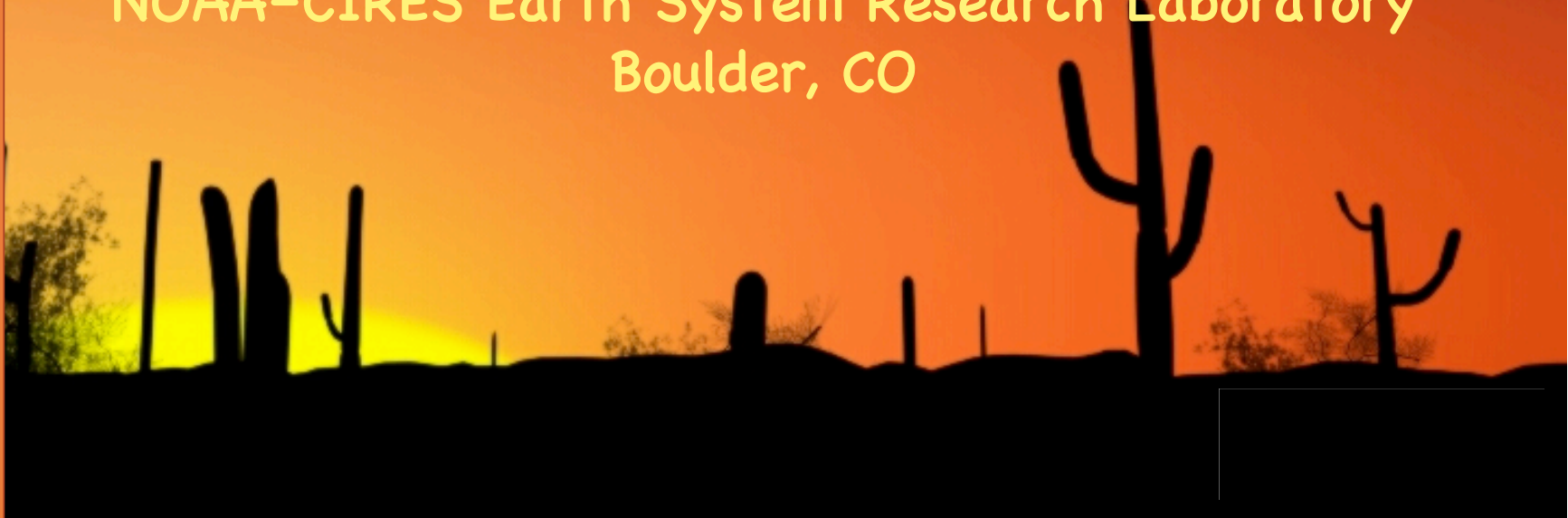




Climate as a Variable: Challenges in Science-Based Resource Management

Henry F. Diaz

NOAA-CIRES Earth System Research Laboratory
Boulder, CO





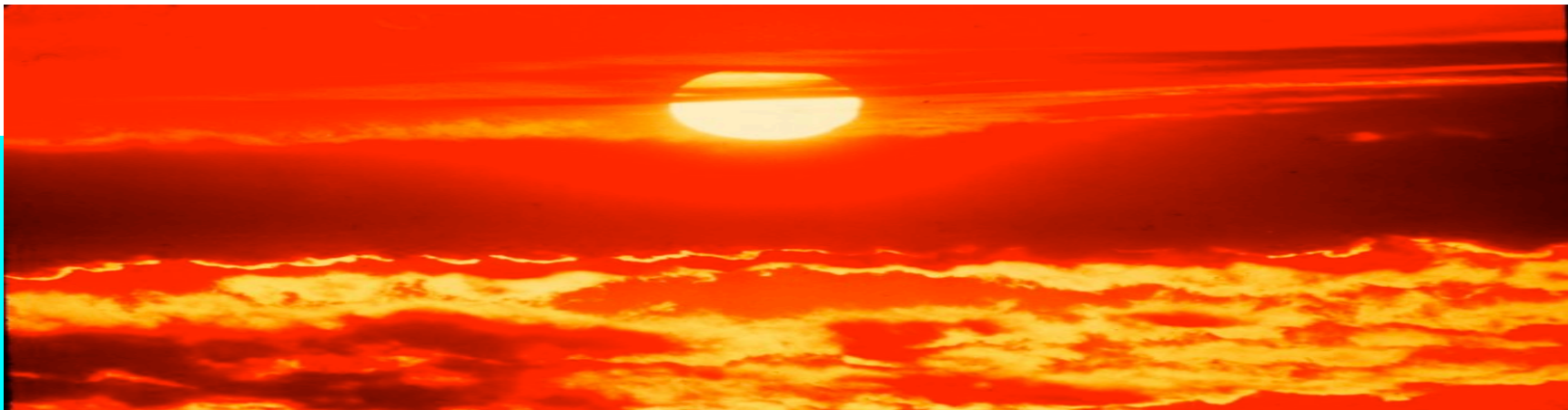
The End of “Stationarity”

Climate change undermines a basic assumption of resources management that the past is the key to the future

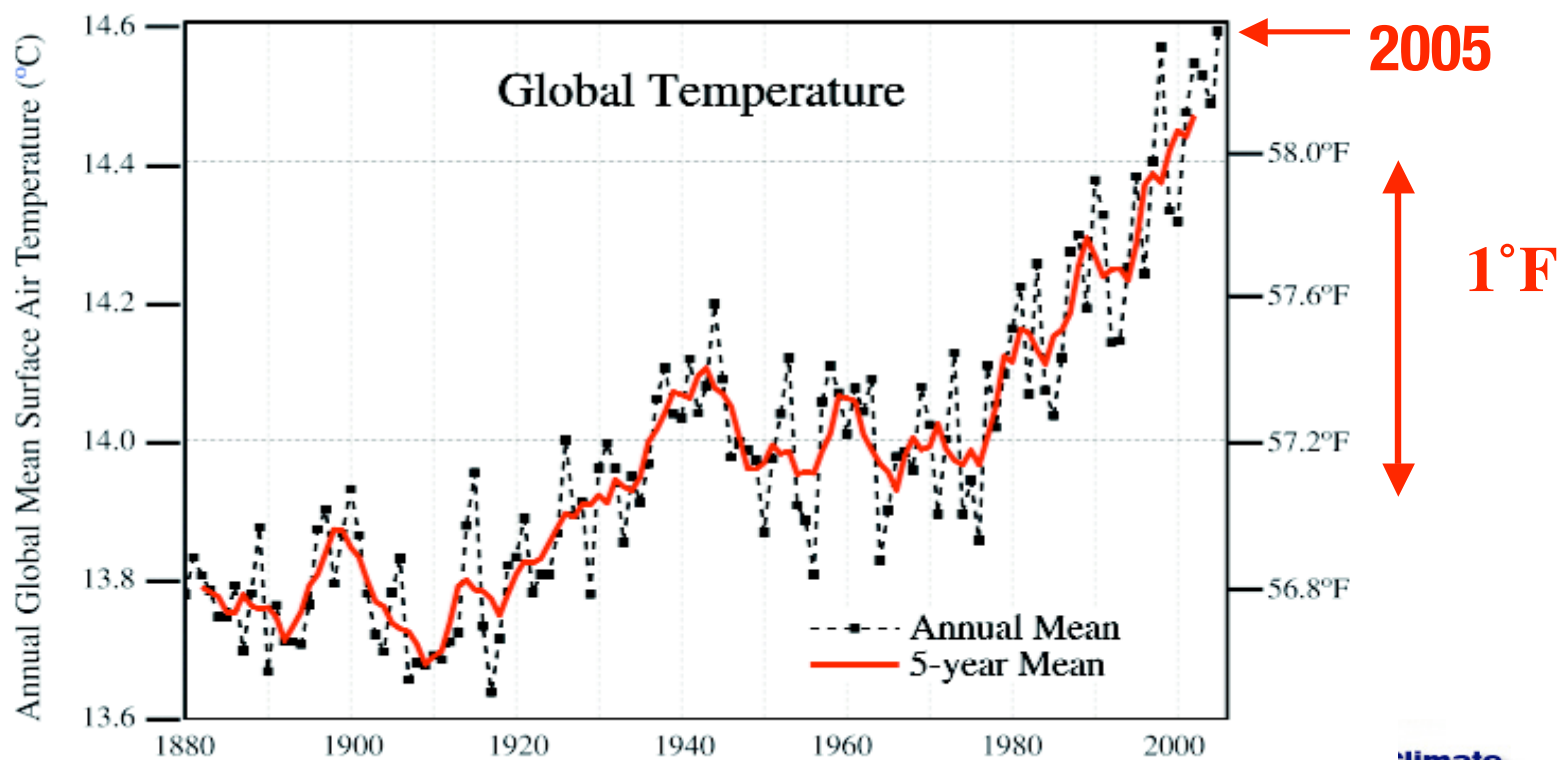
Milly et al. *Science* (2008)

Stationarity Is Dead: Whither Water Management?





