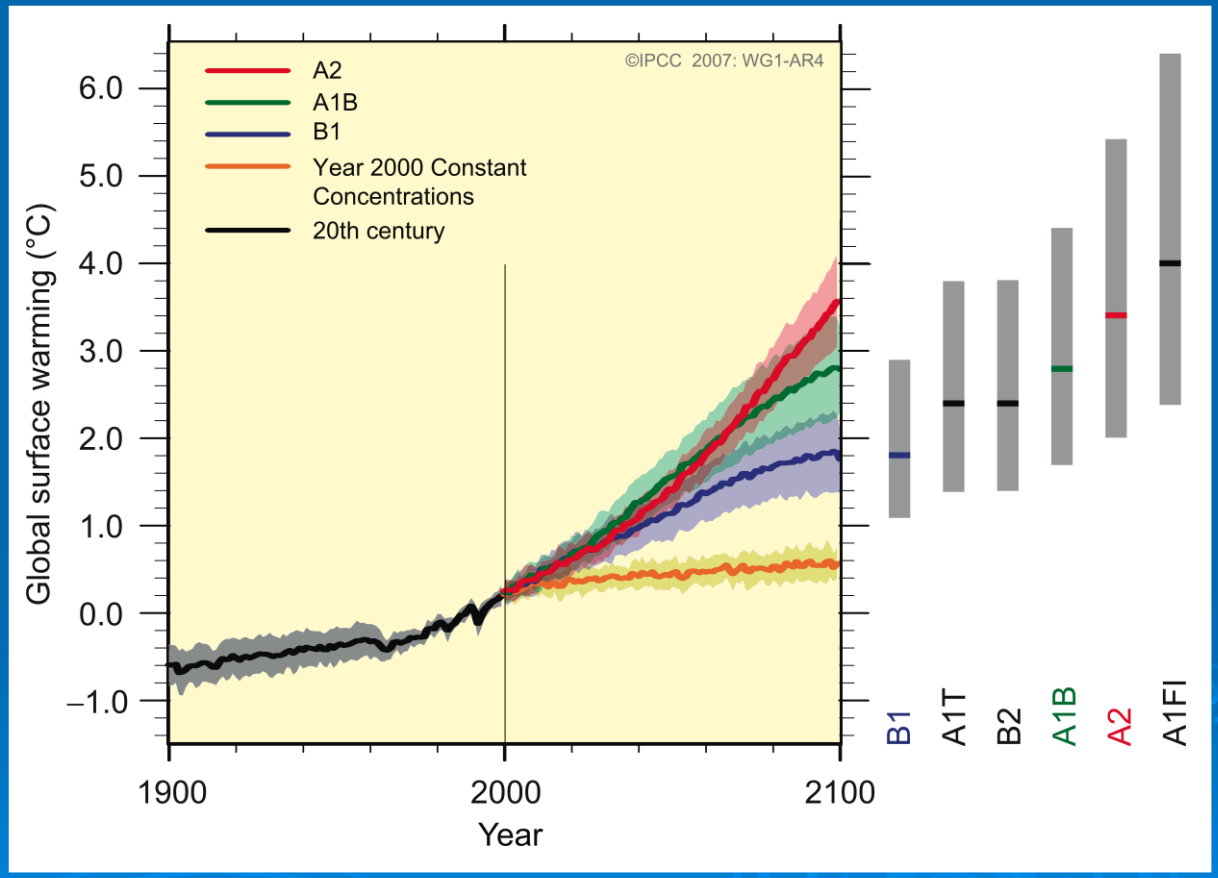
- What does the future hold?



Earth Biomass: NASA

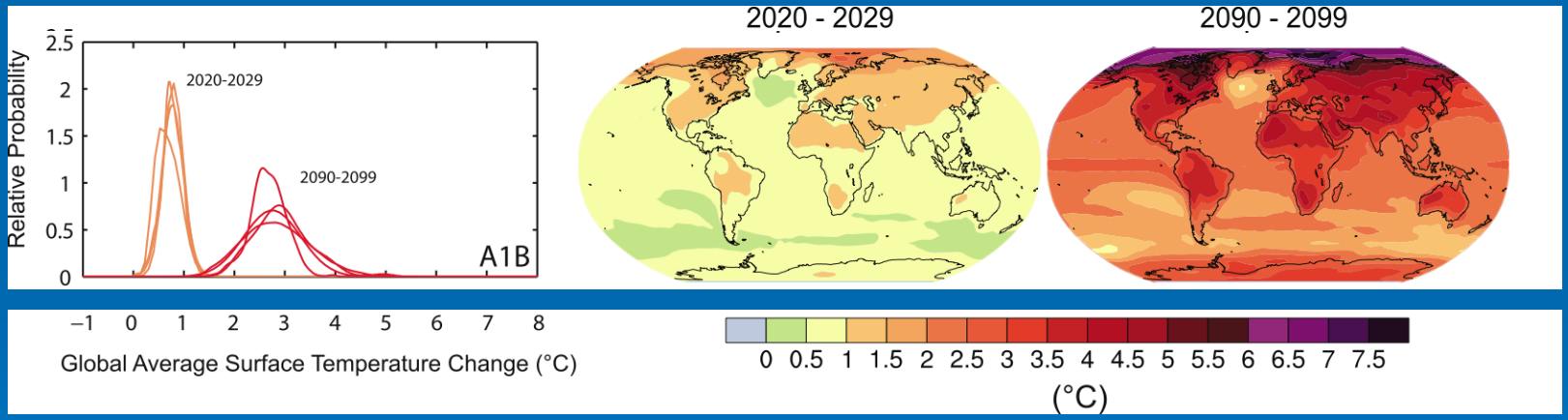
Warming projections

- Global average **surface temperatures** are projected to increase by 1.7 to 4.4 C under A1B.
- The projected **rate of warming** is increasing.



