RECLAMATION

Managing Water in the West

The Middle Rio Grande Water Budget in the Context of Longer Term Trends

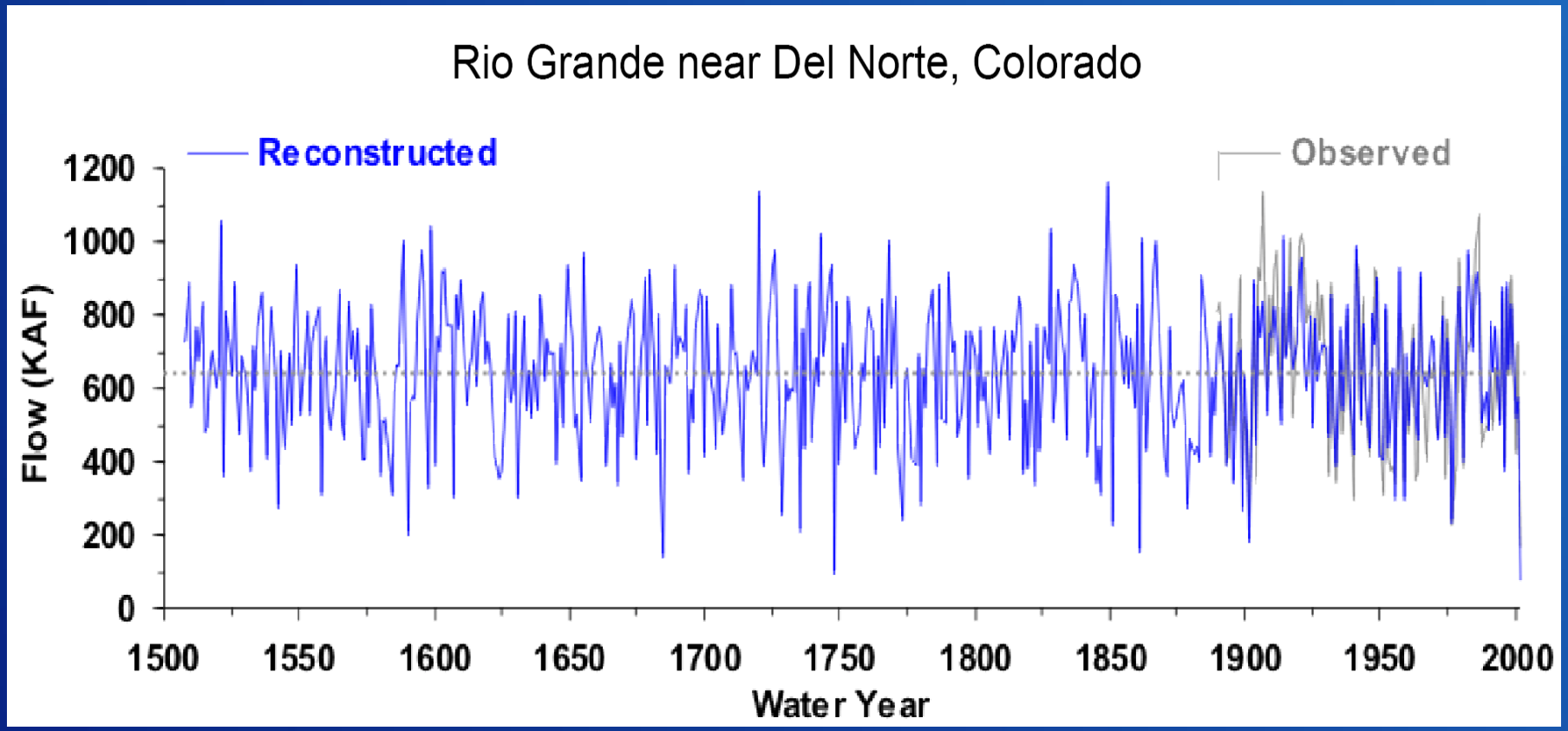
Presentation to the Mid-Region Council of Governments (MRCOG) “Futures 2040” Transportation and Land Use Scenario Planning Project

Dagmar Llewellyn, Reclamation Albuquerque Area Office

July 10, 2014

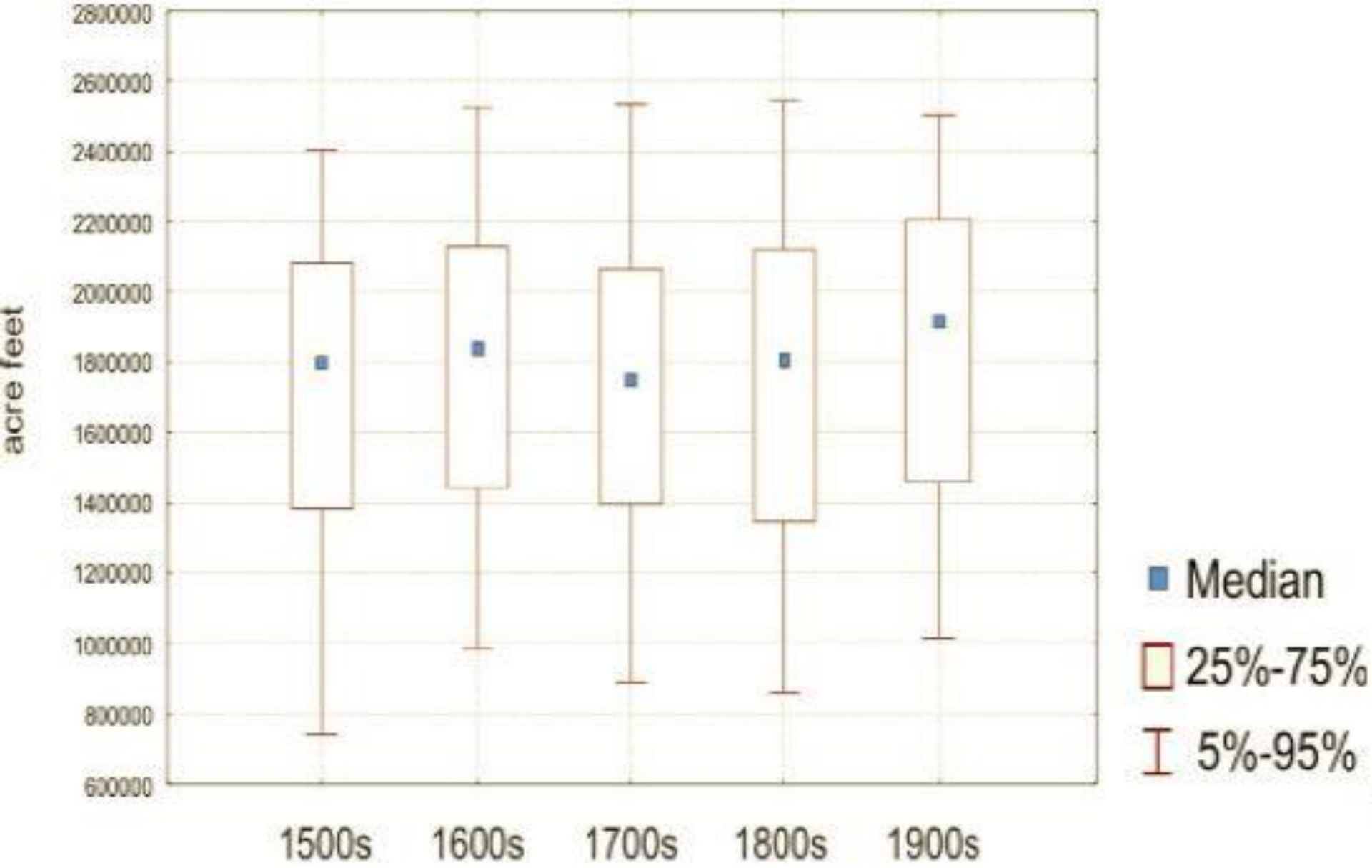
U.S. Department of the Interior
Bureau of Reclamation

Reconstructed flows in the Rio Grande Headwaters



RECLAMATION

Box and whisker plot of reconstructed Otowi natural flow (after Lukas, 2008)

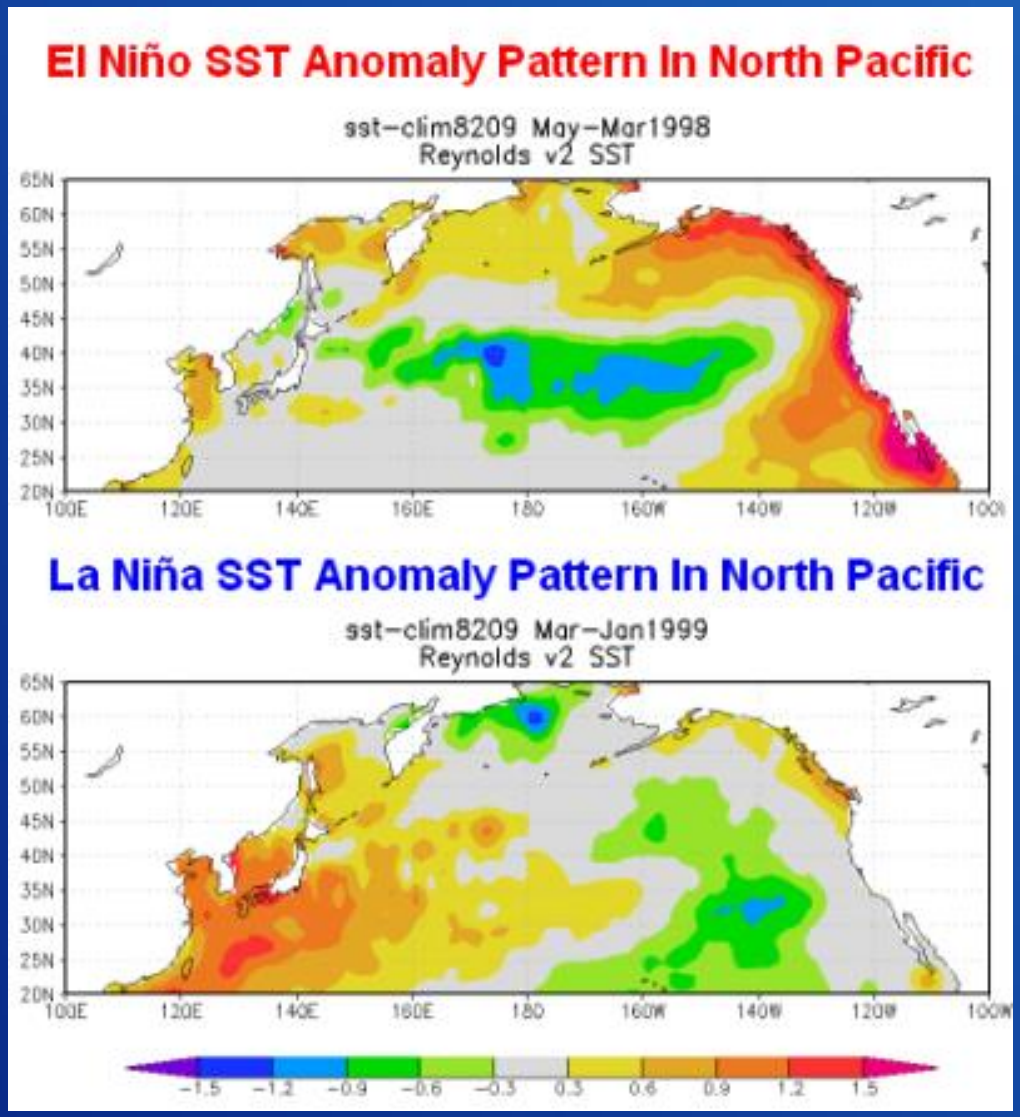


Recent Conditions

The Rio Grande, 2012

Elephant Butte Reservoir

El-Nino Southern Oscillation (ENSO)