6 of the 7 Warmest Years Occur in the 21st Century



National Academy Report 2006

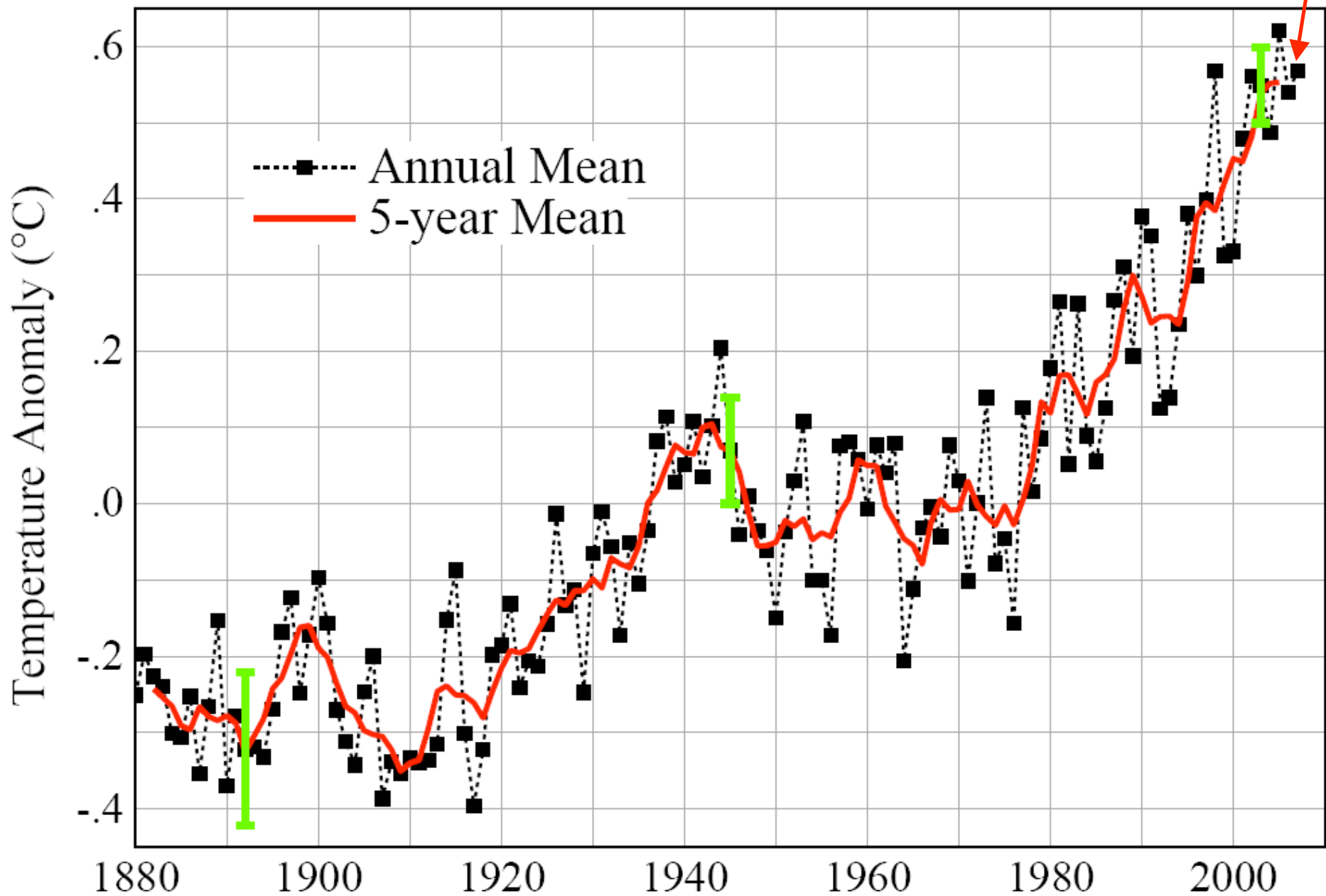




Change and variability are two of the principal attributes of the earth's climate system. This has been true at all time and space scales throughout the earth's evolution. *Diaz (1985) quoting Mitchell (1976)*

- *What is different regarding our present circumstances are the rapidity, magnitude, and irreversible aspects of human-induced global warming.*
- *Although past climatic behavior will continue to be a good basis for future actions, we must be prepared for a future with no-analogs.*

Global Temperature Land-Ocean Index





Simple Summary of the "Climate Crisis"

Well-researched estimates of "irreversible damage" to Earth System caused by increasing CO₂ concentrations is about 450 ppm

Present concentration about 390 ppm

Growth rate about 1% per year

Almost guaranteed to reach 450 ppm by the year 2030





*Are we entering a period of
"inflationary" warming?*

*(i.e., rapid climate change,
resulting in the occurrence
of greater and more
frequent extremes)*

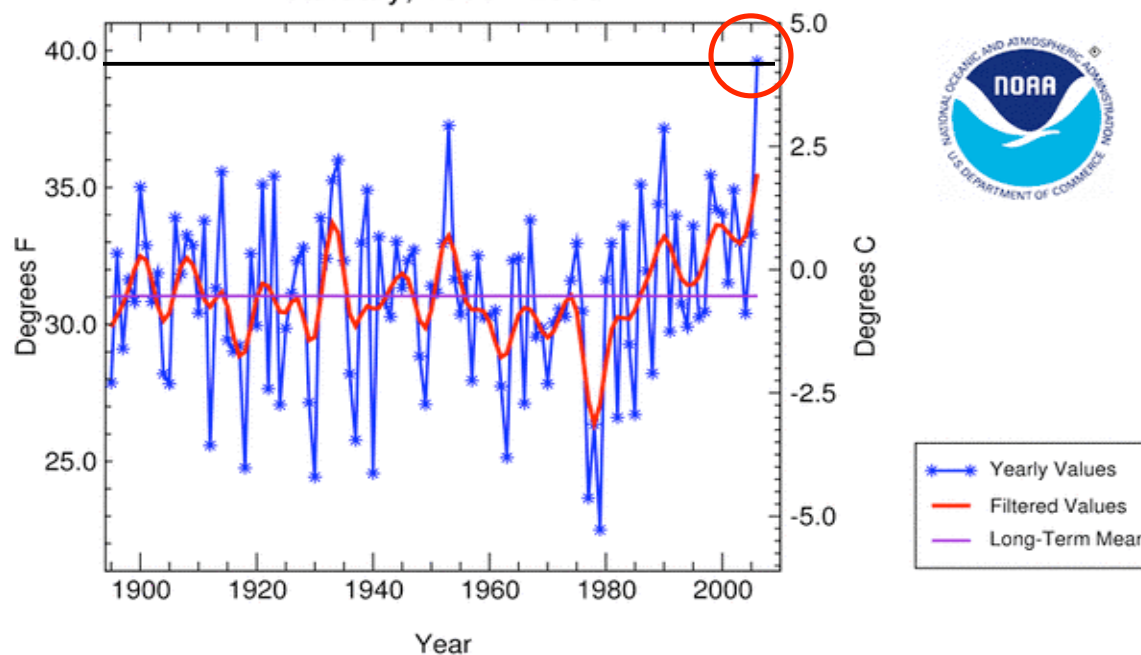




There is evidence for rapid warming and the occurrence of extreme events in most of the conterminous US

January 2006

National (Contiguous U.S.) Temperature
January, 1895 - 2006



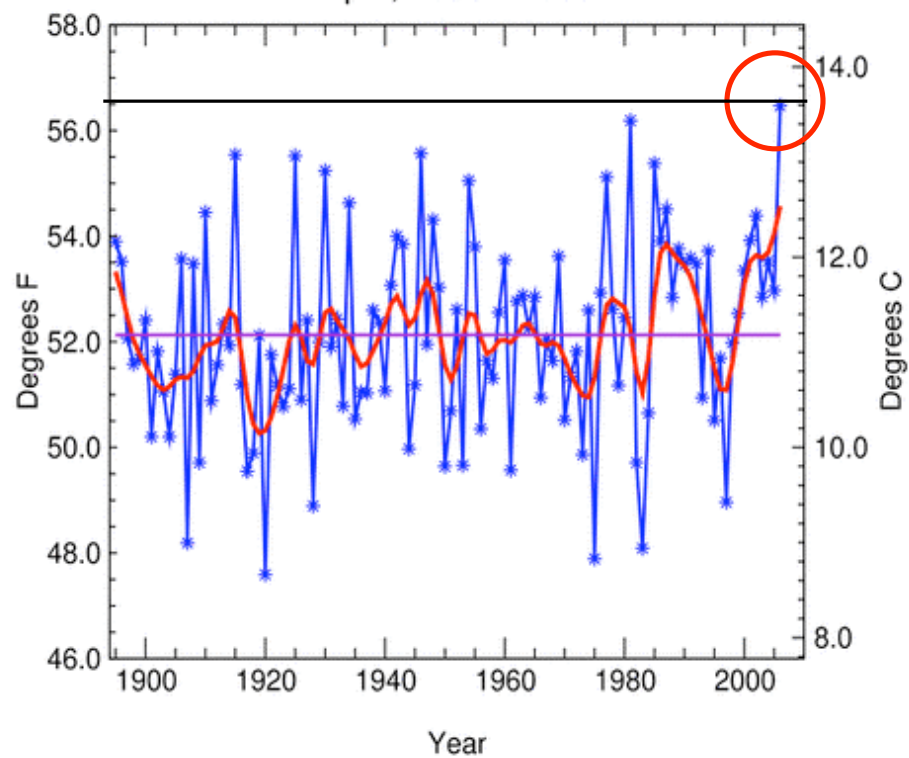
National Climatic Data Center / NESDIS / NOAA