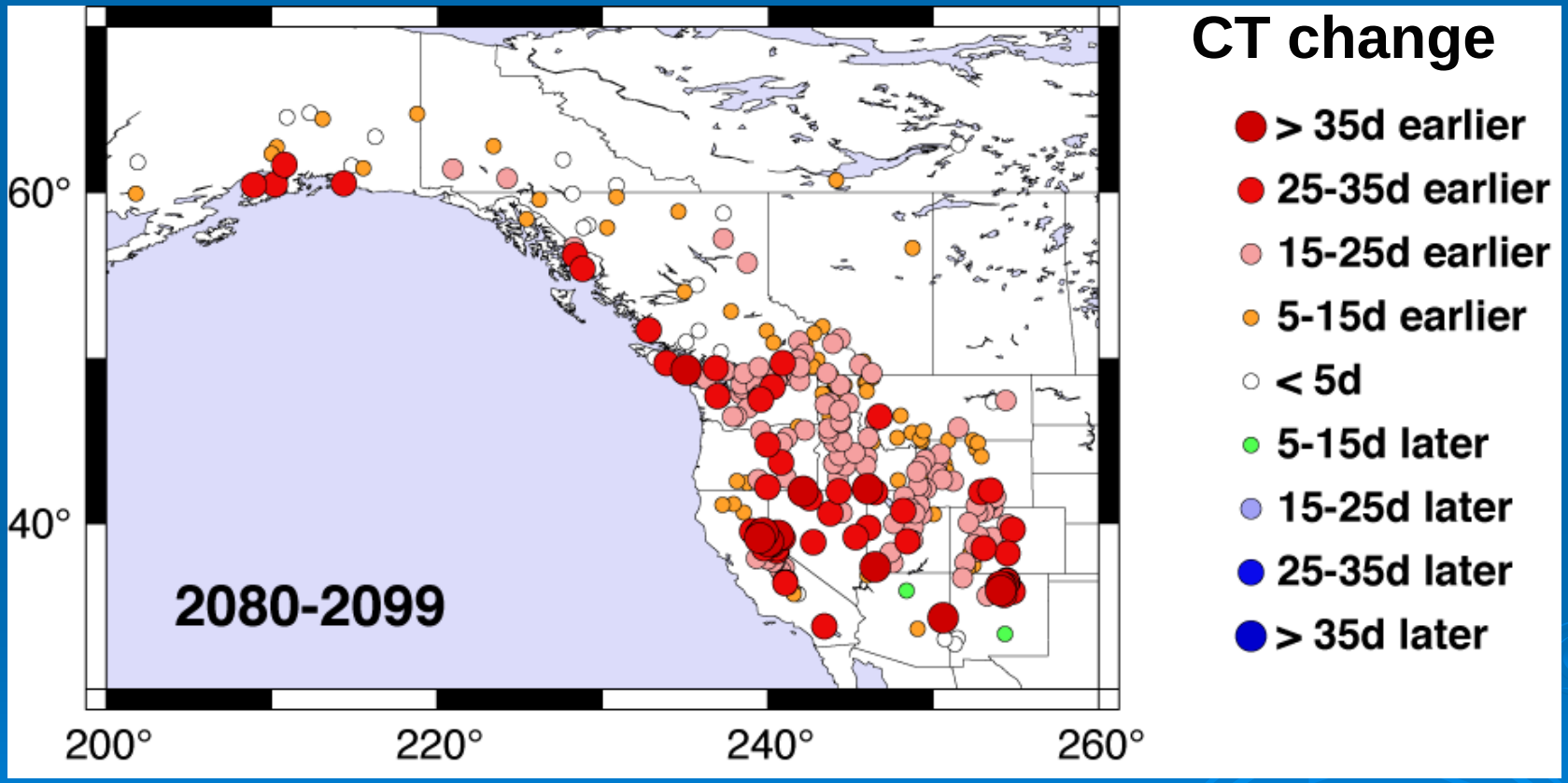
IPCC, 2007

Warming greatest over land and high latitudes



IPCC, 2007

Projected changes in snowmelt timing, 2080-2099



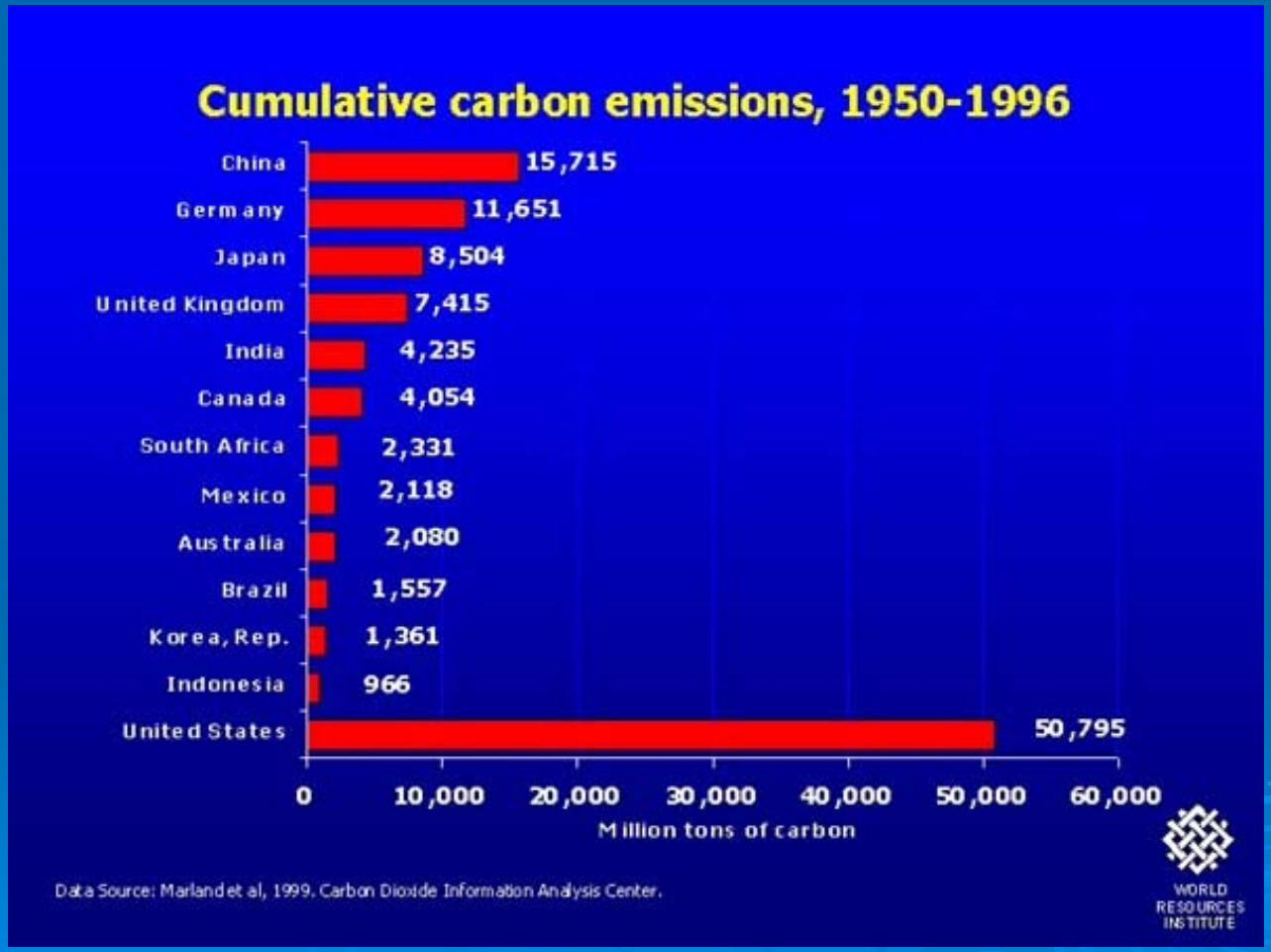
Stewart et al., Climatic Change, 2004

Conclusions

- Snowmelt timing in Colorado has advanced by about 2 weeks since the late 1970's
- Streamflow timing has responded in a similar fashion
- The trends in timing are strongly related to increasing Springtime air temperatures