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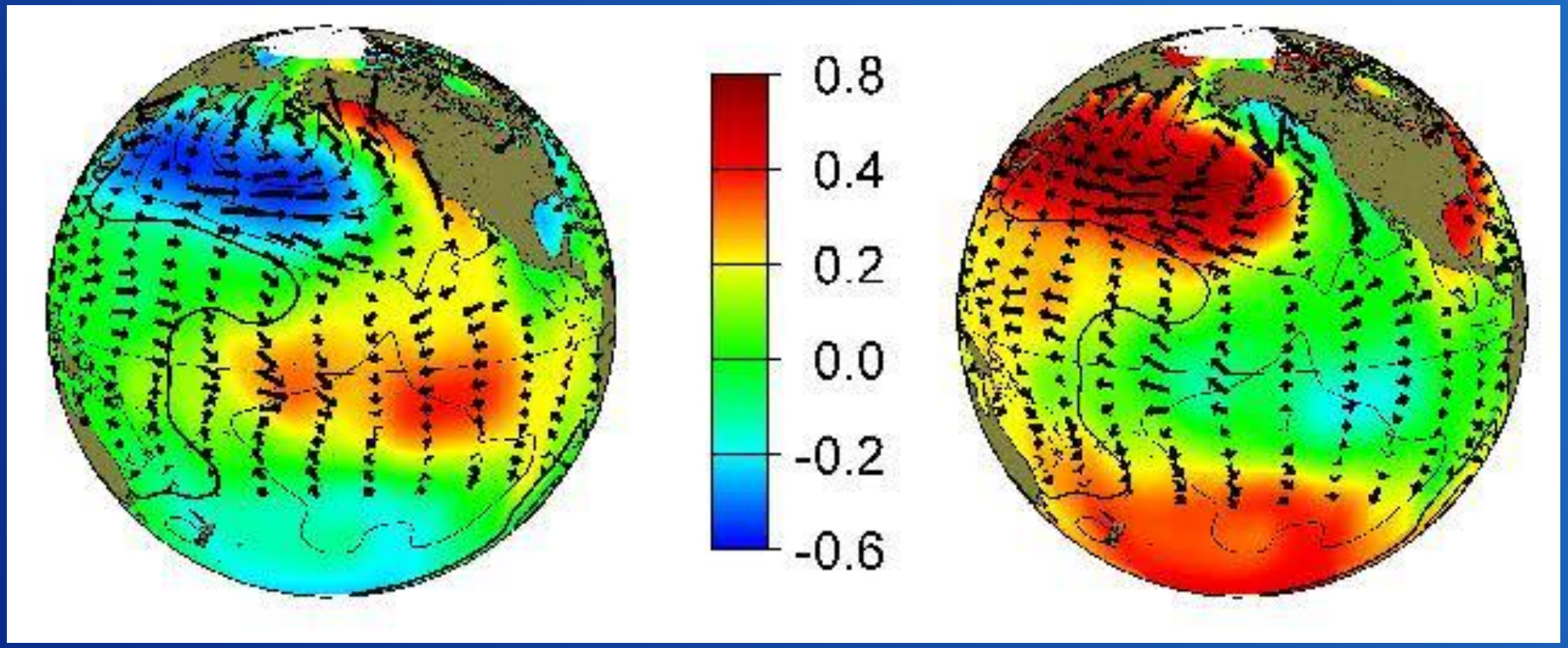

Ocean Circulation Patterns: Pacific Decadal Oscillation (PDO)

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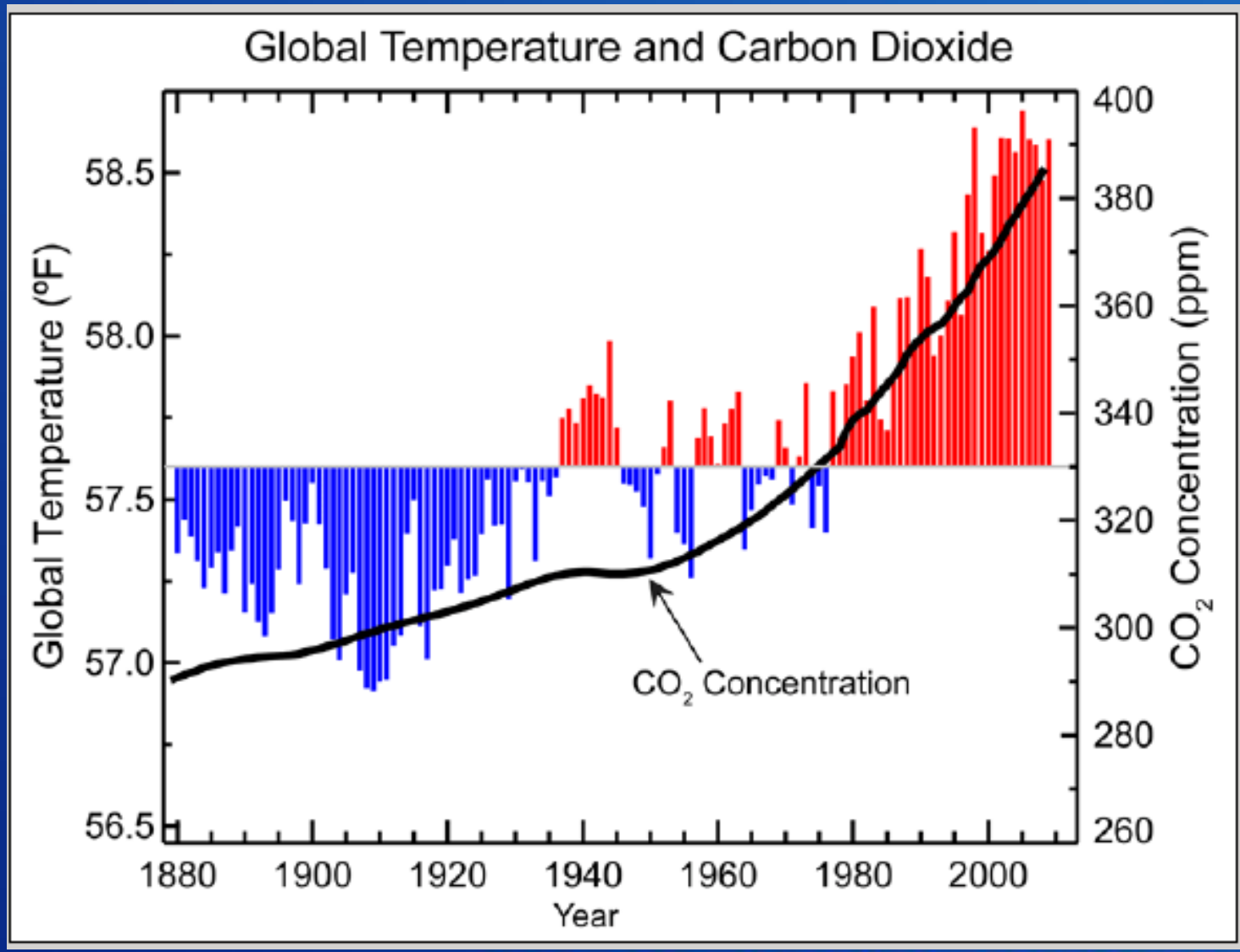
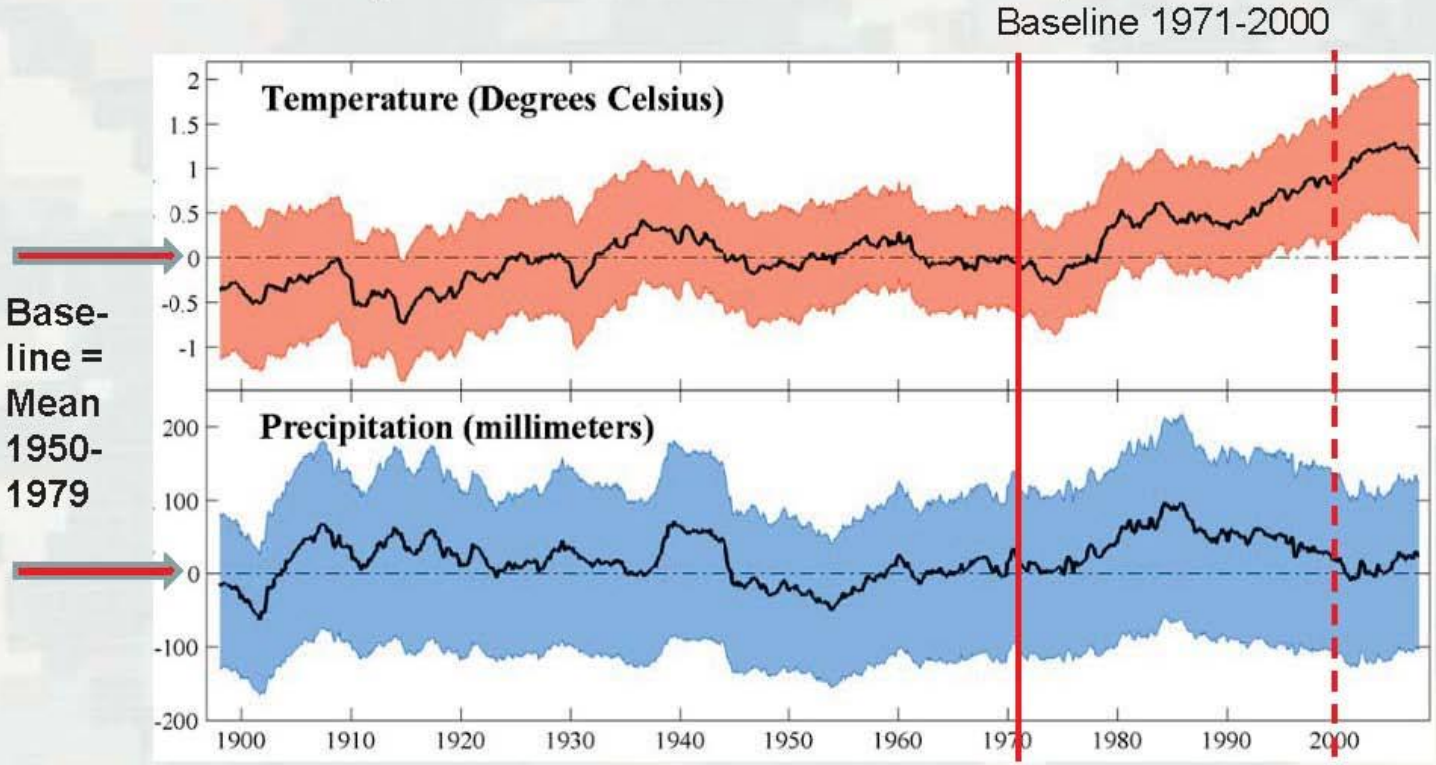
Rio Grande Basin (1971-2011)