April 2006

National (Contiguous U.S.) Temperature April, 1895 - 2006



- * Yearly Values
- Filtered Values
- Long-Term Mean

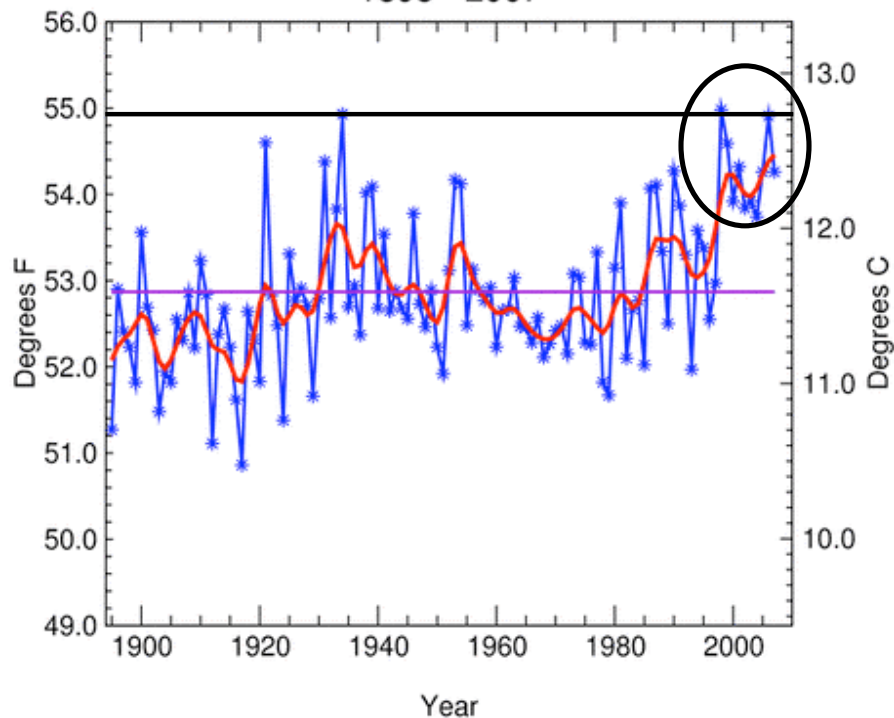
National Climatic Data Center / NESDIS / NOAA





National (Contiguous U.S.) Temperature 1895 - 2007

2°F
↑



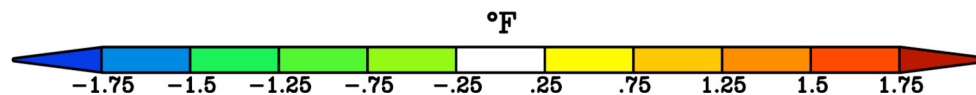
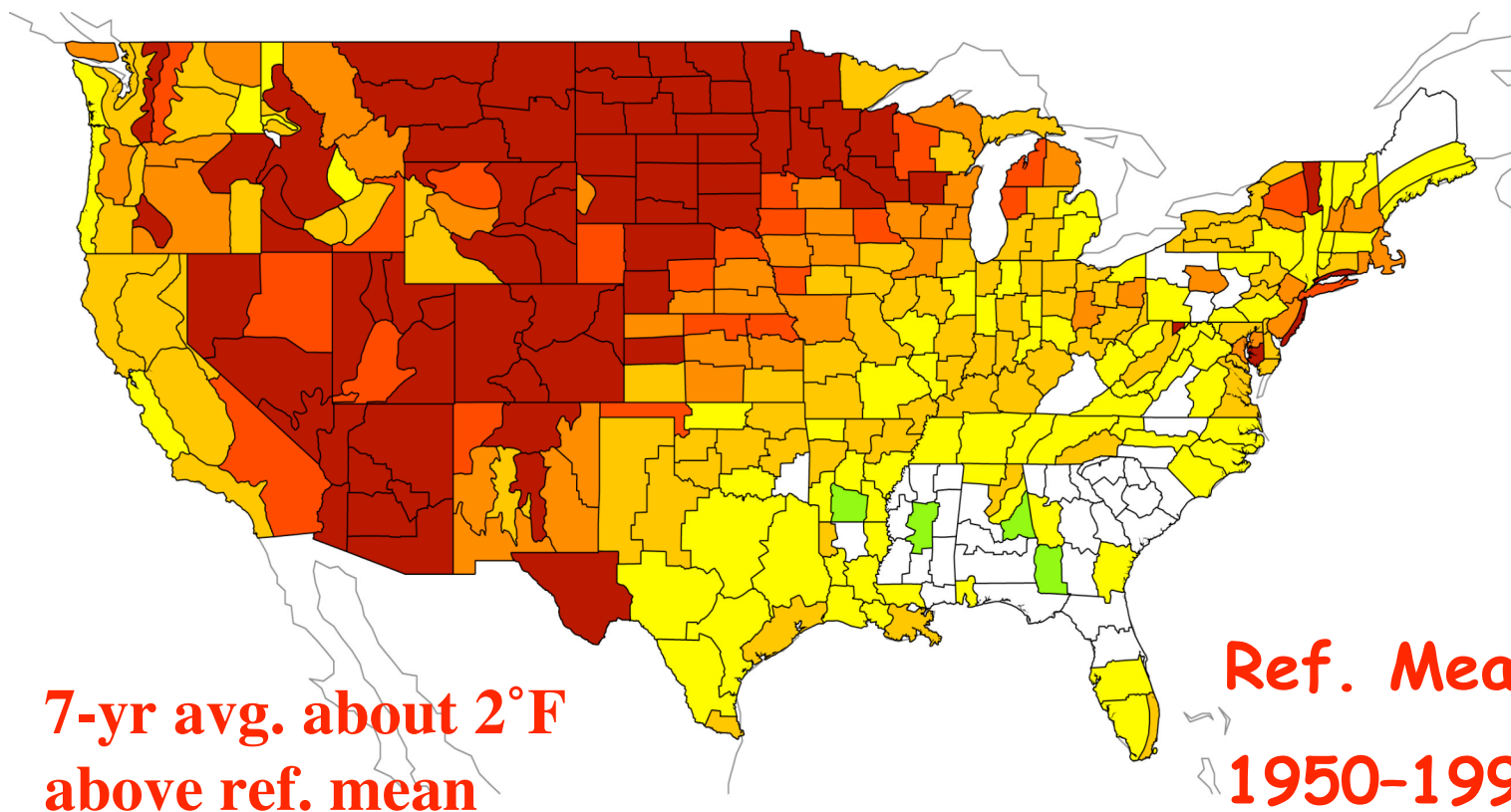
- Yearly Values
- Filtered Values
- Long-Term Mean

National Climatic Data Center / NESDIS / NOAA



America's West: Epicenter for Warming

Observed Annual Temperature Anomaly 2000-2006





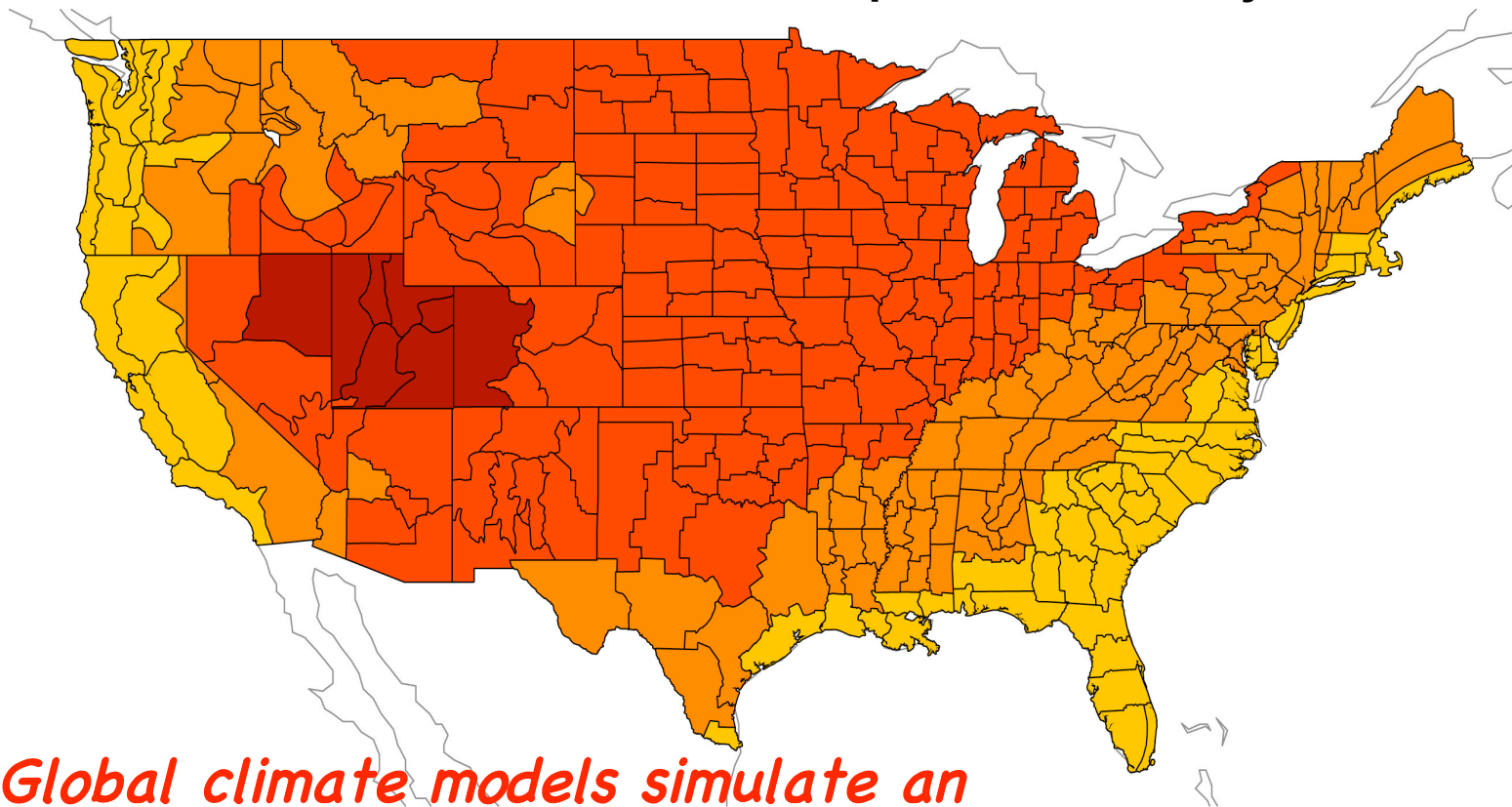
*How do we know that
these changes are caused
by increasing greenhouse
gases?*