- Future trends in the region are uncertain, but global air temperatures are likely to warm significantly

What will impacts on water resources be?

CO_2 emissions by country

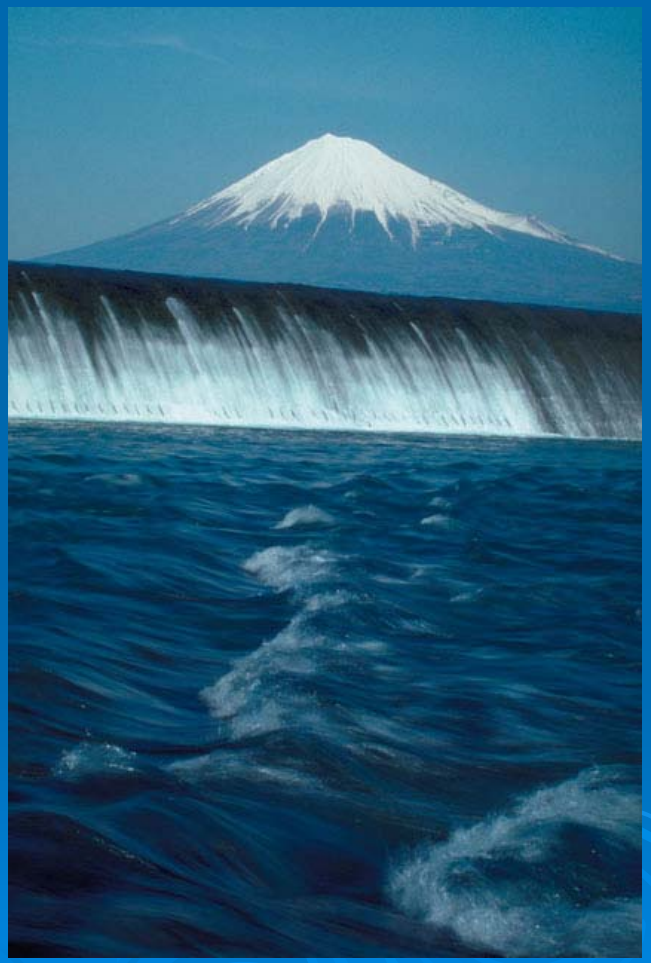


SNOTEL data QA

- Temperature Data
  - Screen for outliers (>3 S.D.)
  - Coherence analysis
  - Compare with cooperative station data
- SWE data
  - Paired t-test comparing before/after pillow replacement