- Average temperature increased by 0.7^{0}F per decade
- Twice the global average

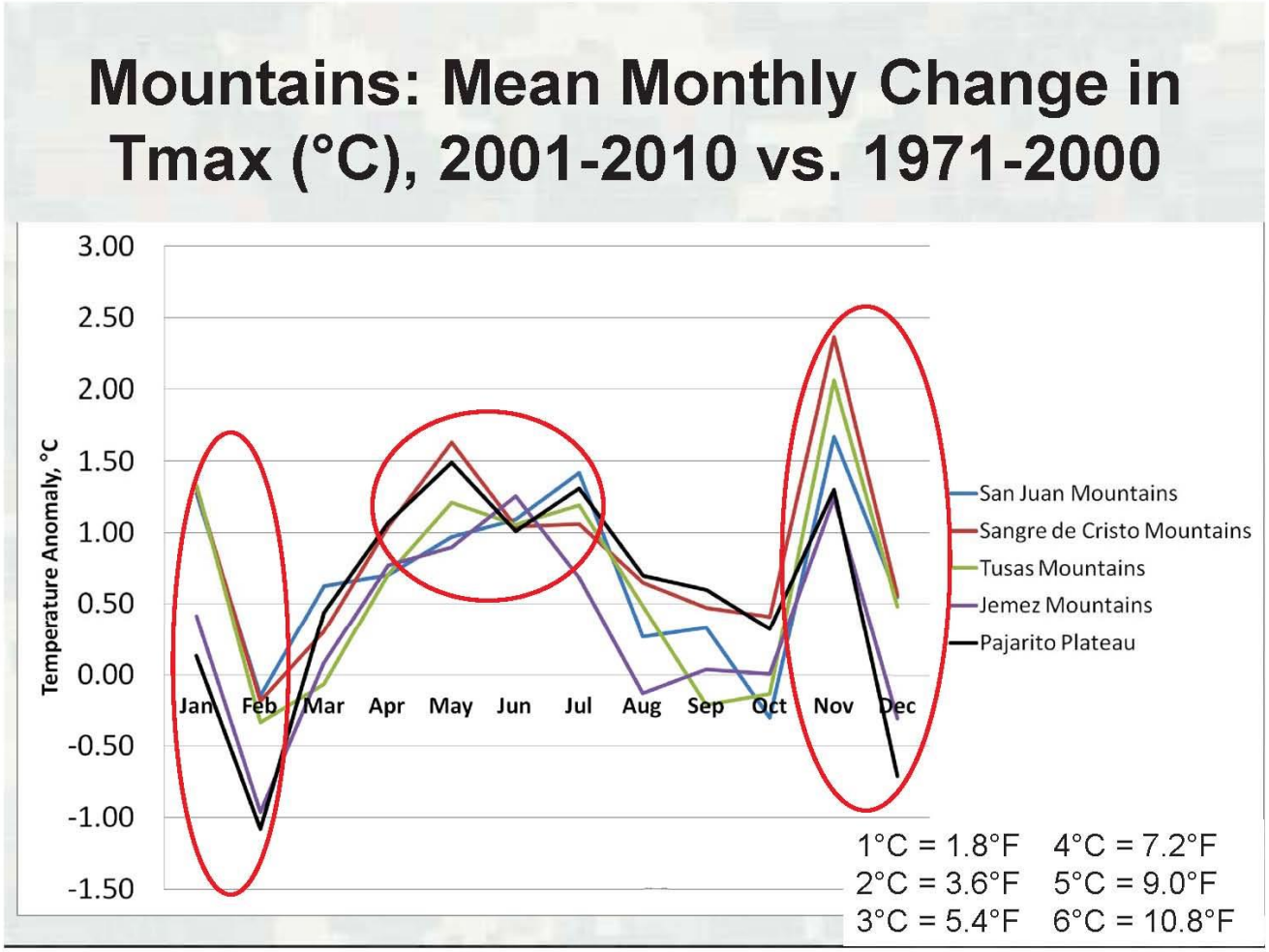


Weather vs. Climate (Southwestern U.S.)



Source: Ariane Pinson, US Army Corps of Engineers

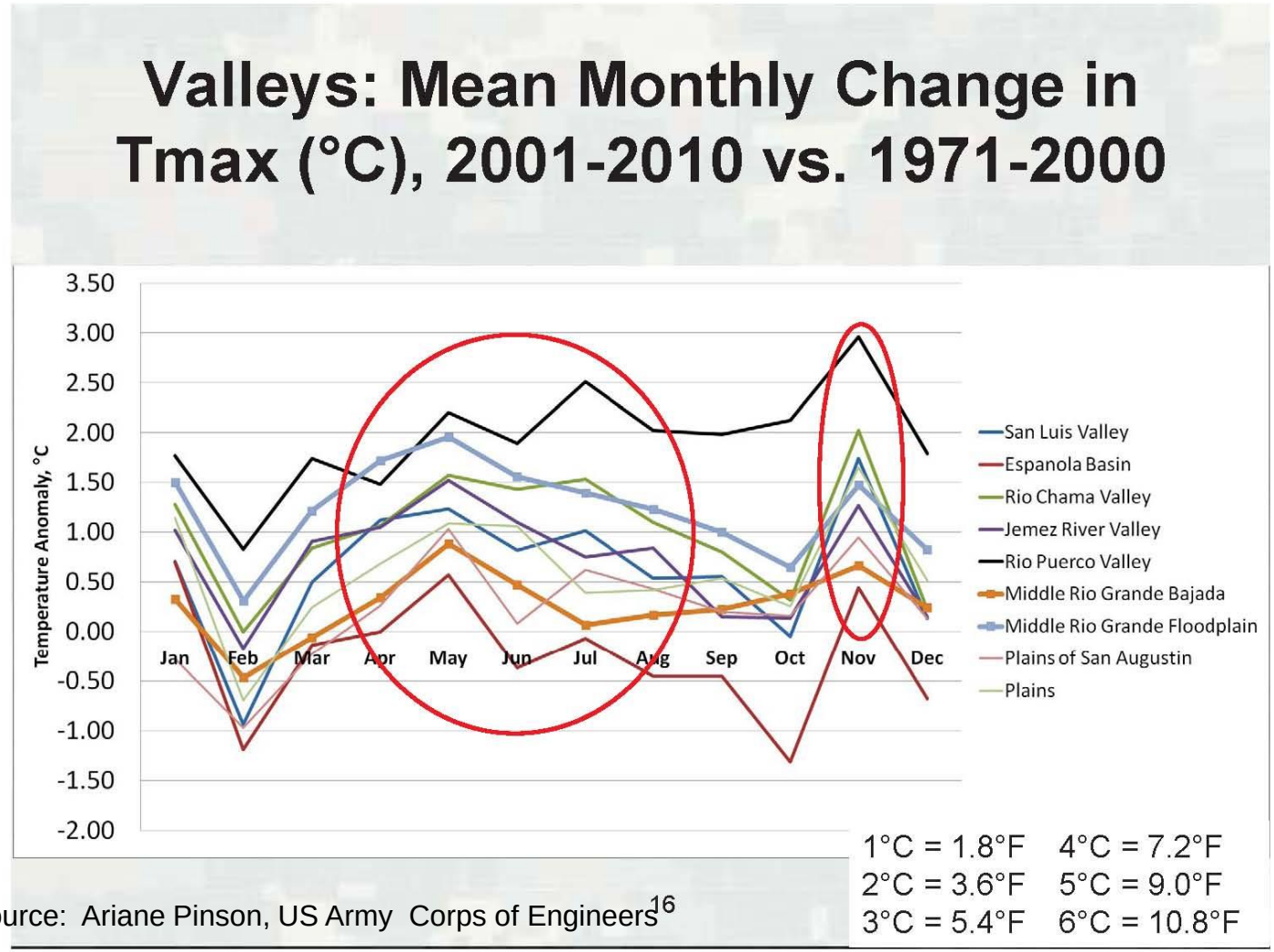
Temperature Trends in the Upper Rio Grande Basin - Mountains



Source: Ariane Pinson, US Army Corps of Engineers

RECLAMATION

Temperature Trends in the Upper Rio Grande Basin - Valleys



Source: Ariane Pinson, US Army Corps of Engineers

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POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2*, *3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

[1]U.S. Geological Survey (USGS), c/o National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA. [2]USGS, Tucson, AZ 85745, USA. [3]Stockholm International Water Institute, SE 11151 Stockholm, Sweden. [4]USGS, Reston, VA 20192, USA. [5]Research Centre for Agriculture and Forest Environment, Polish Academy of Sciences, Poznań, Poland, and Potsdam Institute for Climate Impact Research, Potsdam, Germany. [6]University of Washington, Seattle, WA 98195, USA. [7]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA.

*Author for correspondence. E-mail: cmilly@usgs.gov.