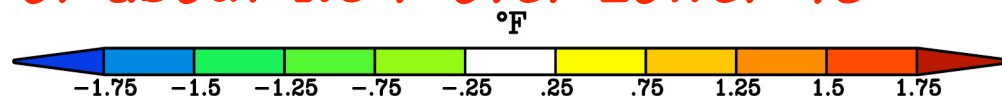


America's West: Epicenter for Warming

Greenhouse Gas Forced Annual Temperature Anomaly 2000-2006



*Global climate models simulate an
increase of about 1.5°F over Lower 48*

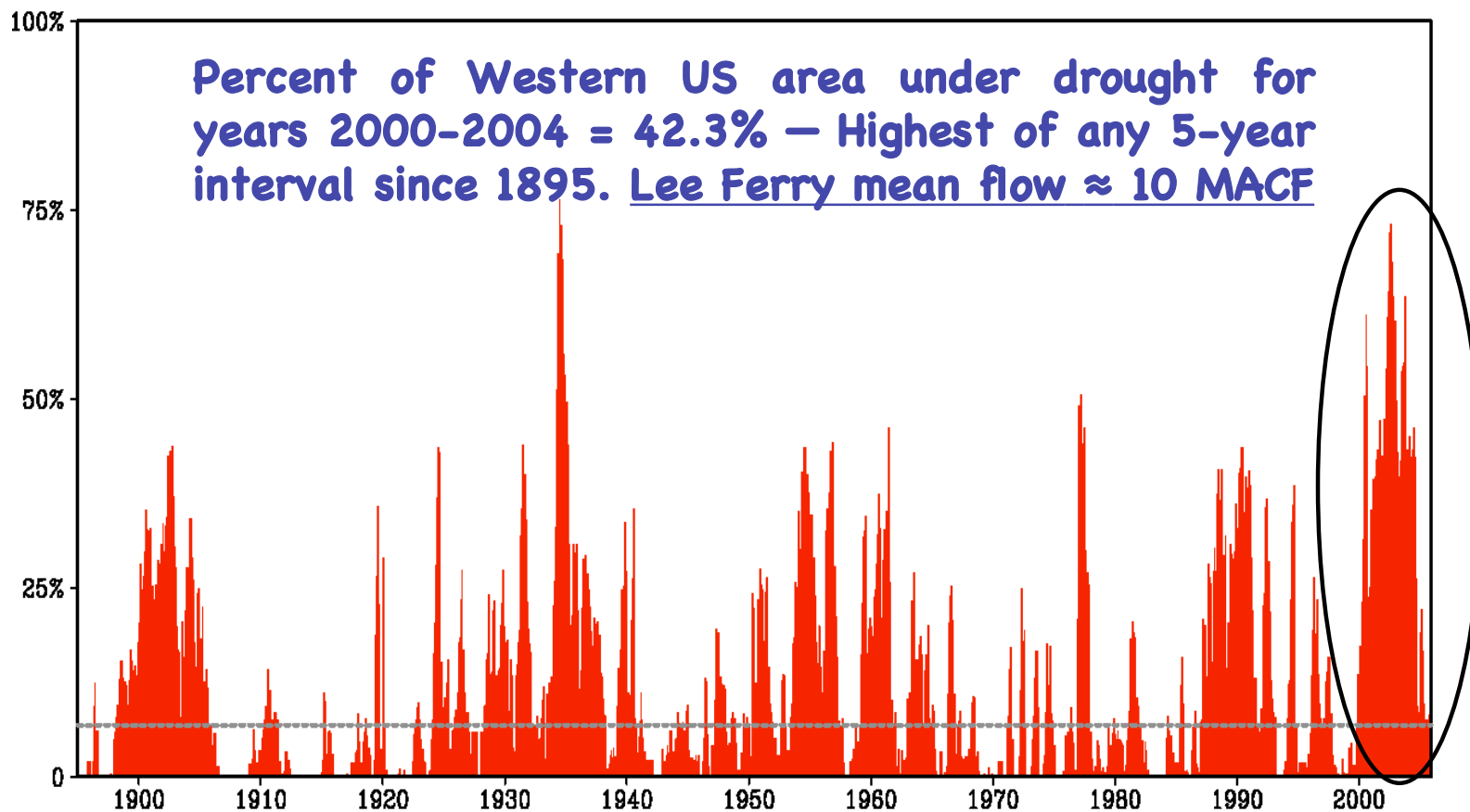




What is happening with Precipitation?



Percent of Western U.S. with PDSI ≤ -3 Jan1895 Dec2005



Level of Lakes Mead and Powell dropped to about 50% of capacity

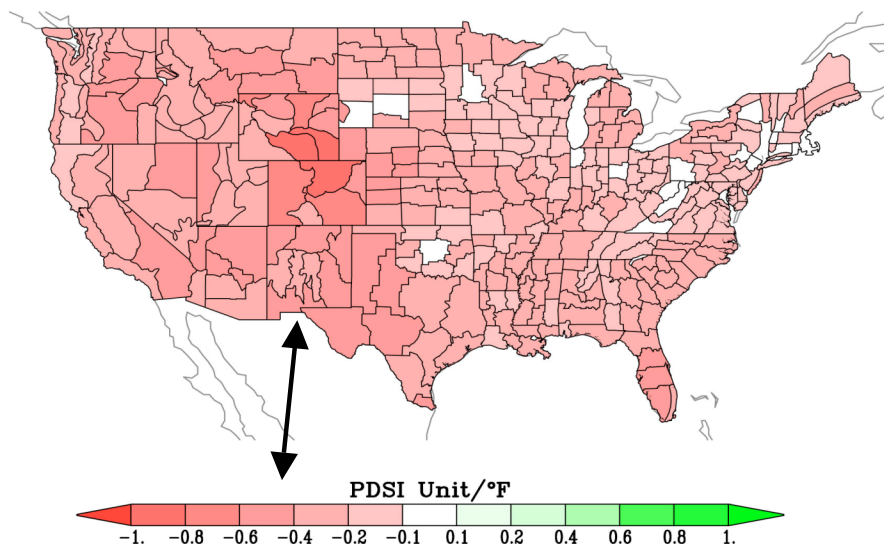




Impact of Mean Temperature and Precipitation Trends

Regression of Water Year PDSI versus mean temperature after removing effect of precipitation changes.

Residual Temperature vs. PDSI: 1896–2005

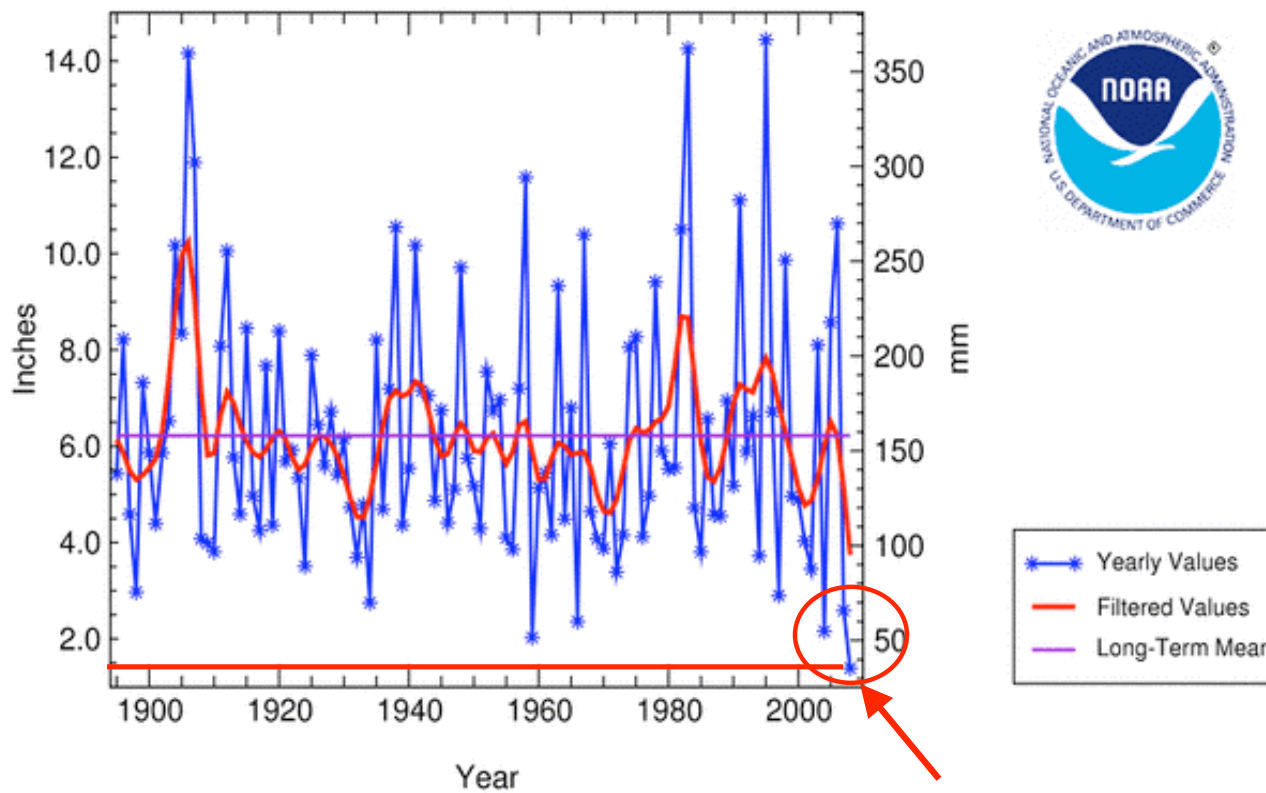


For the West
about -0.5 PDSI unit of
change per 1°F of
warming





California Statewide Precipitation March - August, 1895 - 2008



National Climatic Data Center / NESDIS / NOAA



What is happening at the higher elevations in the West?