Future Work

- Proposal submitted to CWCB, with possible other contributors
- Add streamflow sites, especially in western Colorado
- Complete analysis
- Publish results



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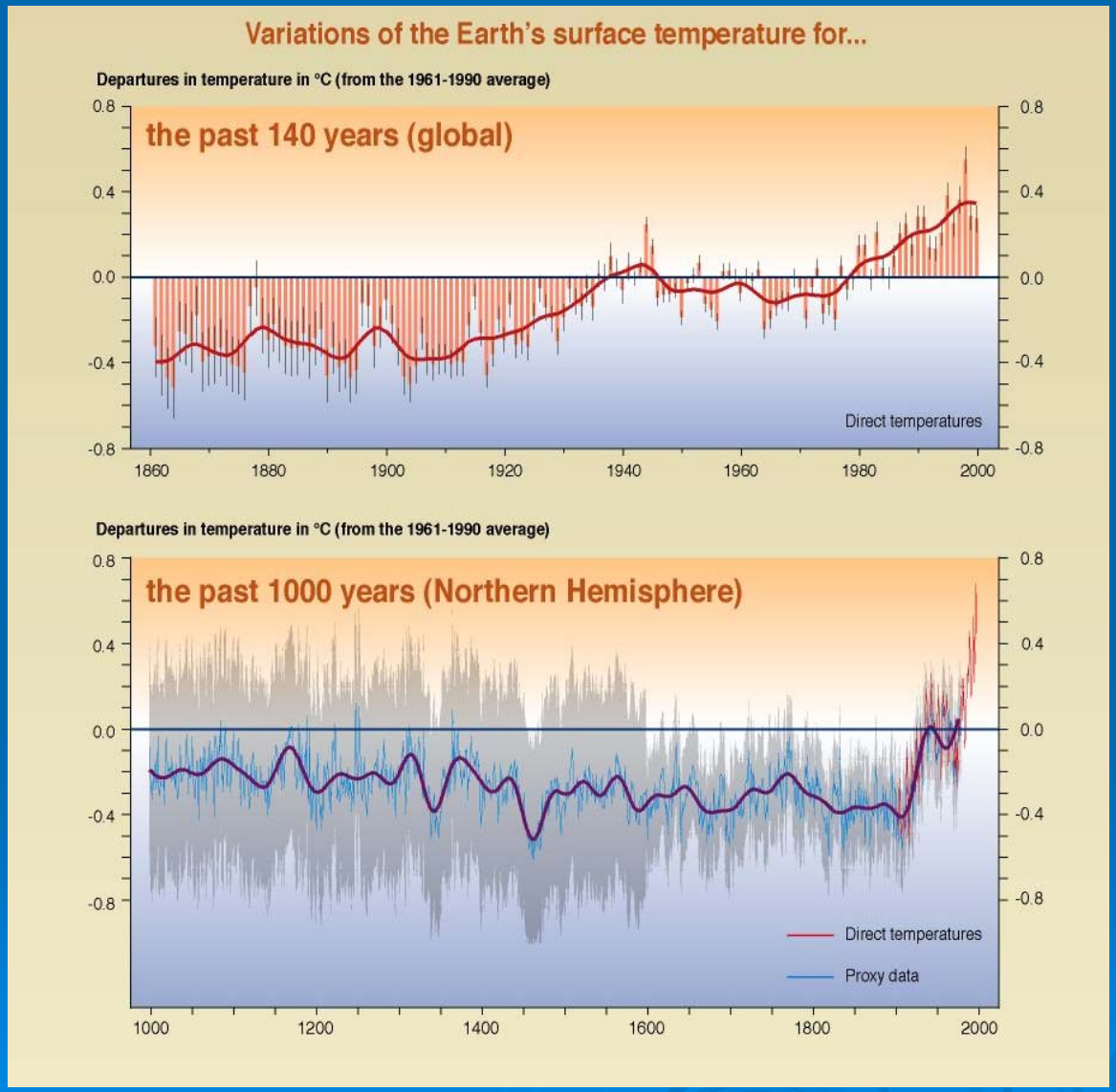
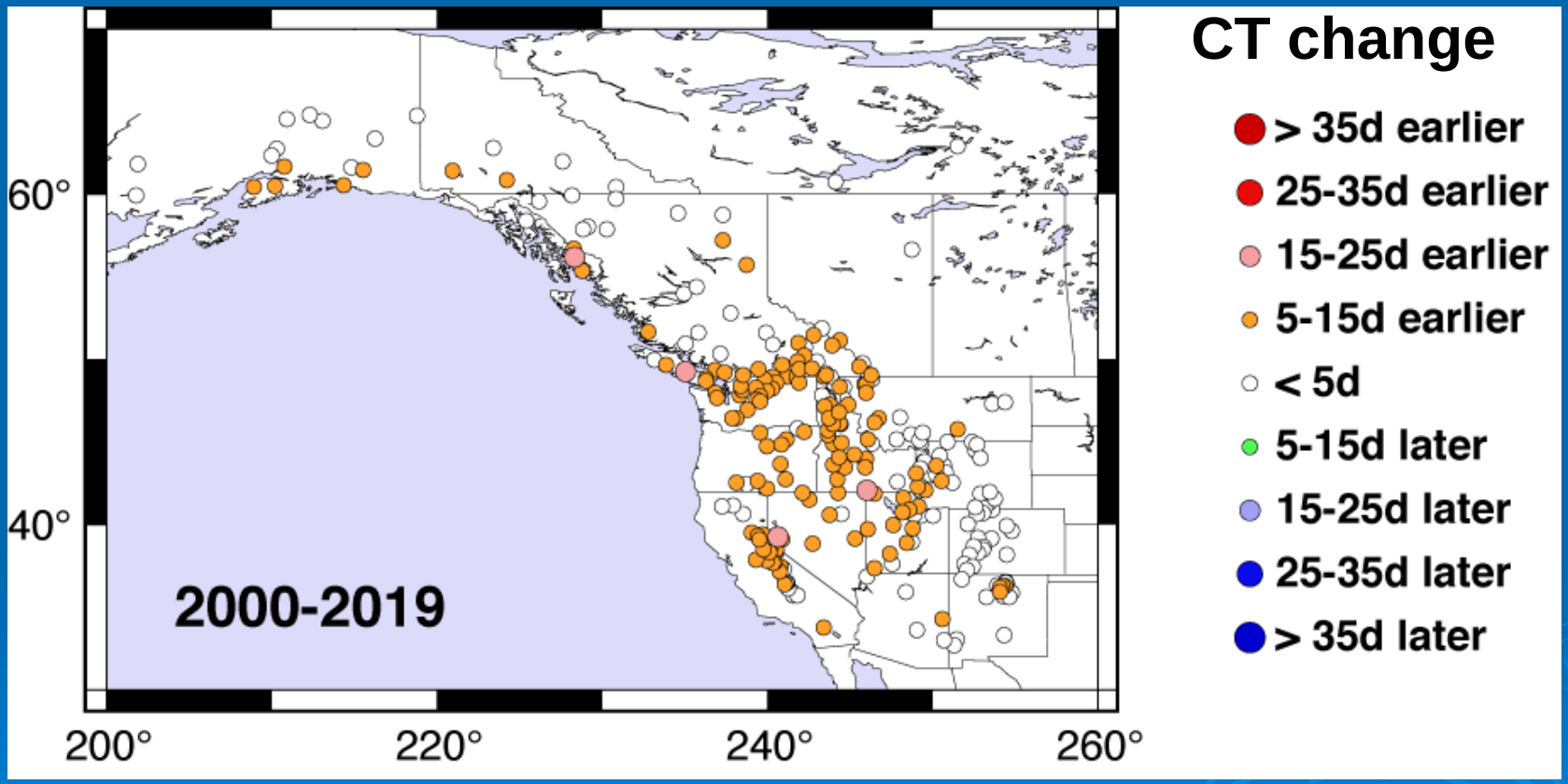