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4*, *5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*, *18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4*, *20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21*, *22*), the assumption of stationarity was

Published by AAAS

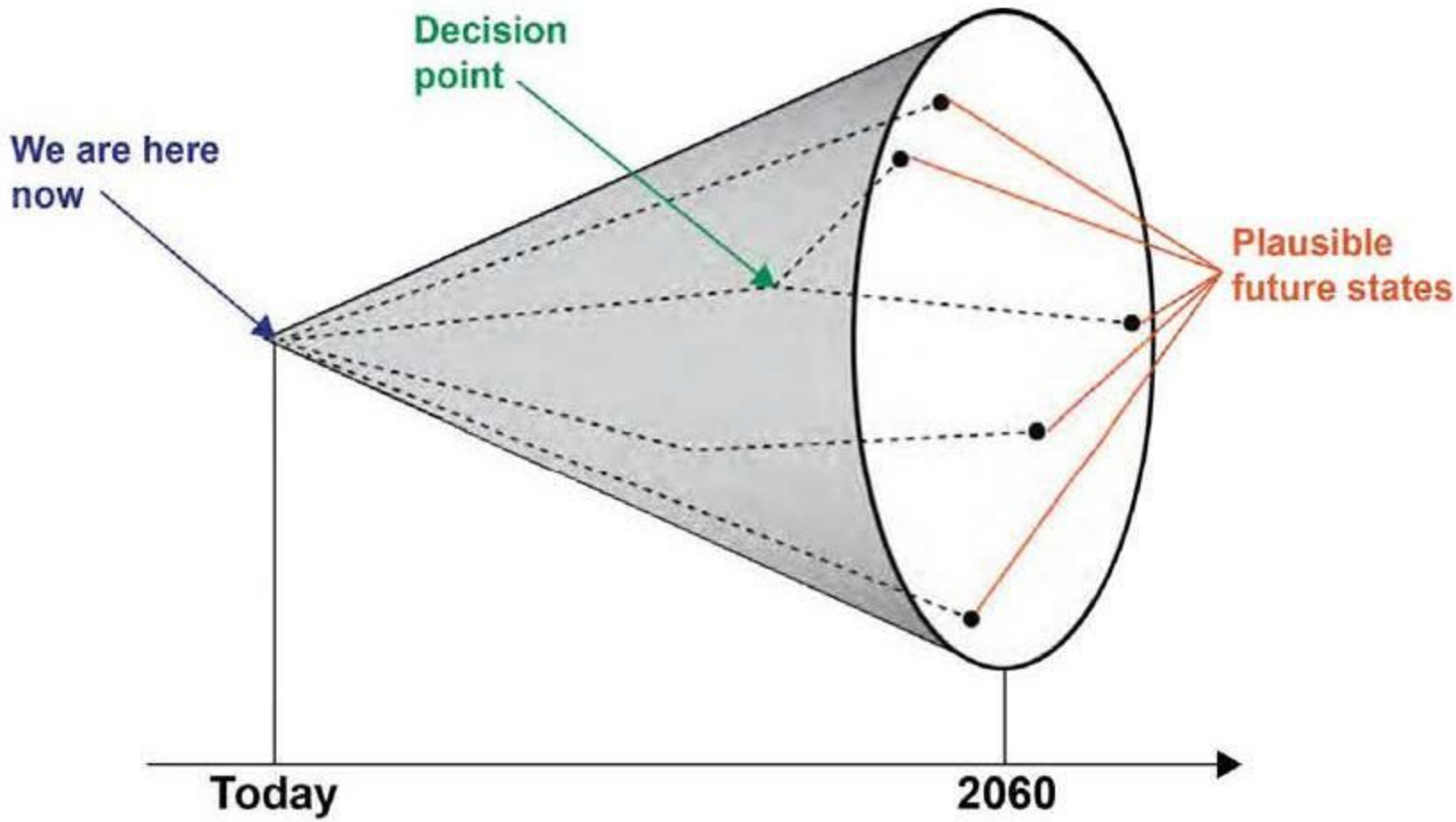
"Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks."

Stationarity assumes that the statistical properties of hydrologic variables in future time periods will be similar to past time periods

RECLAMATION

The “Scenario Funnel”

Conceptual Representation of the Uncertain Future of a System, Also Known as “The Scenario Funnel”
Adapted from Timpe and Scheepers, 2003.



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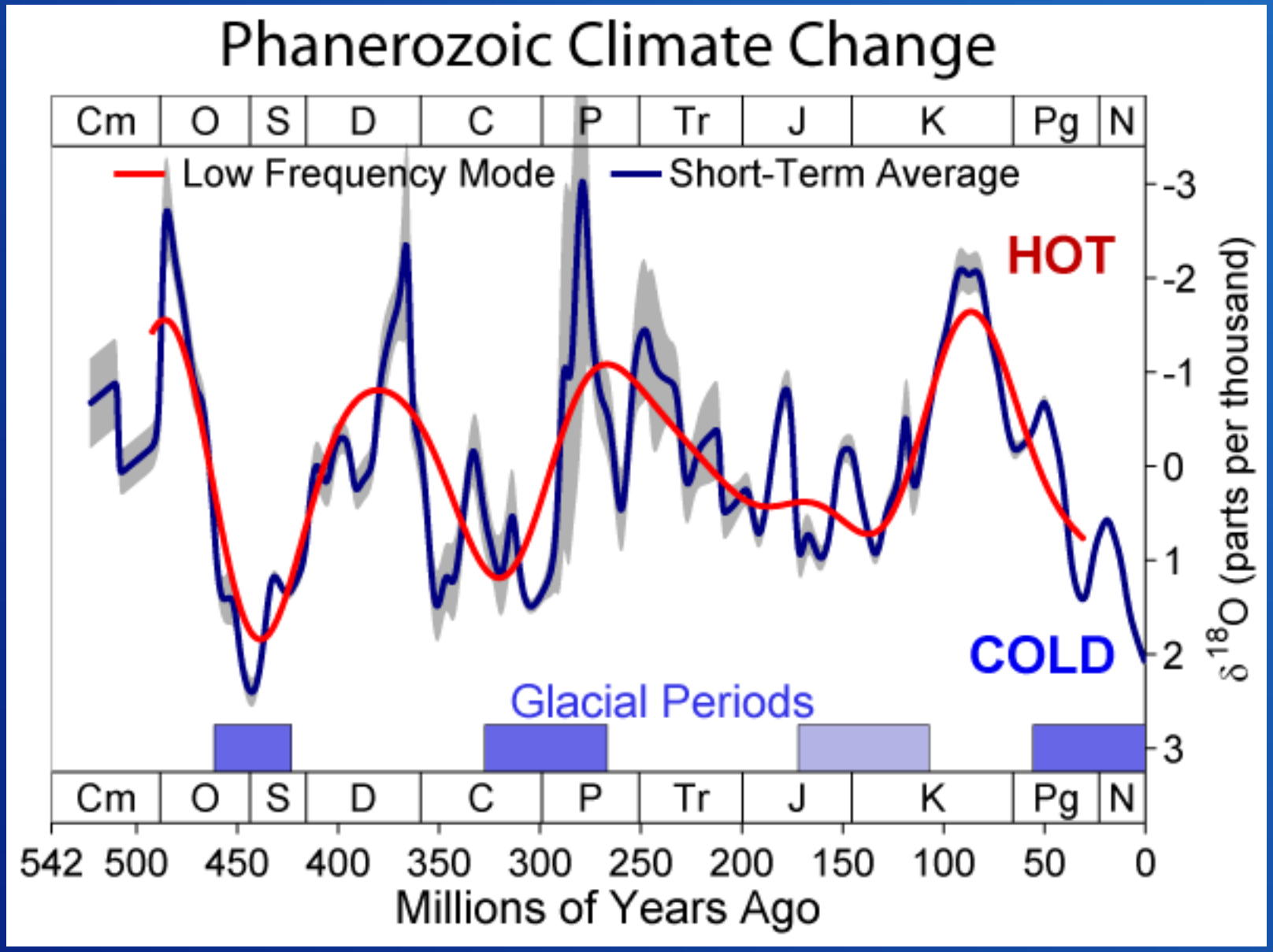