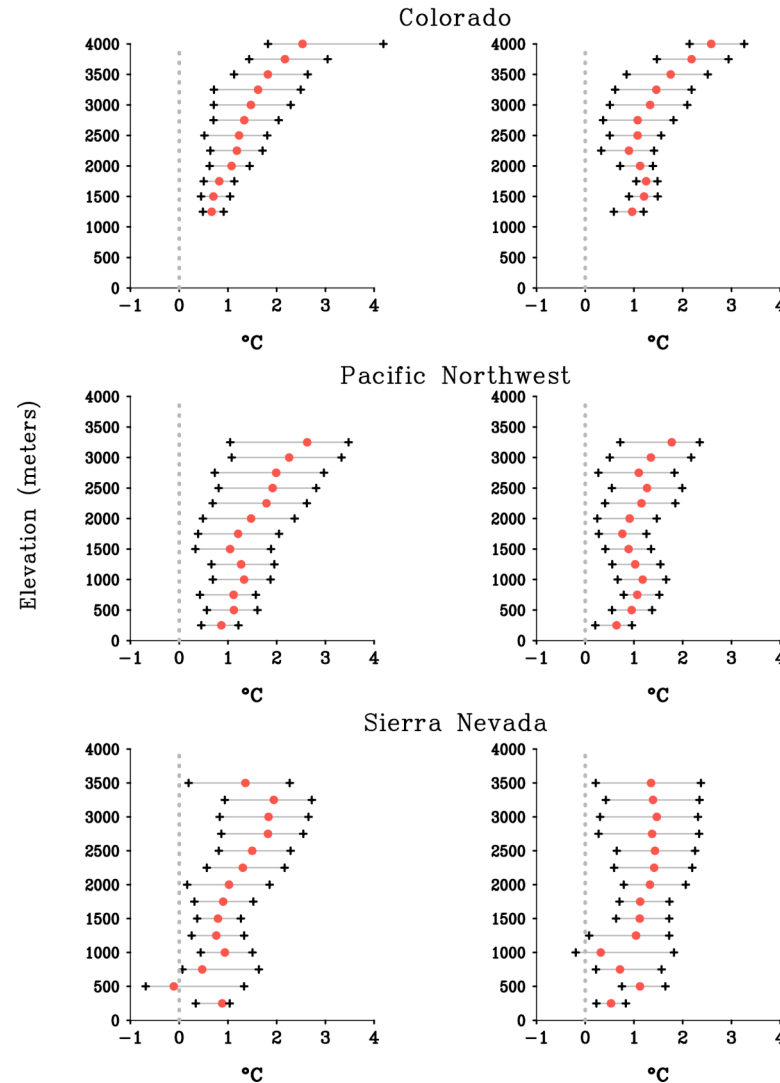


America's West: Greater Warming at Higher Elevations

Post-1978 Observed Temperature Trends vs Station Elevation

Minimum Temperature

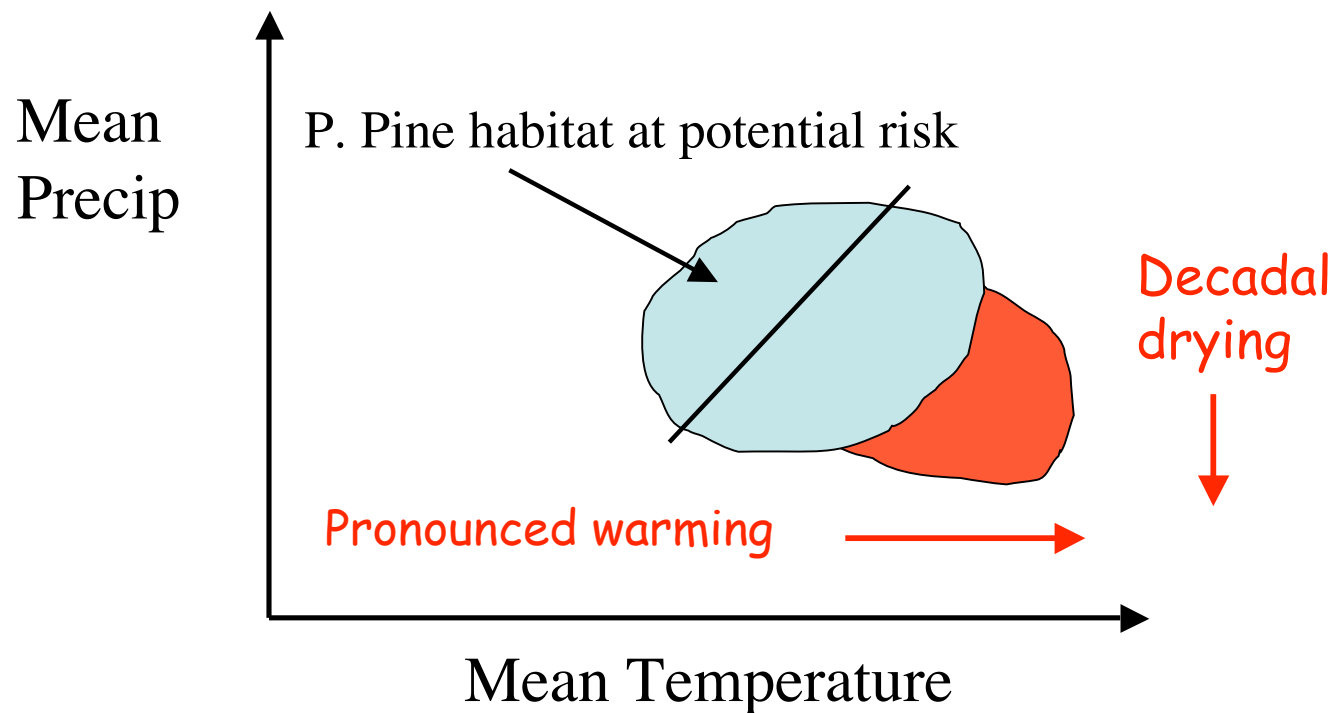
Maximum Temperature



Warming of $\sim 1-2^{\circ}\text{C}$ ($\sim 2-3^{\circ}\text{F}$) at mid-to-upper elevations in the West in the past 3 decades

*From Diaz and Eischeid
Geophys. Res. Lett. 2007*





Ponderosa Pine habitat ~6000–7000 ft elevation
getting drier and warmer



Western US climate is becoming warmer, with greater variability and more frequent extremes

What are some of the impact of these climate trends on western forests?