IPCC, 2001

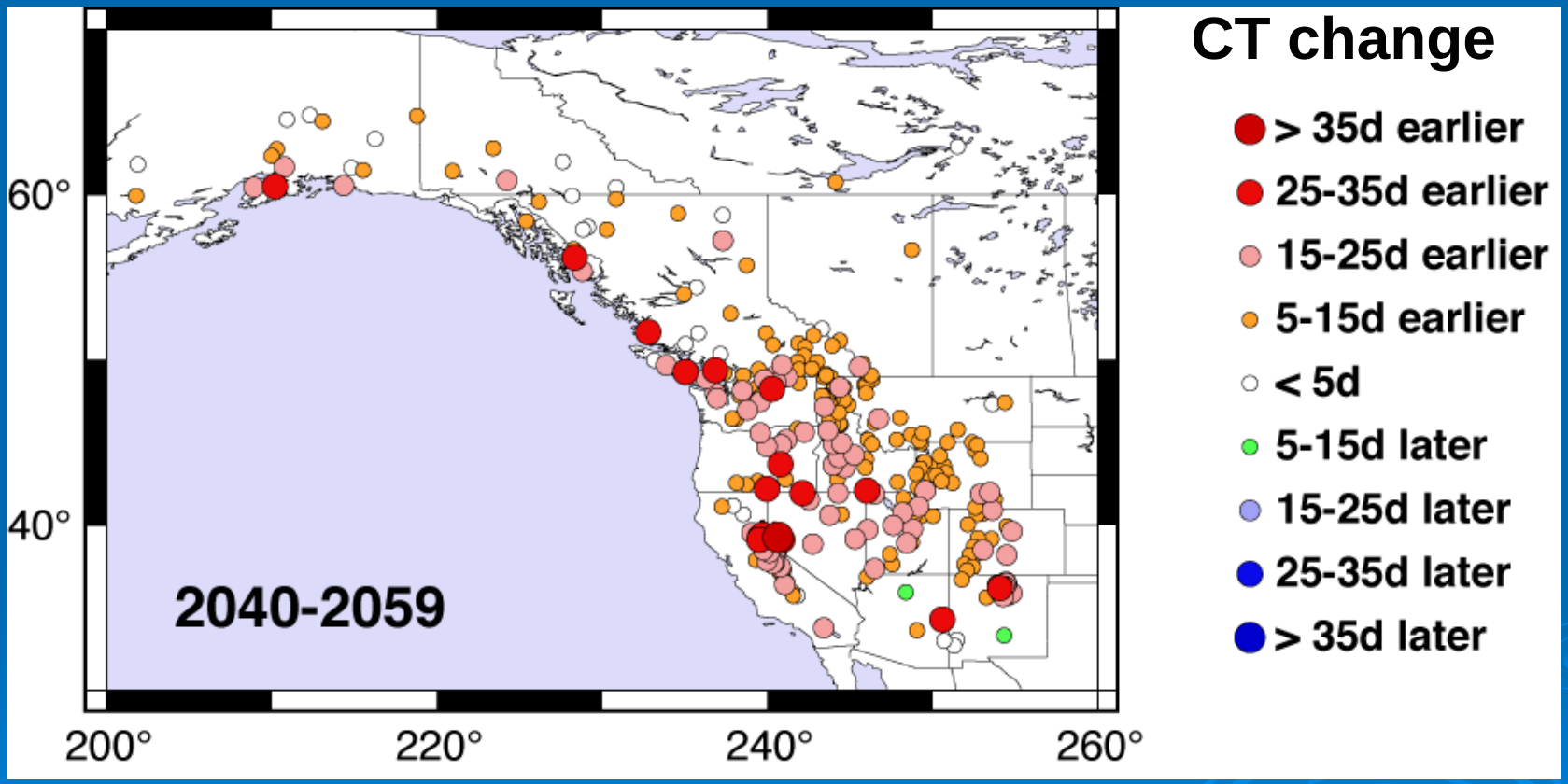
- The rate of warming in the last century was greater than in the last 1000 years
  - IPCC, 2001
- 2006 was the warmest year on record in the contiguous U.S.
  - NOAA, 2007