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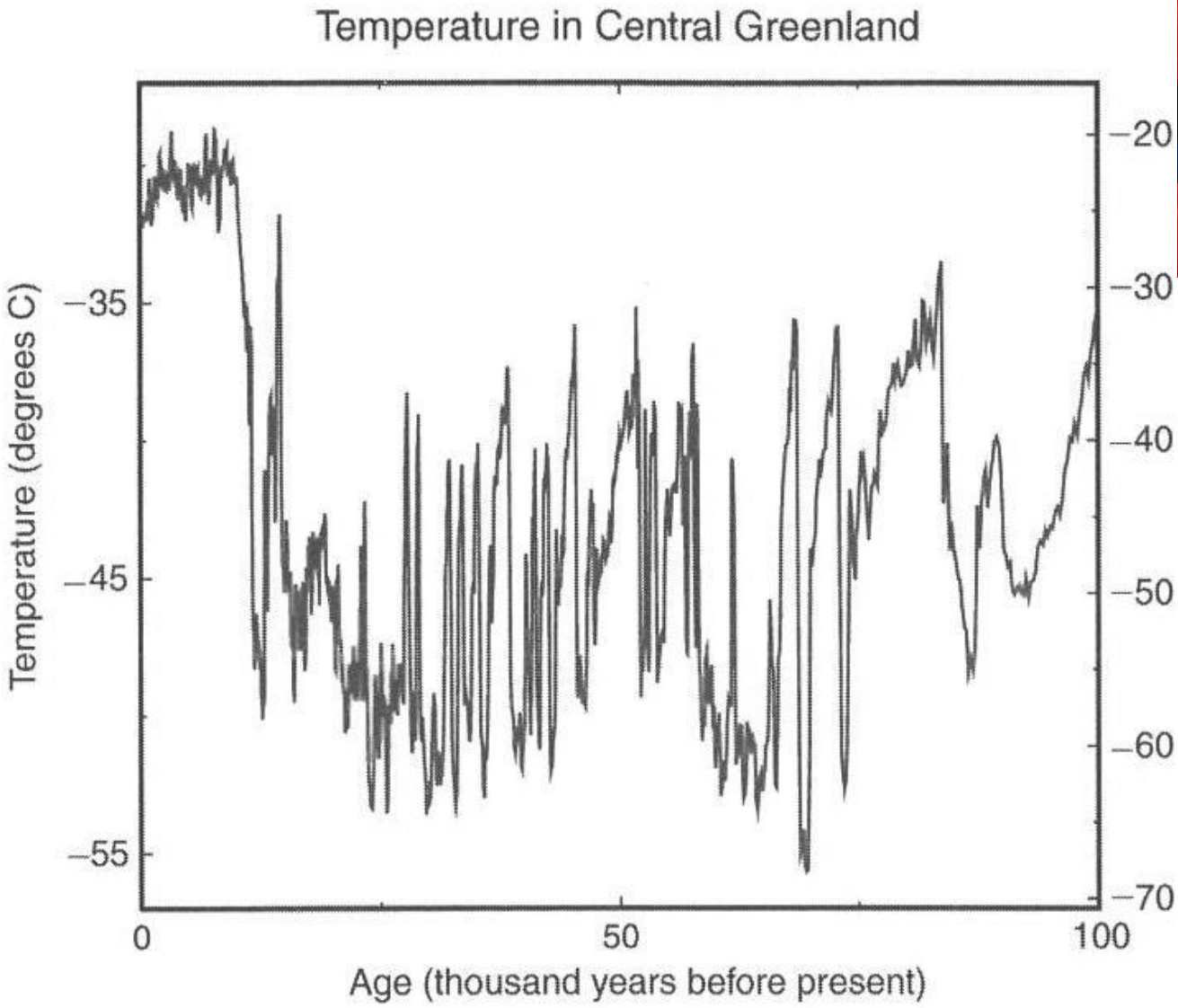
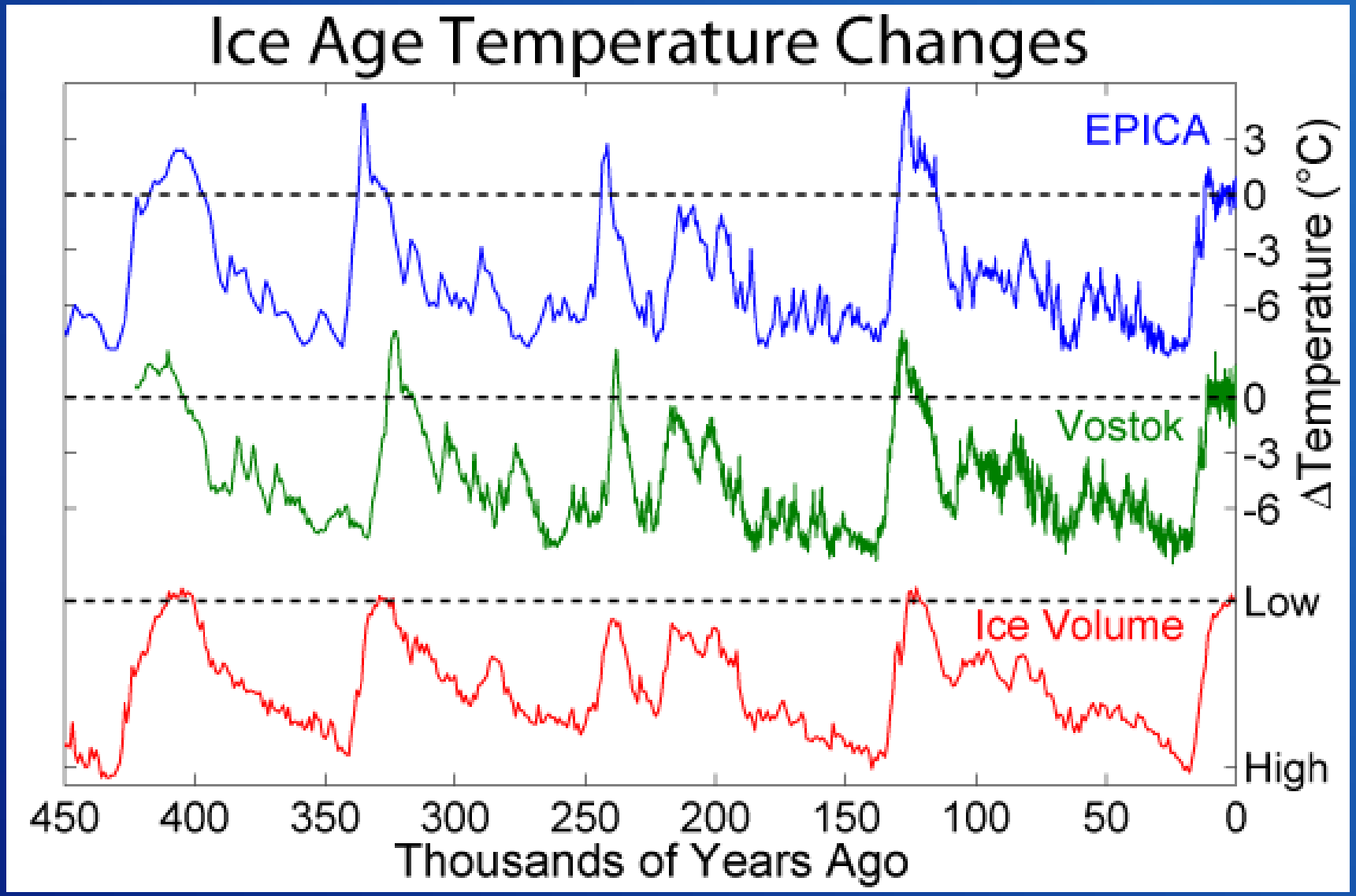


Source: Richard Alley, 2000

RECLAMATION



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Basin Study Program

WWCRA

- Baseline Assessment of risks and impacts
- Determine Imbalances in Water Supply & Demand
- SECURE Guidance Development

Basin Studies

- Stakeholder engagement
- Develop adaptation strategies

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- Understand risks in a landscape context
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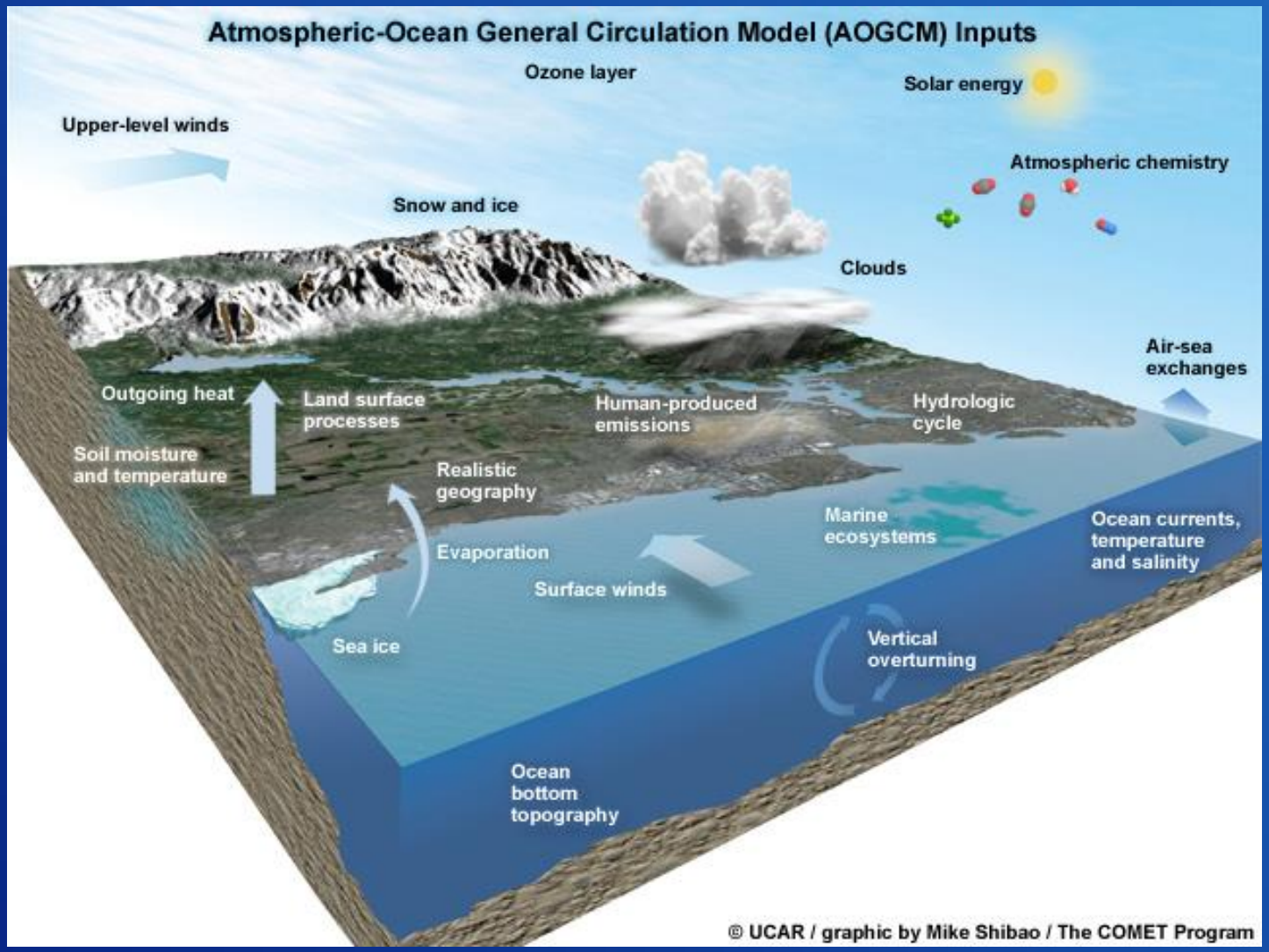
- Flow & Water dependent ecological resiliency
- Flood control management