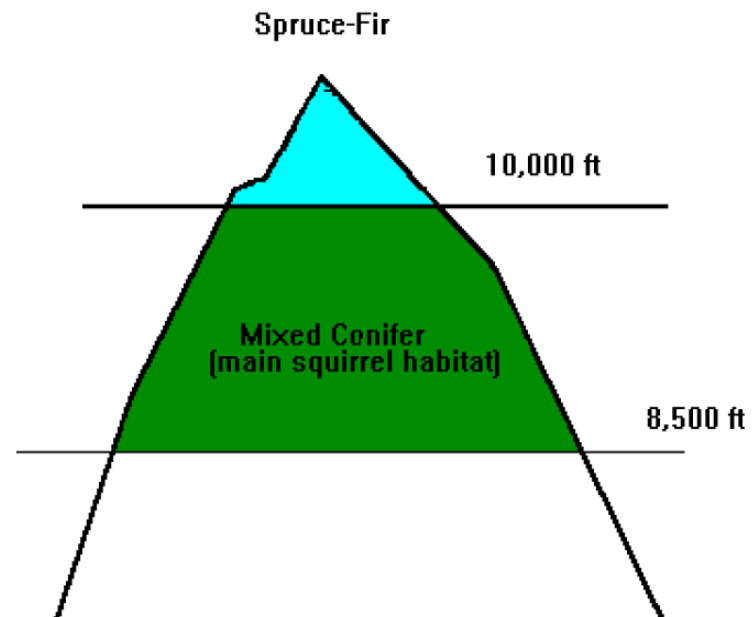


Mt. Graham Red Squirrel



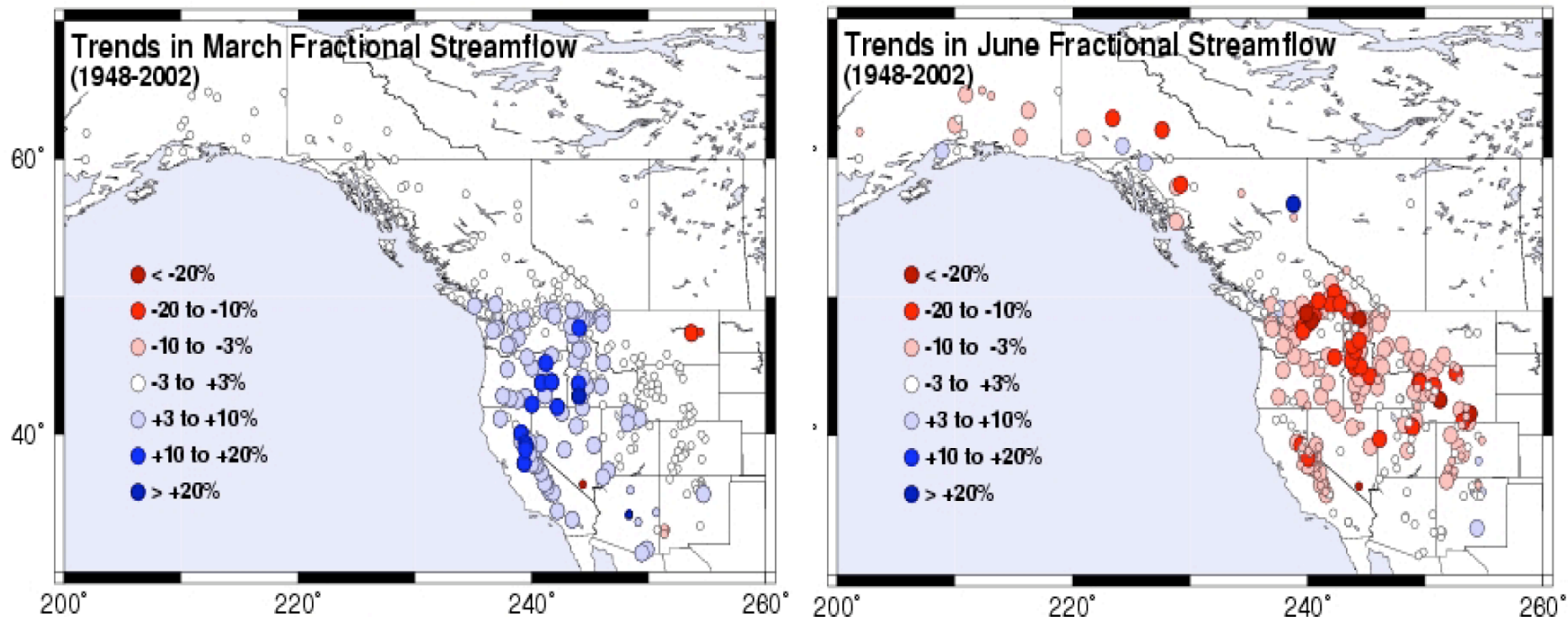
Mount Graham Red Squirrel (Credit: Claire Zugmeyer)

*Upward shift of ecotonal
boundaries?*



Western Sky Islands

...Spring is Coming Earlier in the West



After Stewart, Cayan, and Dettinger (2005)

- *Trend towards an earlier melt out and earlier peak flows throughout the Western US are consistent with a warming trend.*
- *Changes in seasonal cycle have potentially important implications for water management. Both supply and demand are affected.*



Fish/Aquatic Ecosystem Vulnerability to Heat



Heat Kills Fish in Yellowstone

By Cory Hatch
July 7, 2007

Water temperatures of up to 82 degrees killed hundreds of rainbow and brown trout on the Firehole River this past week as warm, dry weather continues to pummel the Greater Yellowstone ecosystem.

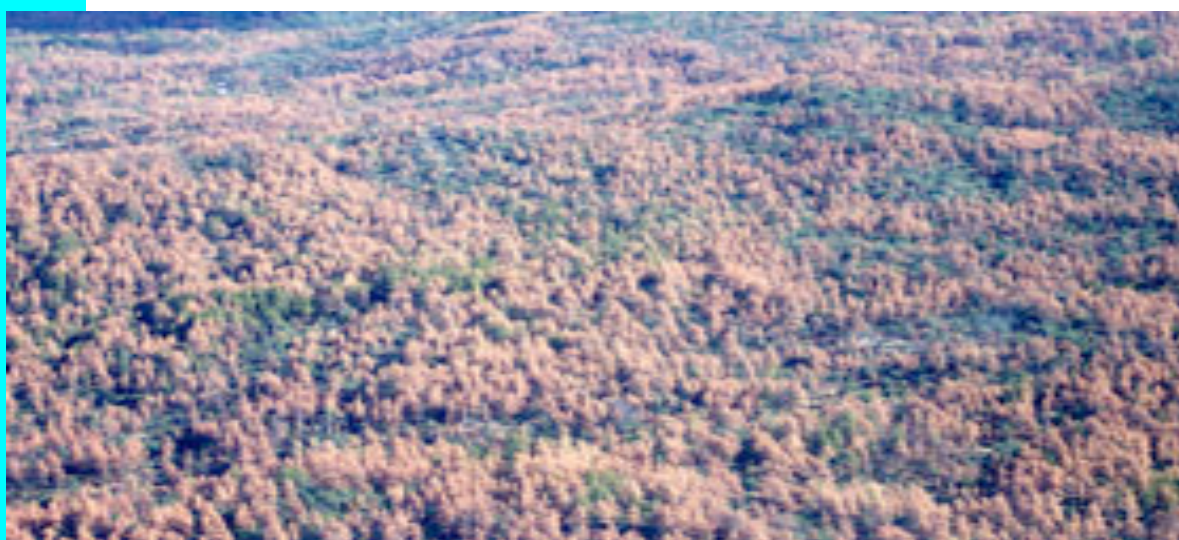
Exceedance of threshold values for sustainable ecosystems





Failing Health of Colorado's Forests

Explosive Growth of Pest Insect Infestation





Forthcoming Demise of Lodgepole Pines (?)

From Rocky Mountain News
15 January 2008



*“Every large, mature lodgepole pine forest in Colorado and southern Wyoming will be dead within three to five years, killed in a **mountain pine beetle** infestation unprecedented in the state.”*

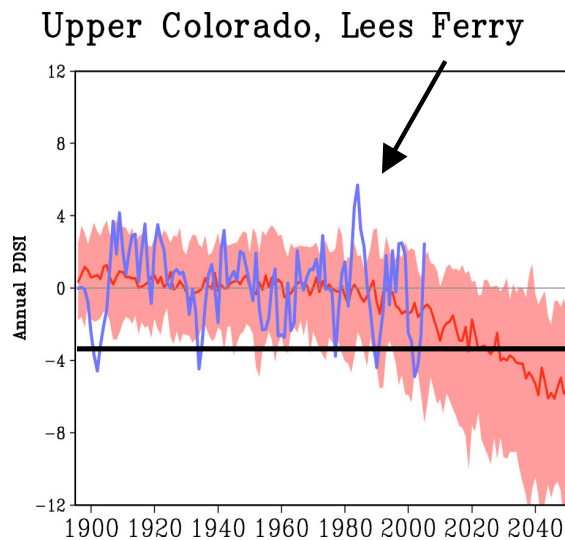
*In 2007 alone, the infestation tore through another 500,000 high-elevation acres and embedded itself along the Front Range, exploding in Boulder and Larimer counties where affected acres grew by **1,500 percent**.*

Foresters, calling the numbers "catastrophic," said recent aerial surveys reveal the dead and dying lodgepole acreage now has grown to 1.5 million since the first signs of outbreak in 1996. With 22 million acres of forest in Colorado, the beetles won't kill it all, but they could do away with most of the "pure lodgepole" stands as well as many of the trees within mixed systems of lodgepole, spruce, fir and ponderosa.

The U.S. Forest Service describes the die-off as "a huge, unprecedented event" with major social and economic implications.”



Potential Drought Change for the Upper Colorado Basin by 2060 (Worse case scenario!)



Slope of
regression

Change in PDSI

$$1.69 \times (-4) \sim -6.8 \text{ MACF}$$

$$\approx 15 - 6.8 = 8.2 \text{ MACF !}$$

Approx. 55% of historical values!

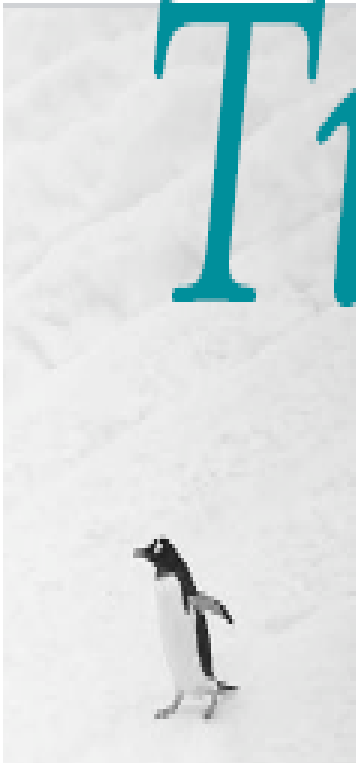
More likely scenario: $\Delta T \sim 2.5F \approx -1.5$ (Δ PDSI)

$$1.69 \times (-1.5) \sim -2.5 \text{ MACF} \rightarrow 12.5 \text{ MACF}$$

Approx. 85% of historical values



Tipping Point



“Our home planet is dangerously near a tipping point at which human-made greenhouse gases reach a level where major climate changes can proceed mostly under their own momentum”

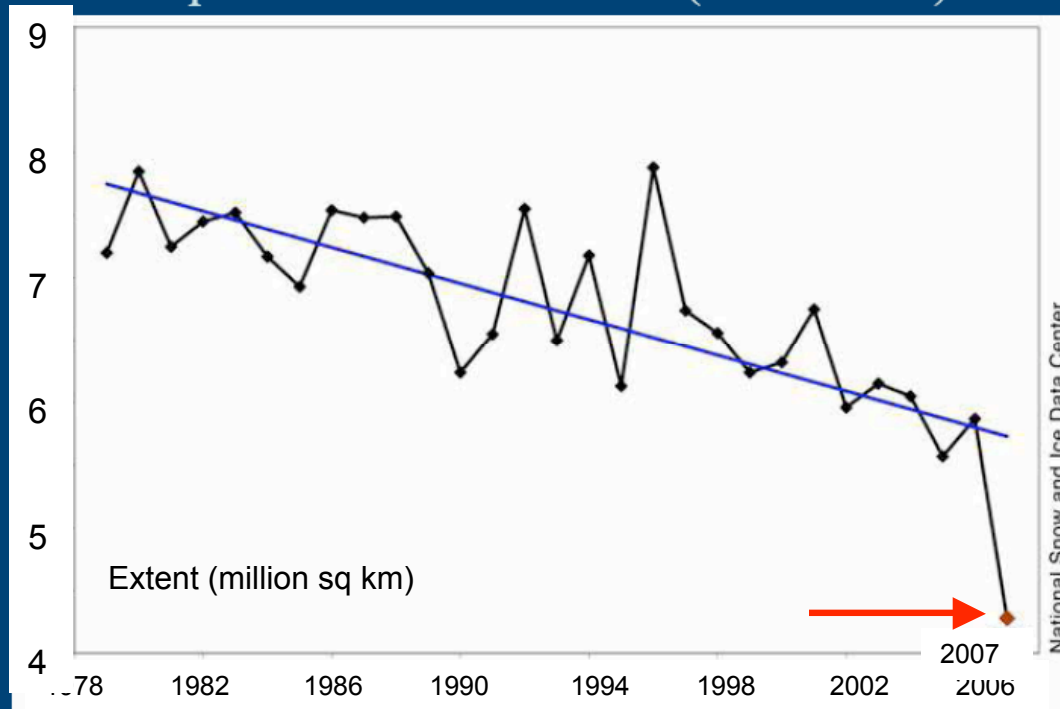
Jim Hansen





2007 Sea ice conditions in context

September Sea Ice Extent (1979–2007)