Projected changes in response to temperature, 2000-2019



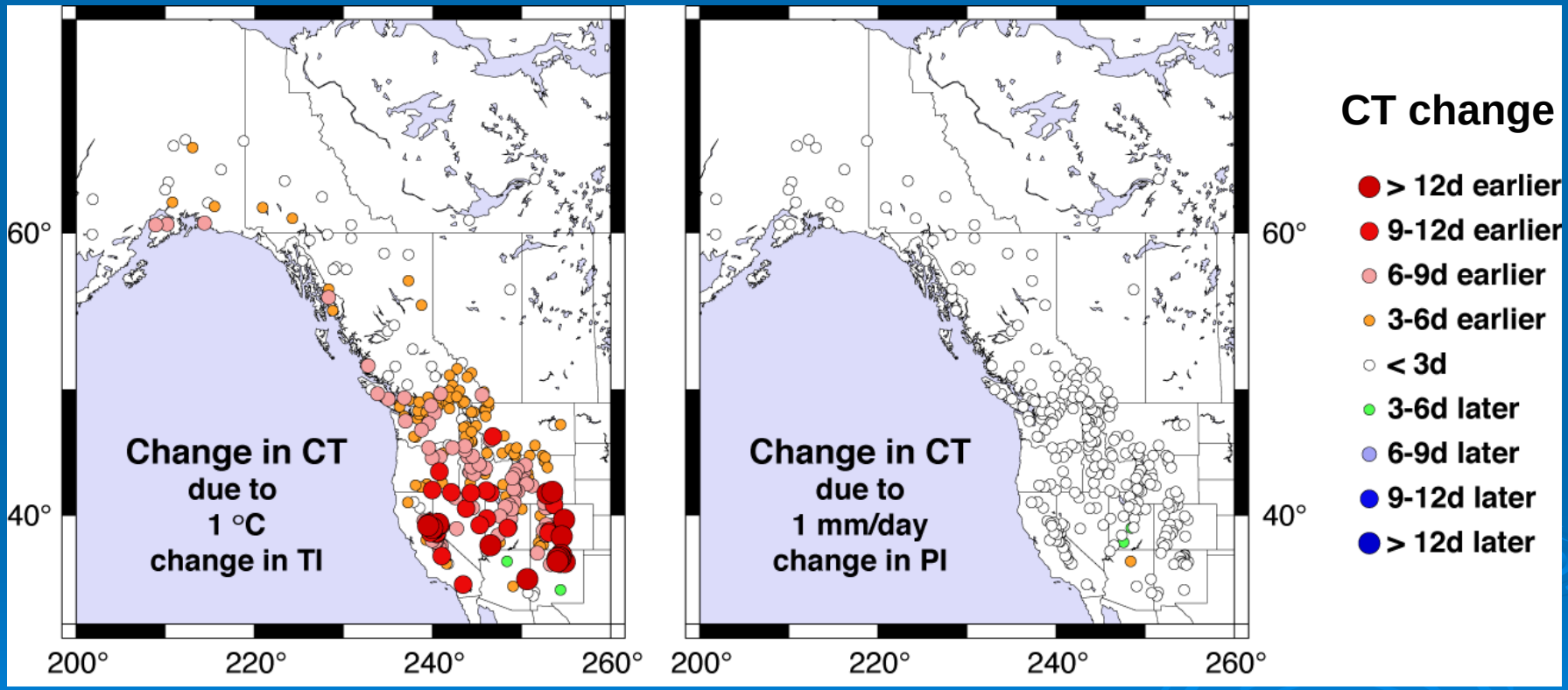
Stewart et al., 2004

Projected changes in response to temperature, 2040-2059



Stewart et al., 2004

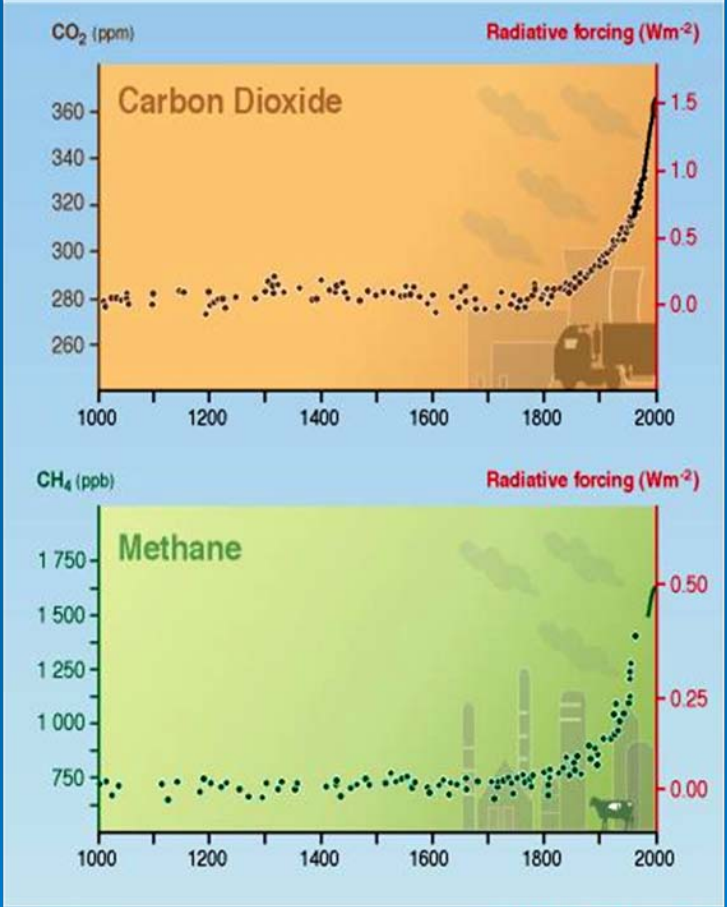
Streamflow timing more sensitive to temperature than precipitation

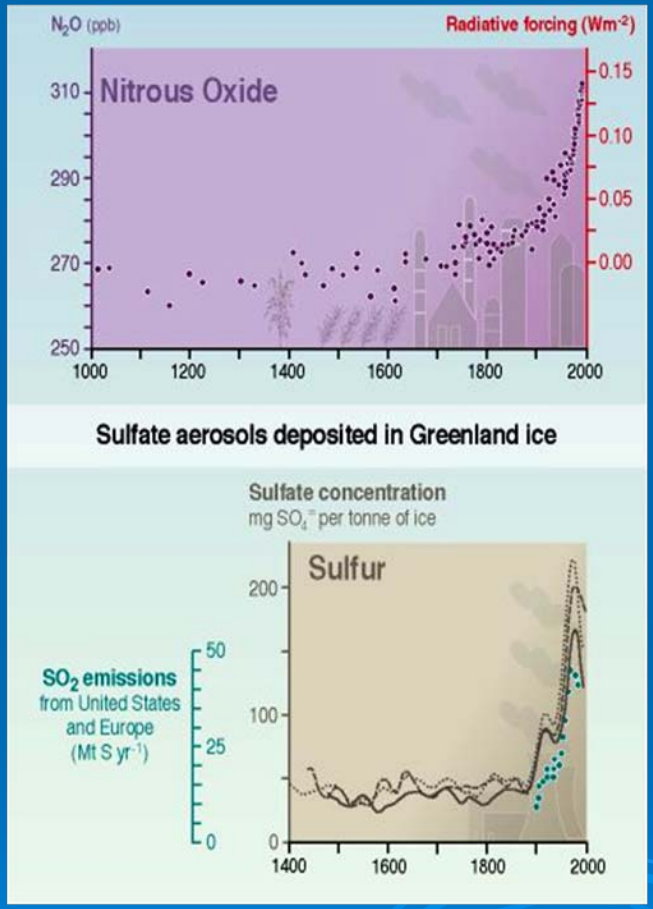


Based on observed relations

Stewart et al., 2004

Greenhouse gas concentrations have increased substantially in the last 1000 years