RECLAMATION

Processes depicted in General Circulation Models



RECLAMATION

Predictions vs. Projections

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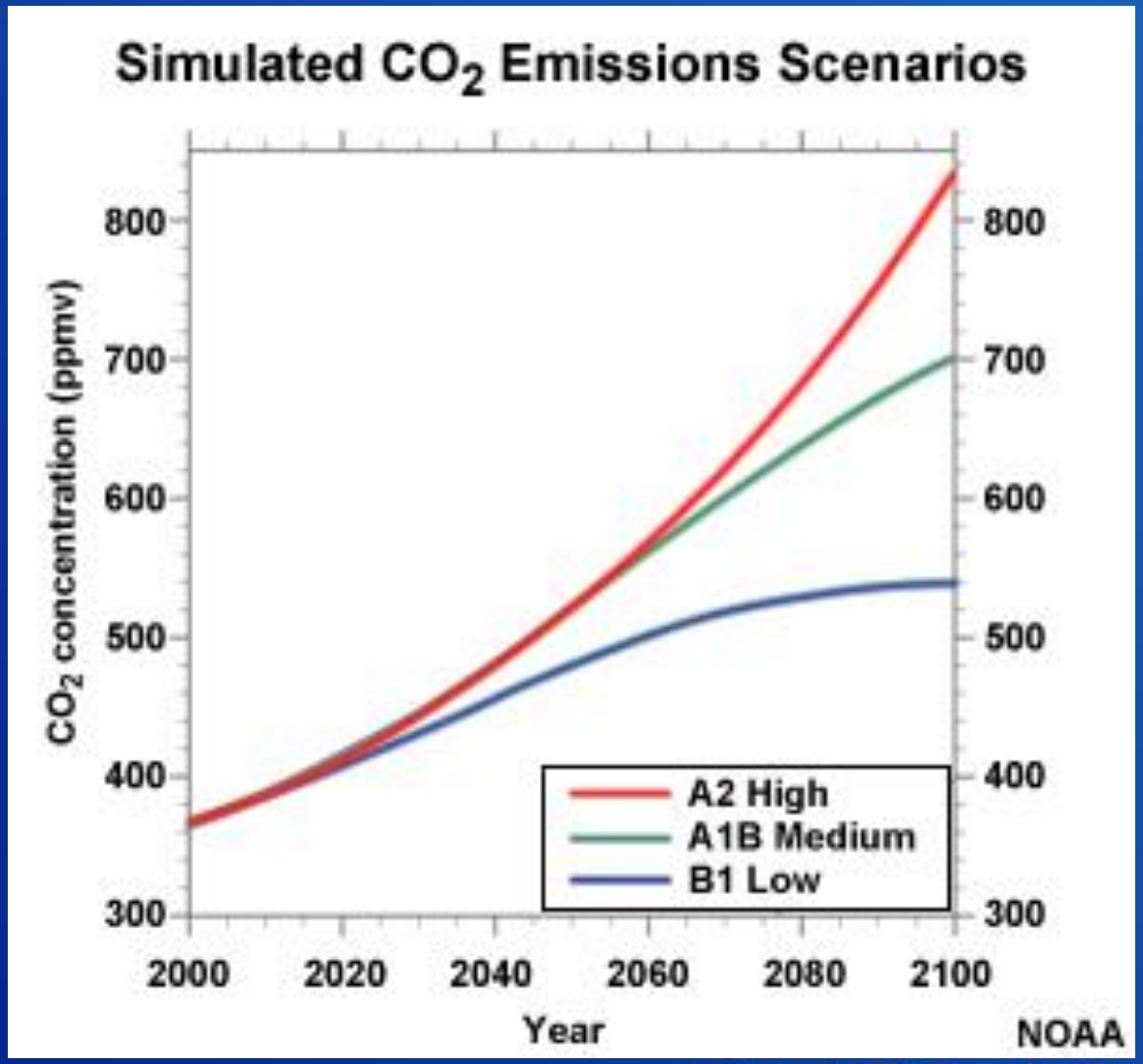
Carbon Dioxide Concentrations Associated with modeled Emission Scenarios



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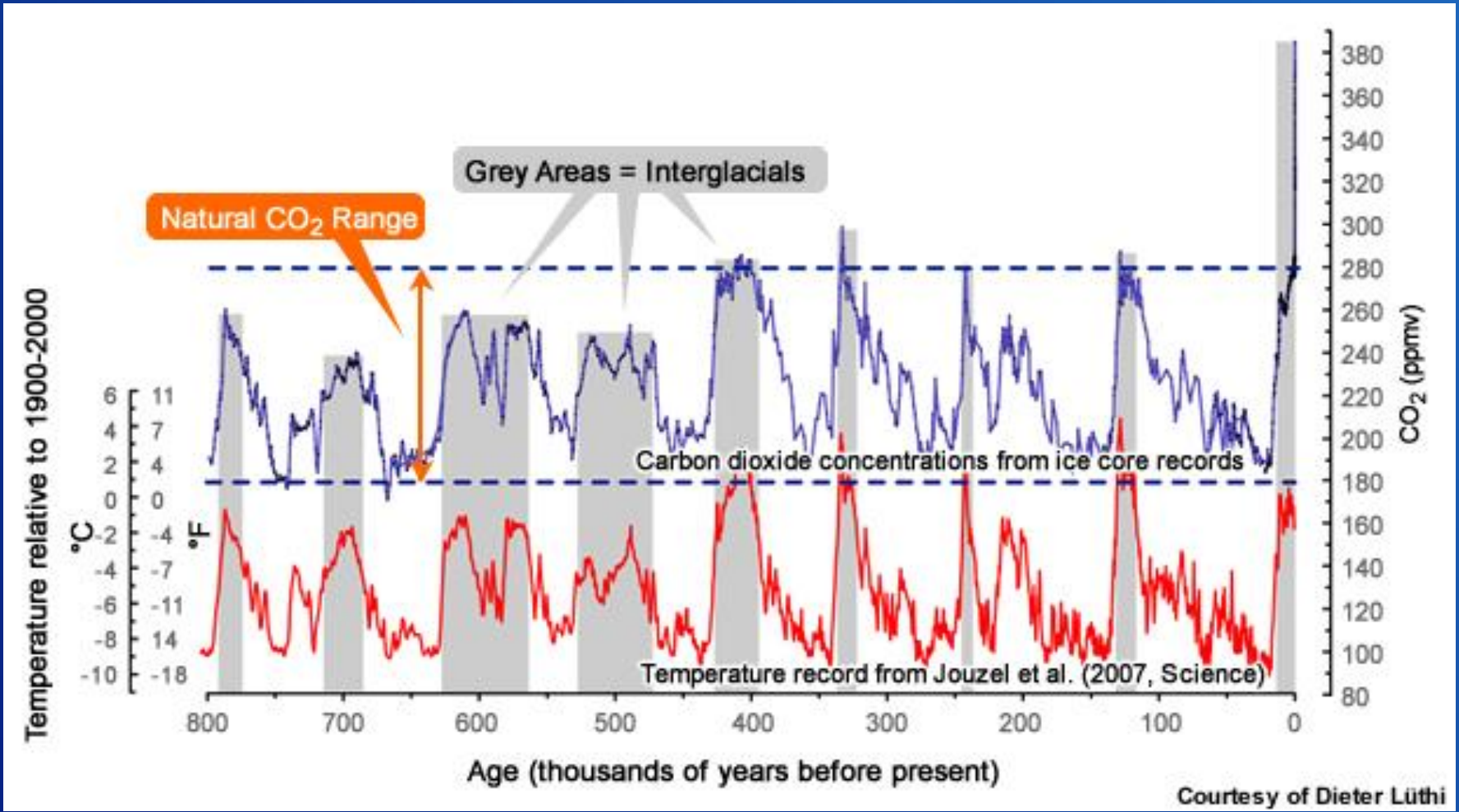
Global Temperature Correlation with Atmospheric Carbon Dioxide



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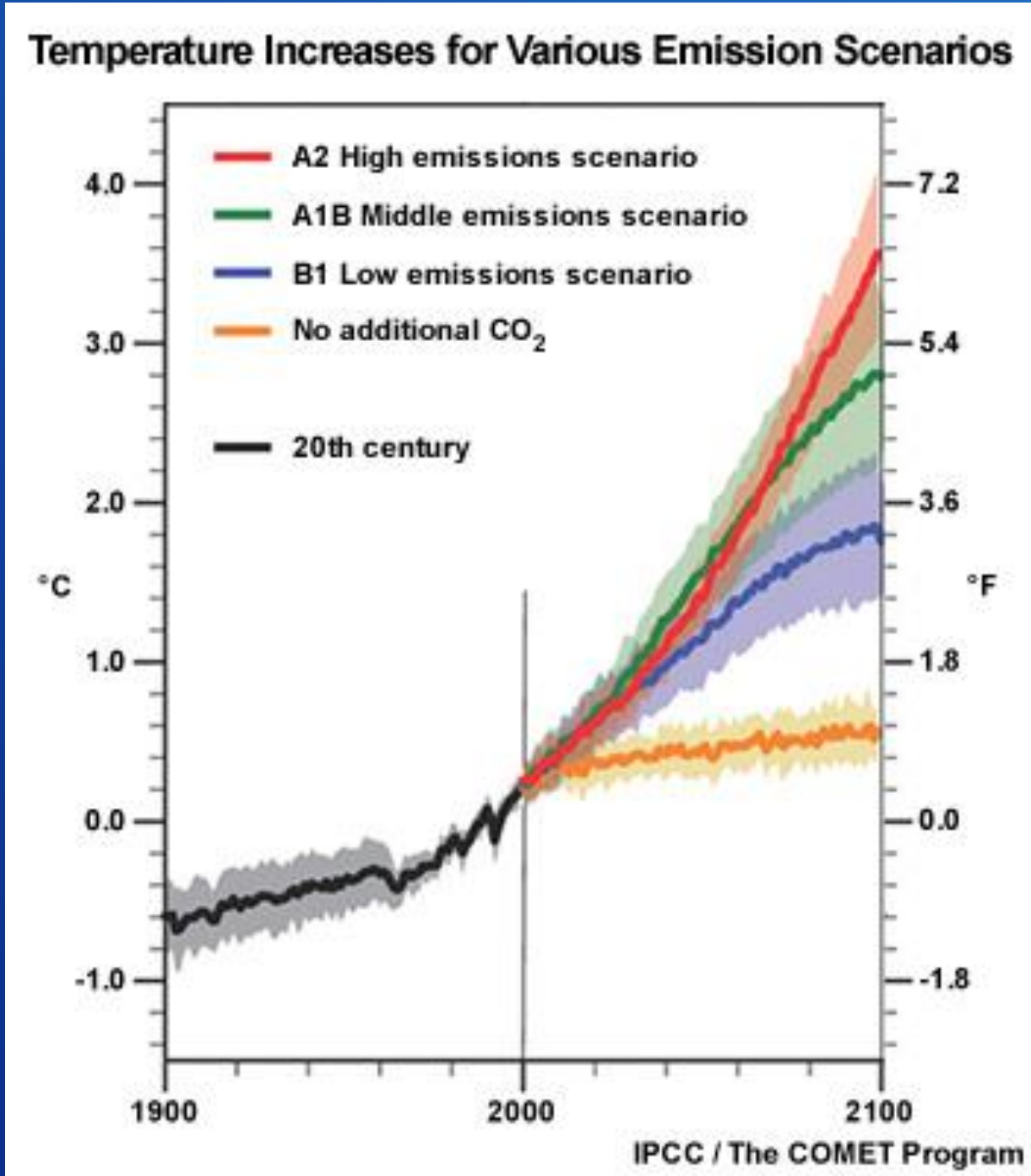
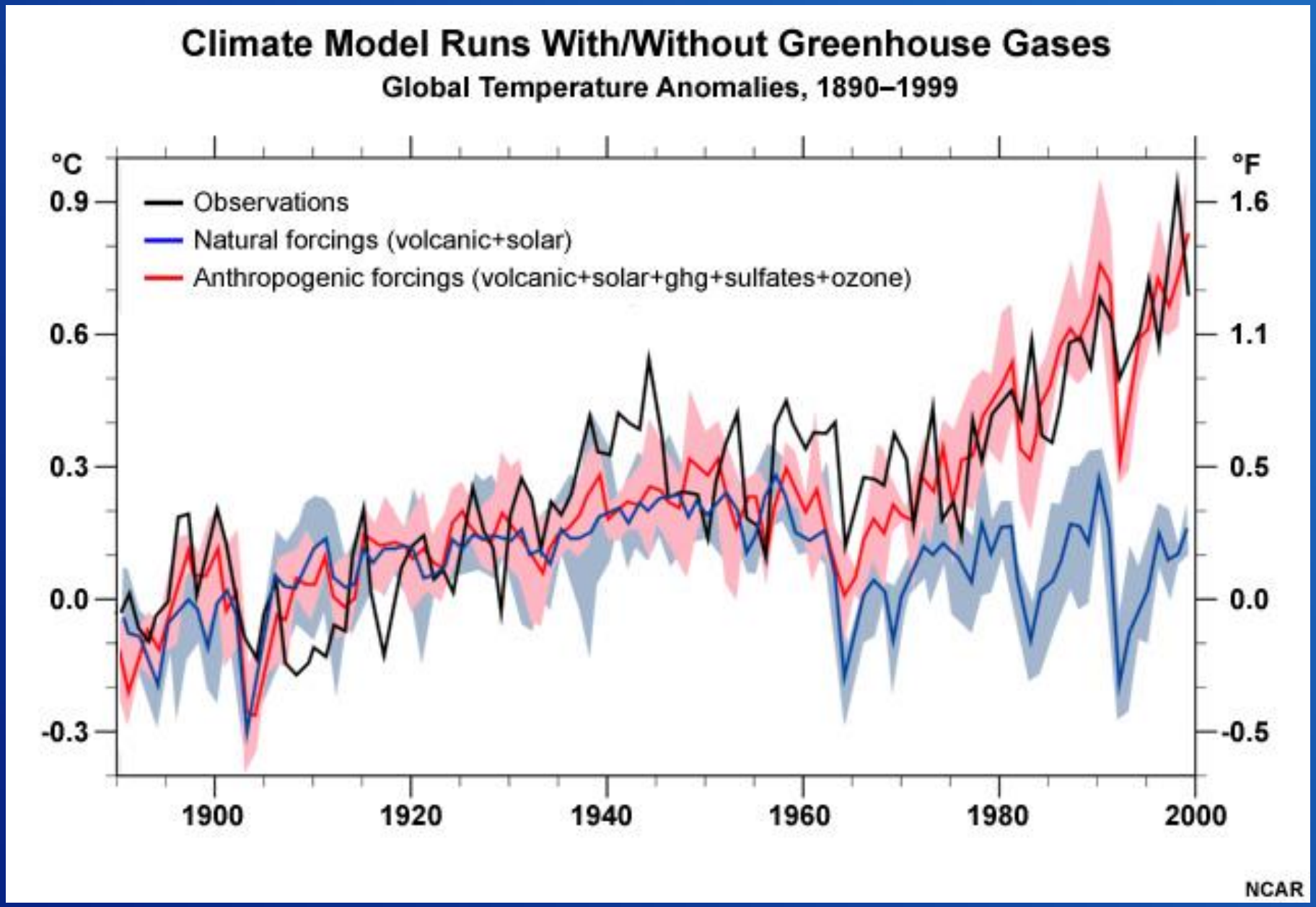
Projected temperature increases over the rest of the century