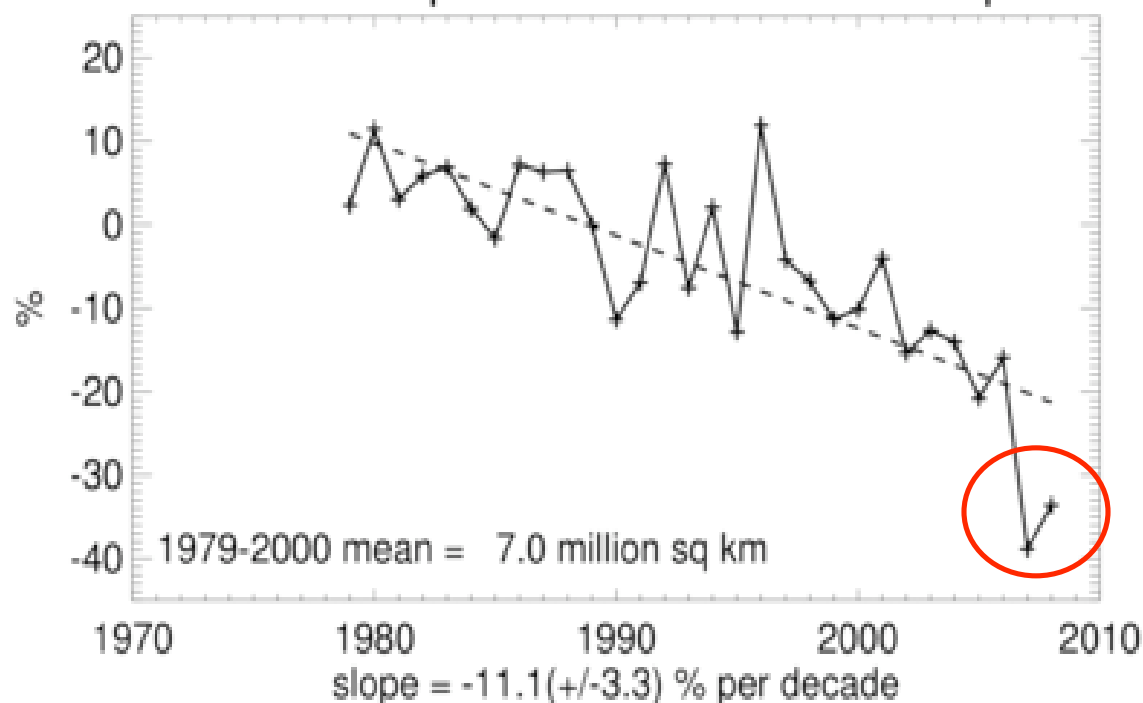


September 2007
4.28 million km²

Mark Serreze, Julienne Stroeve, Walt Meier, Ted Scambos, Marika Holland, Jim Maslanik, Stephanie Renfrow, Matt Savoie



Northern Hemisphere Extent Anomalies Sep 2008



System does not recover

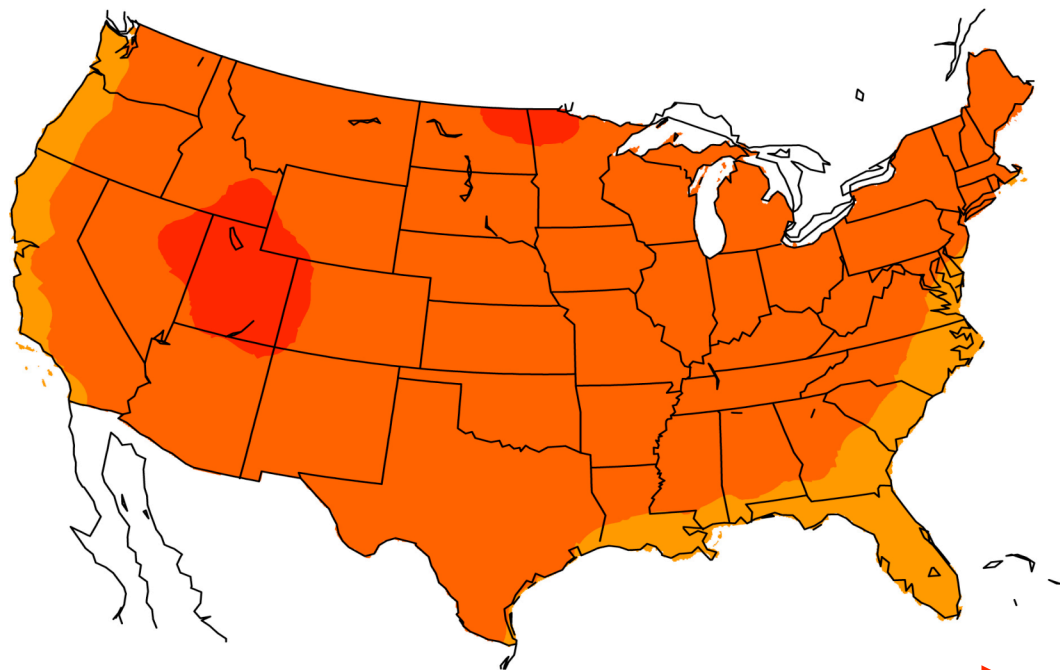
Implications: Faster sea-level rise than anticipated just a few years ago on account of warmer oceans and faster ice-melt from Greenland.



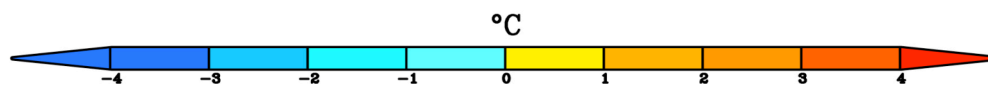
Projected Western US Warming +4°C by 2100

For every 0.5°C warming, montane tree lines advance ~300 feet

Projected (2100) Annual Temperature



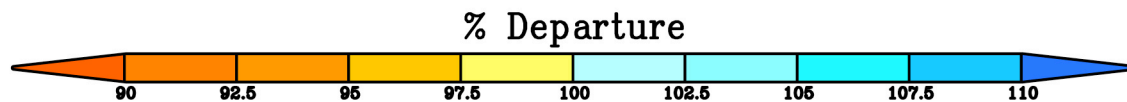
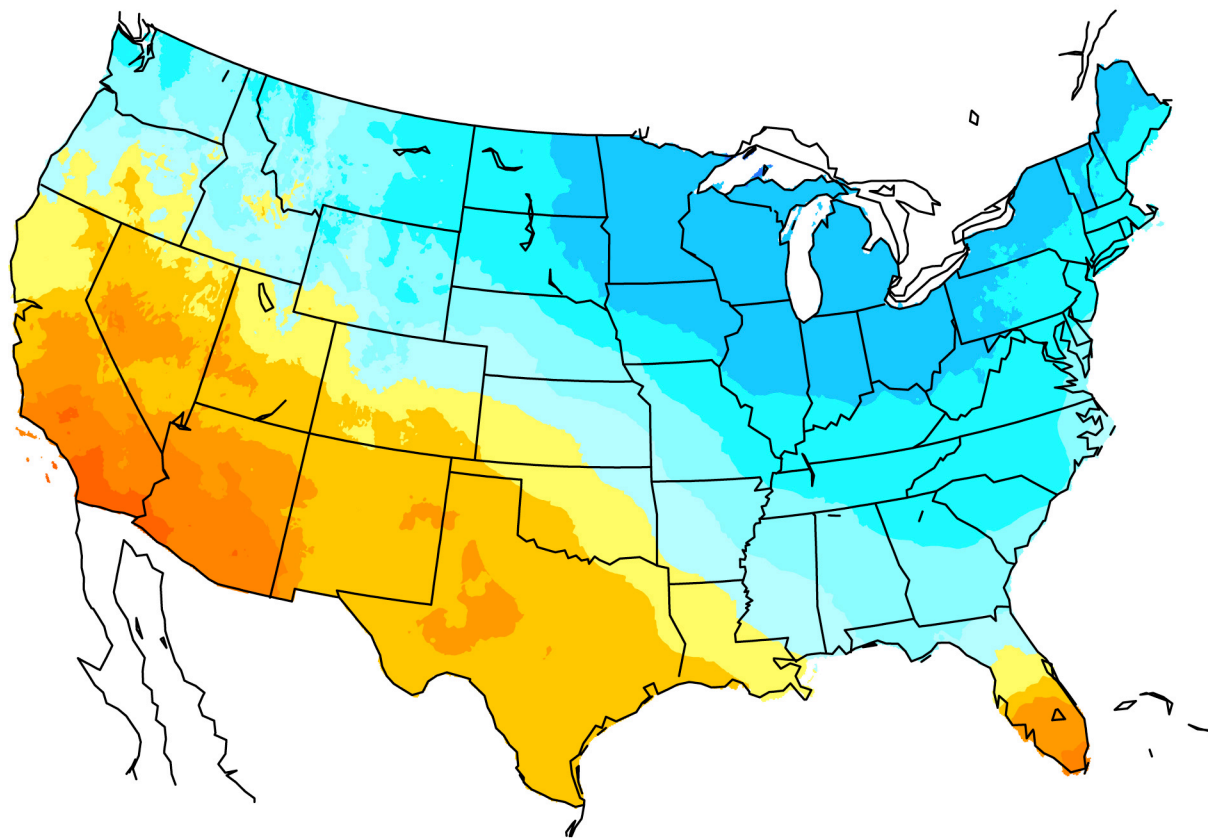
→ **> 3°C/5°F**