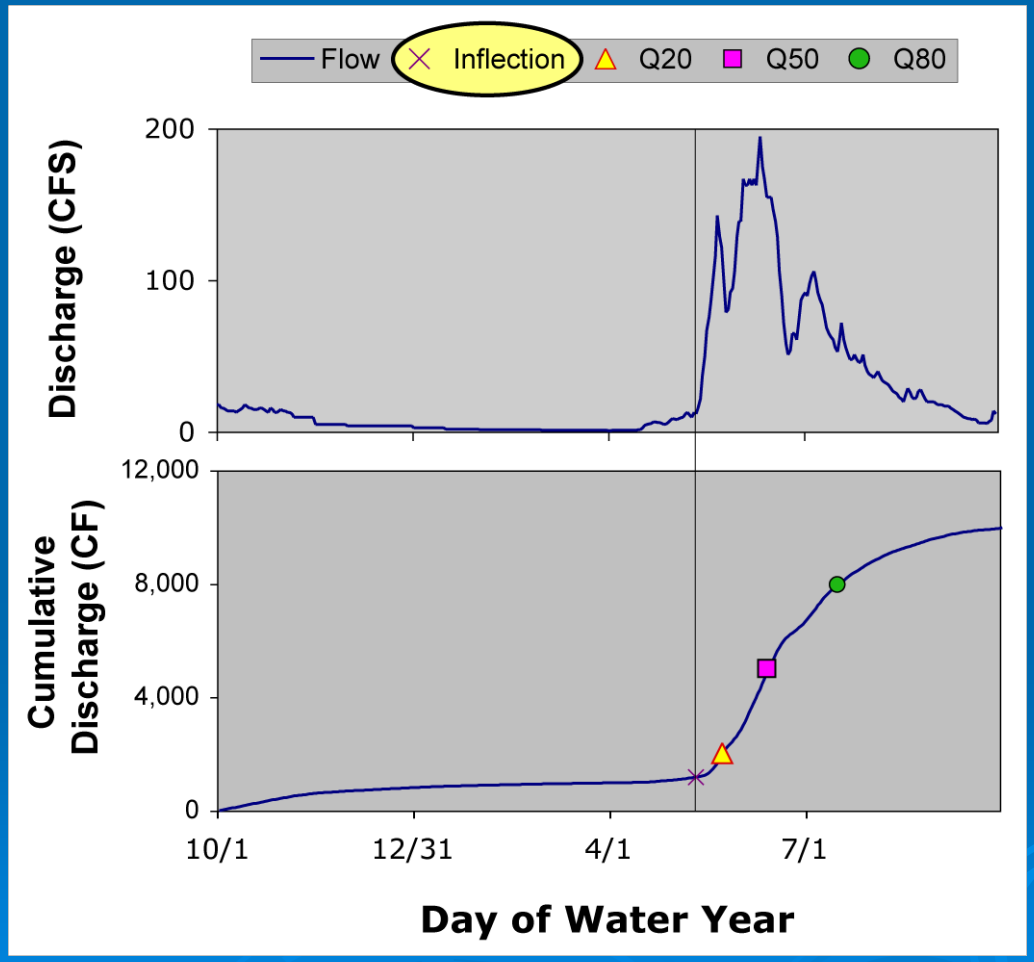
CO_2 concentrations have not been exceeded in at least the past 650,000 years, and probably not during the last 20 million years.

IPCC, 2007

Streamflow and snowmelt timing in the western US

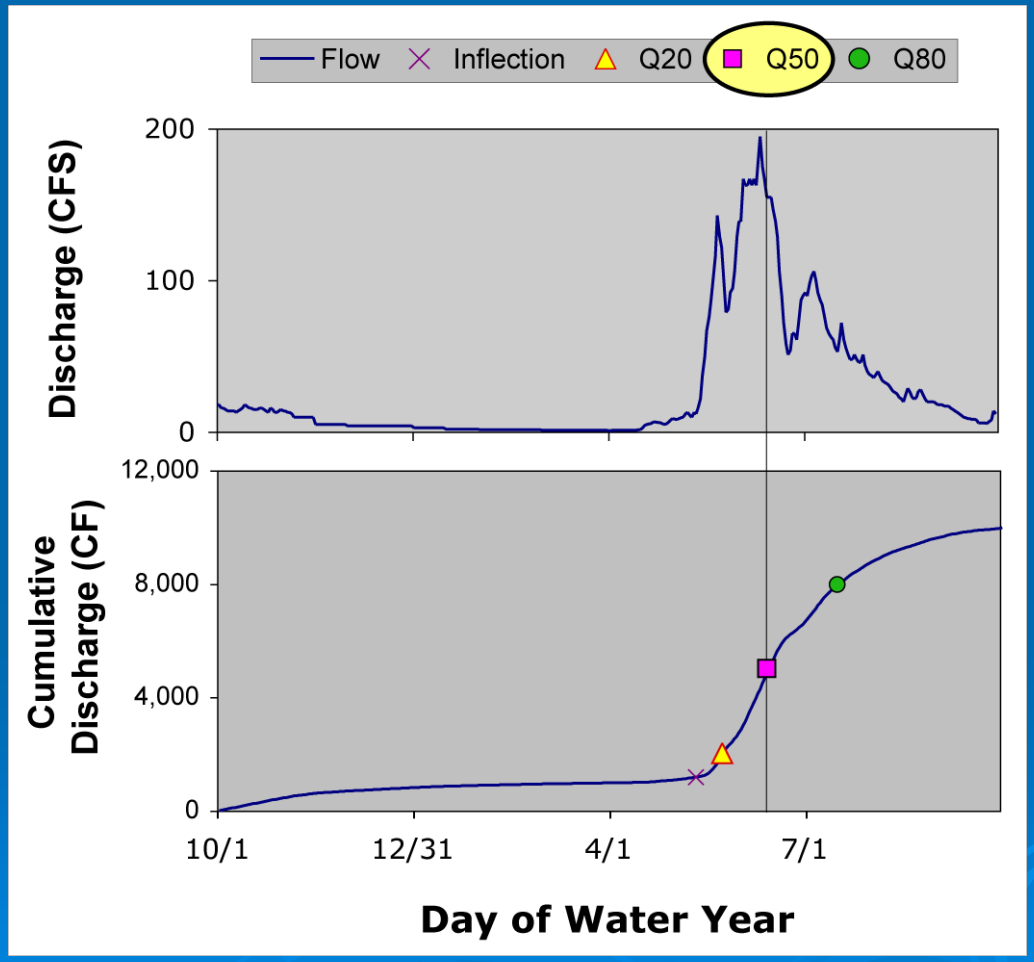
- Methods
- Previous Work
- Results from Current Study

Streamflow Timing Example



Halfmoon Creek, WY 1948

Streamflow Timing Example



Halfmoon Creek, WY 1948

Causes of warming, Natural and Anthropogenic

During the past 30 years, natural climate variability fails to explain the globally averaged surface warming trend