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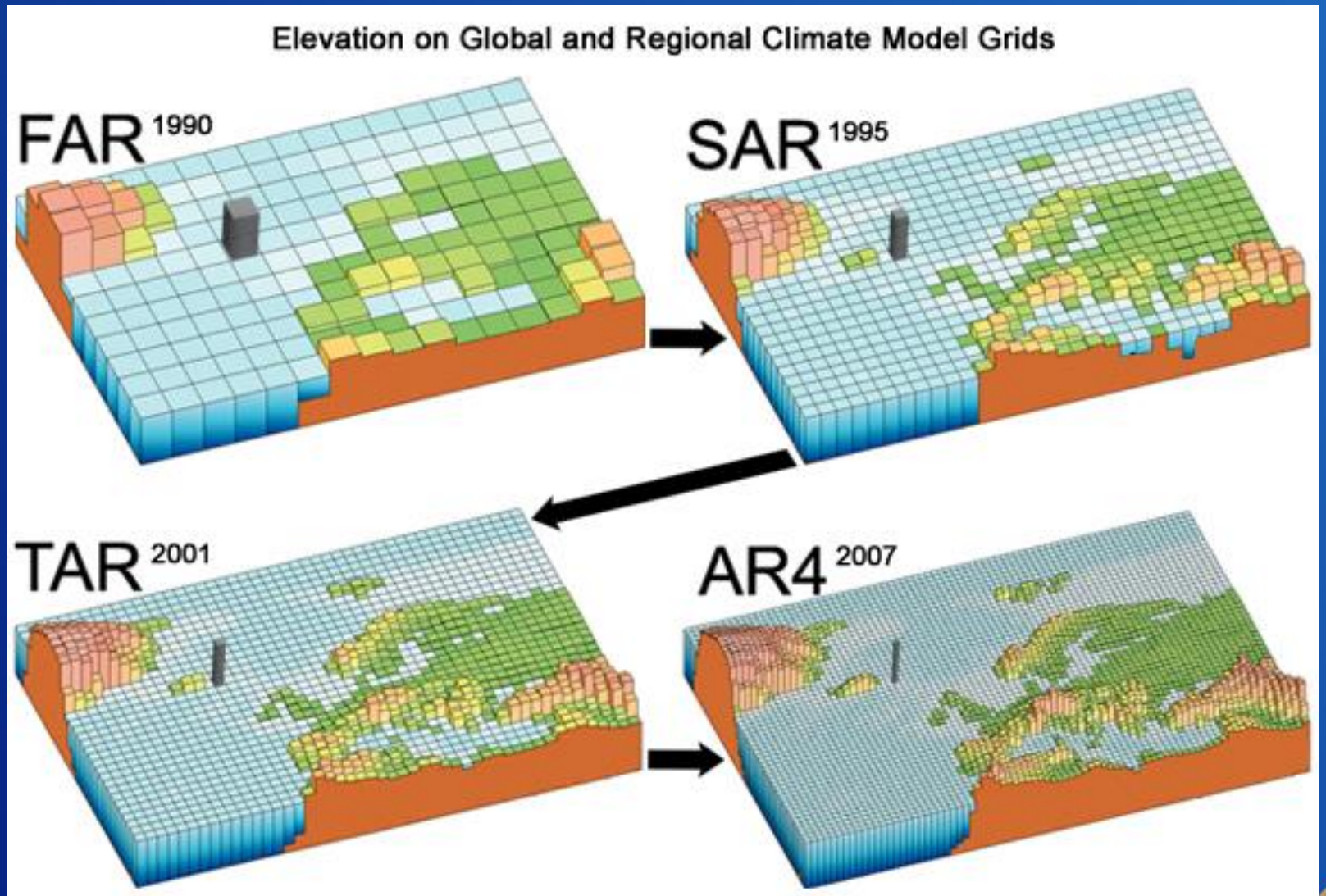
Scale Refinements in Assessments by the International Panel on Climate Change (IPCC)



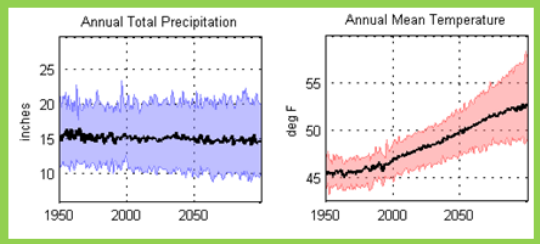
Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 1.4. Cambridge University Press.

Development of Projections of the Future Climate and Hydrology of the Upper Rio Grande Basin

112 runs
1950-2099

General Circulation Model (GCM)

112 Statistically Downscaled Regional Projections of ΔP and ΔT



Variable Infiltration Capacity Model (VIC)

112 Runoff Projections Using Rainfall Runoff Model

Post processing bias correction of flows (224 hydrographs)

Operations model (URGSiM)

Impacts to water deliveries, flows, and reservoir levels.

Uncertainty

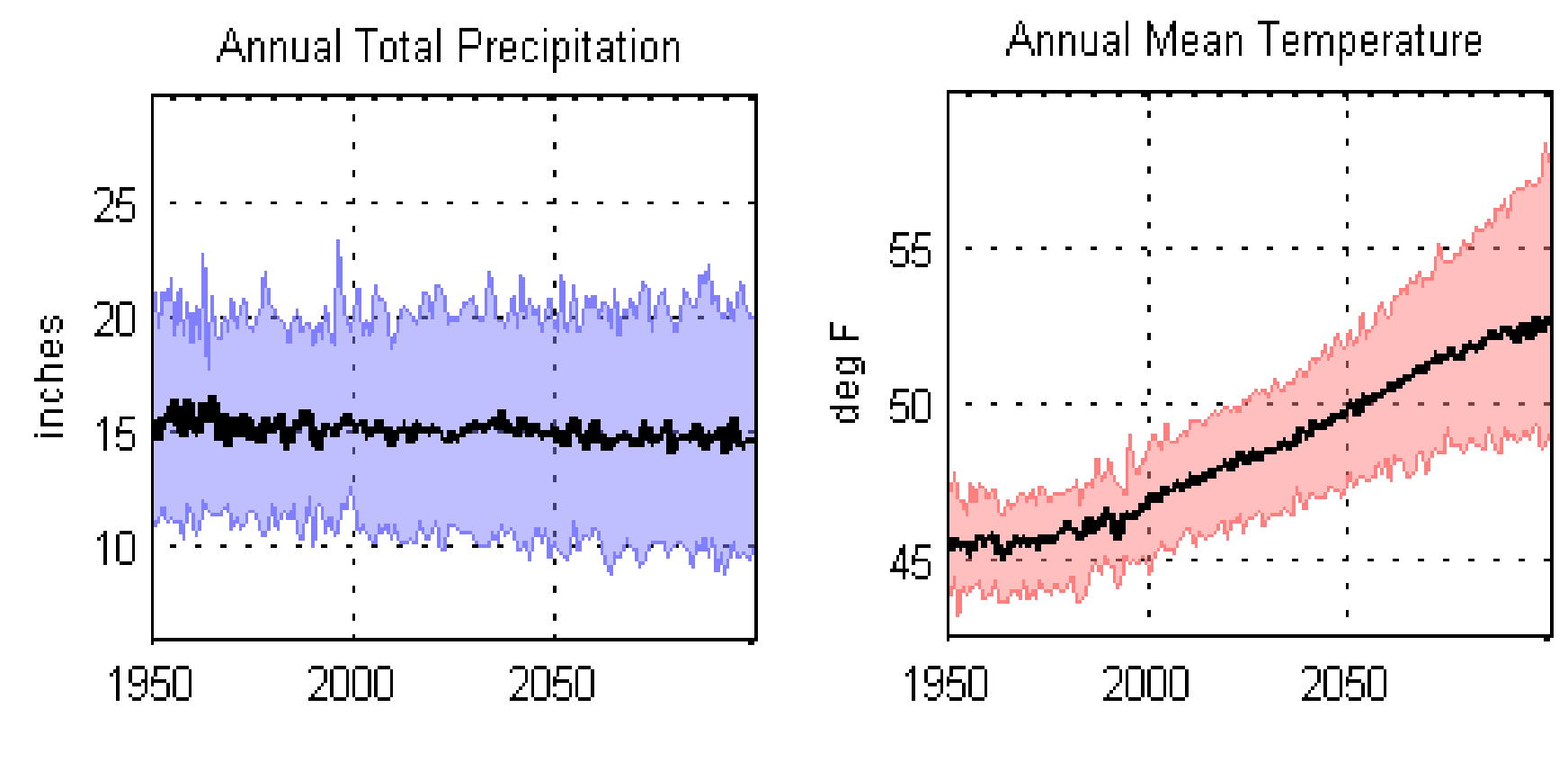
Taking action under Uncertainty involves risk…but so does taking no action.