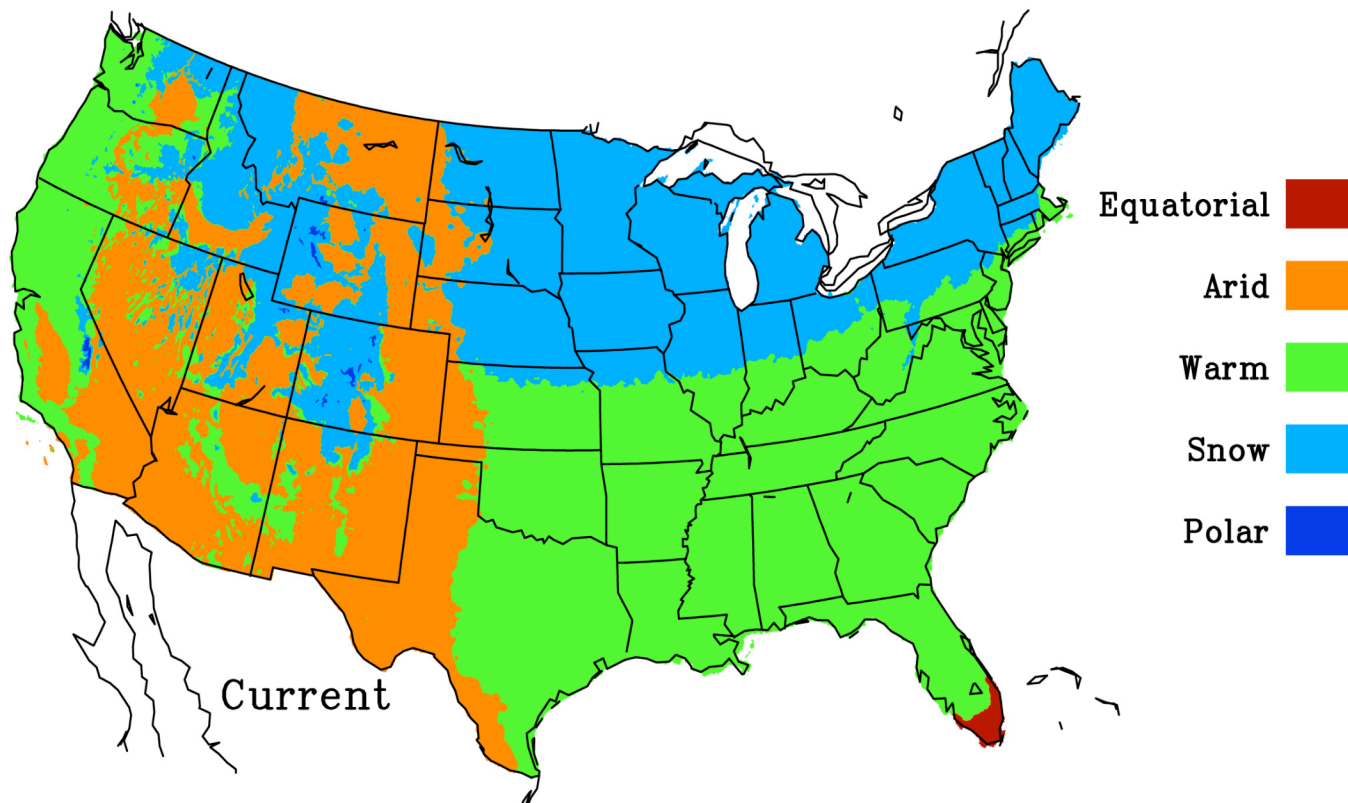


Southwest Reduction in Precipitation by 2100

Projected (2100) Annual Precipitation



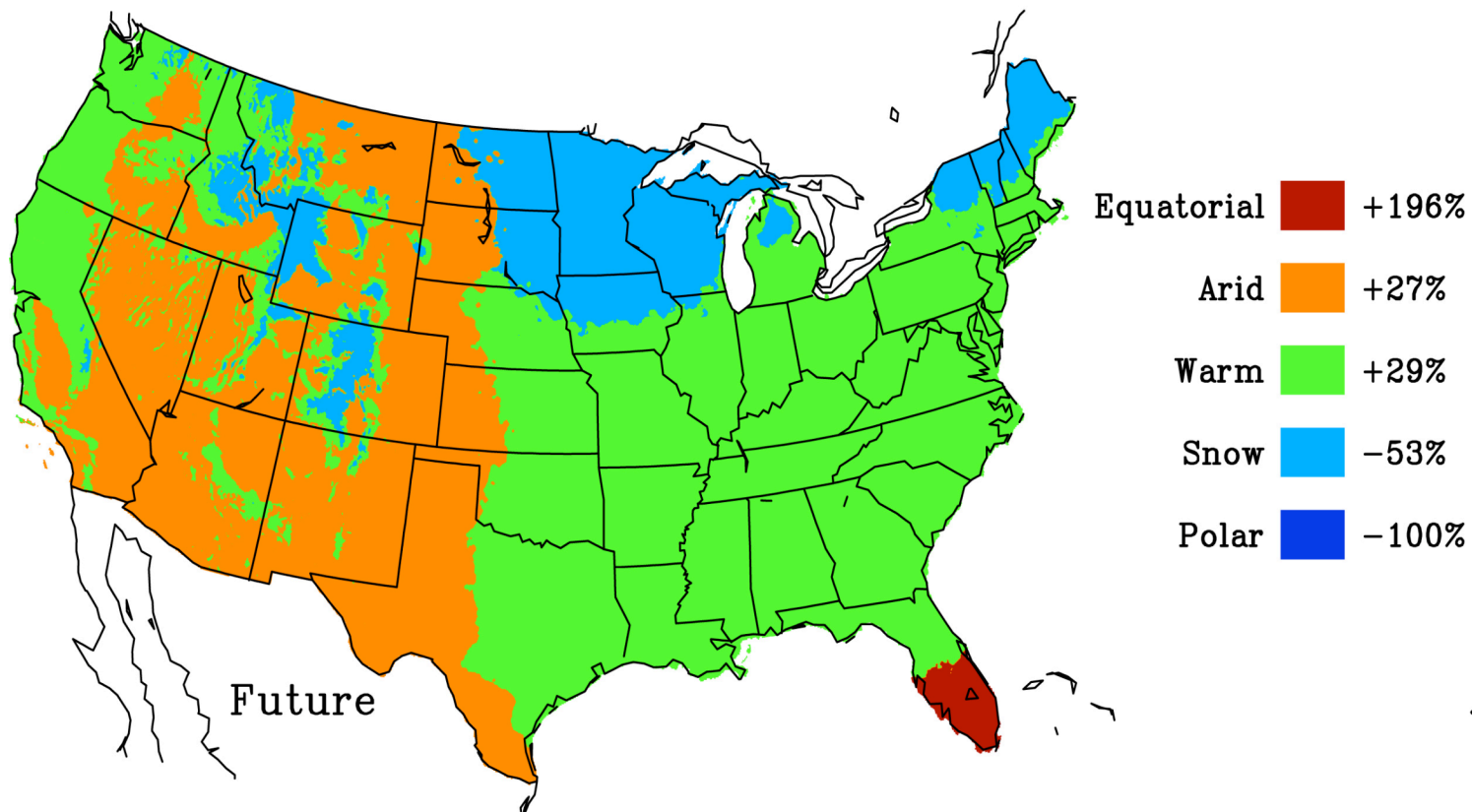
Köppen–Geiger Climate Classification



**Climate Classification Based on Historical
(20th Century) Climate Values**



Köppen–Geiger Climate Classification



Climate Classification Based on Late
21st Century Climate Values





Some Current & Future Climate Change Impacts in the Greater Western States

- *Mountain glaciers would largely disappear.*
- *Snow cover reduction is highly likely.*
- *Warmer mountain streams may harm cold water species.*
- *Parks/forests likely to experience increased fires.*
- *Plant species distributions likely to change.*
- *Rare alpine plants/ecosystems to become increasingly rare.*
- *Plants/animals in alpine lakes above treeline may vanish.*
- *Treelines likely to continue upward advance.*



<http://www.fs.fed.us/psw/cirmount/>

Mapping New Terrain Climate Change and America's West



Anticipating Challenges to Western Mountain Ecosystems and Resources

The Consortium for Integrated Climate Research in
Western Mountains
(CIRMOUNT)

July 2006

imate
gnostics
Center



Carbon Sequestration Through Reforestation and/or Avoided Deforestation

- Three trees will sequester one ton of carbon over a lifetime of 55 years
- Urban reforestation very effective at reducing carbon in the atmosphere through both direct photosynthesis and shading effects on cooling loads

www.americanforests.org





“Because the climate change crisis is at its root, a crisis of lifestyle... addressing it will also involve profound changes in the way we live”

“Personal choices, no matter how virtuous cannot do enough. It will also take laws and money.”

There ain't no easy way out...





Thank you!



© John D. Ingram