Credit: Guy and Rod

HE ONLY HAD ENOUGH MONEY FOR ONE, AND FOR THE LIFE OF HIM HE COULDN'T REMEMBER THE DIFFERENCE.

Basin-mean Climate Projections: Warmer, similar precipitation

112, 1/8 Degree Regional Projections of ΔP and ΔT



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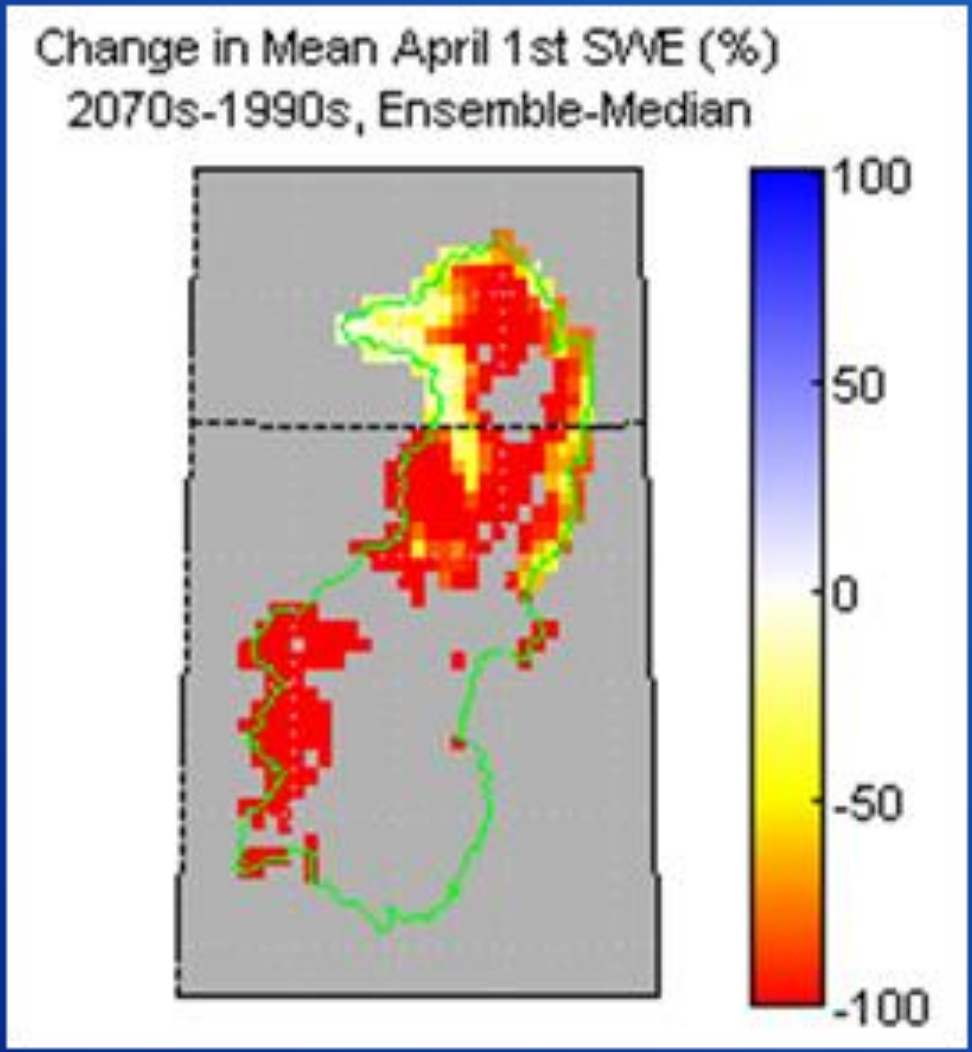
Future Climate:
Basin-Distributed Snow (2070s):



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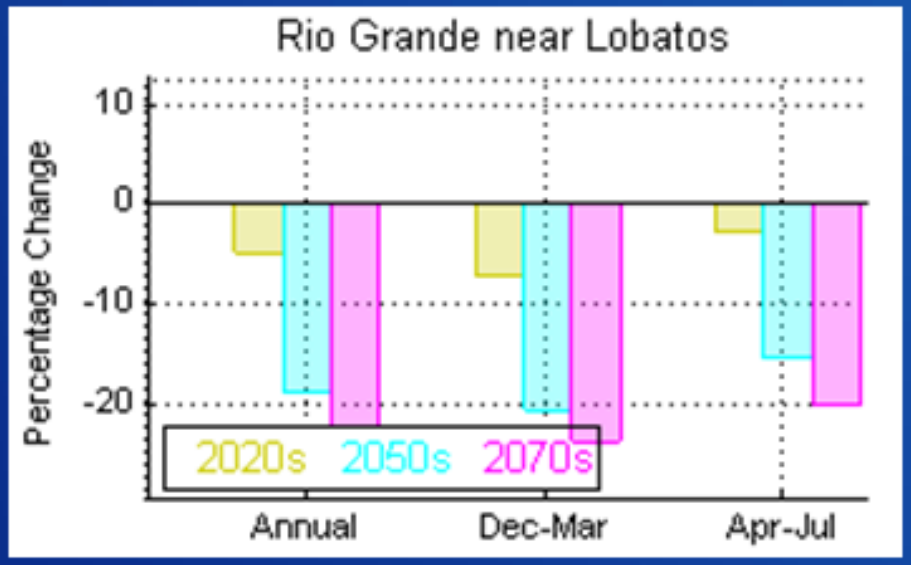
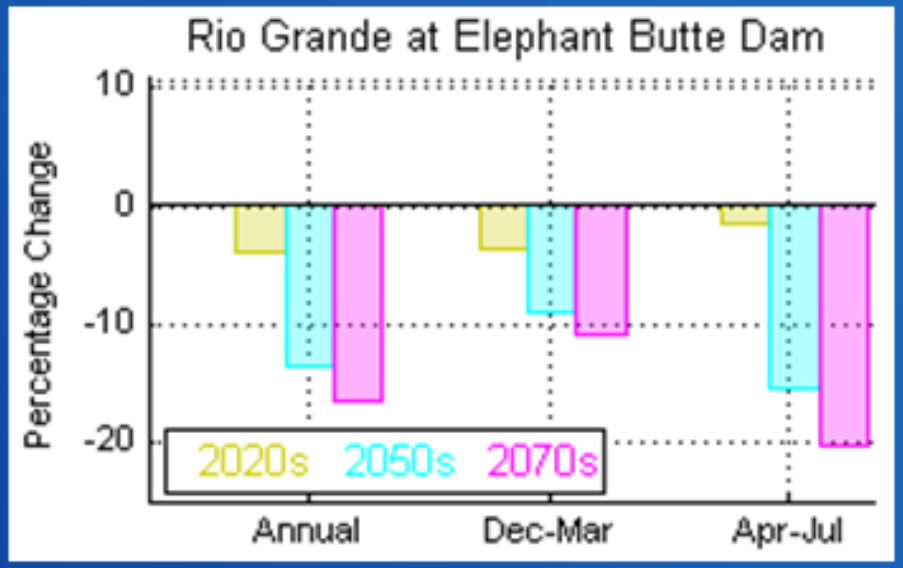
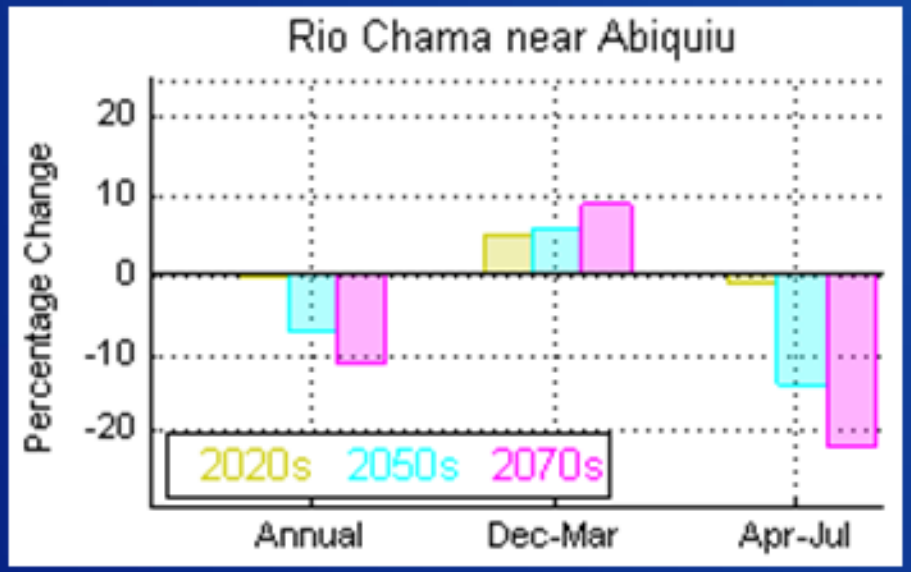
Projected Impacts to Flow Timing







- Decreased annual runoff throughout basin
- Some regions have increased cool season runoff and reduced warm season runoff

<u>Competing Questions</u>

- Floods - Increased storage needed
- Storage – greater need to store for summertime/dry season

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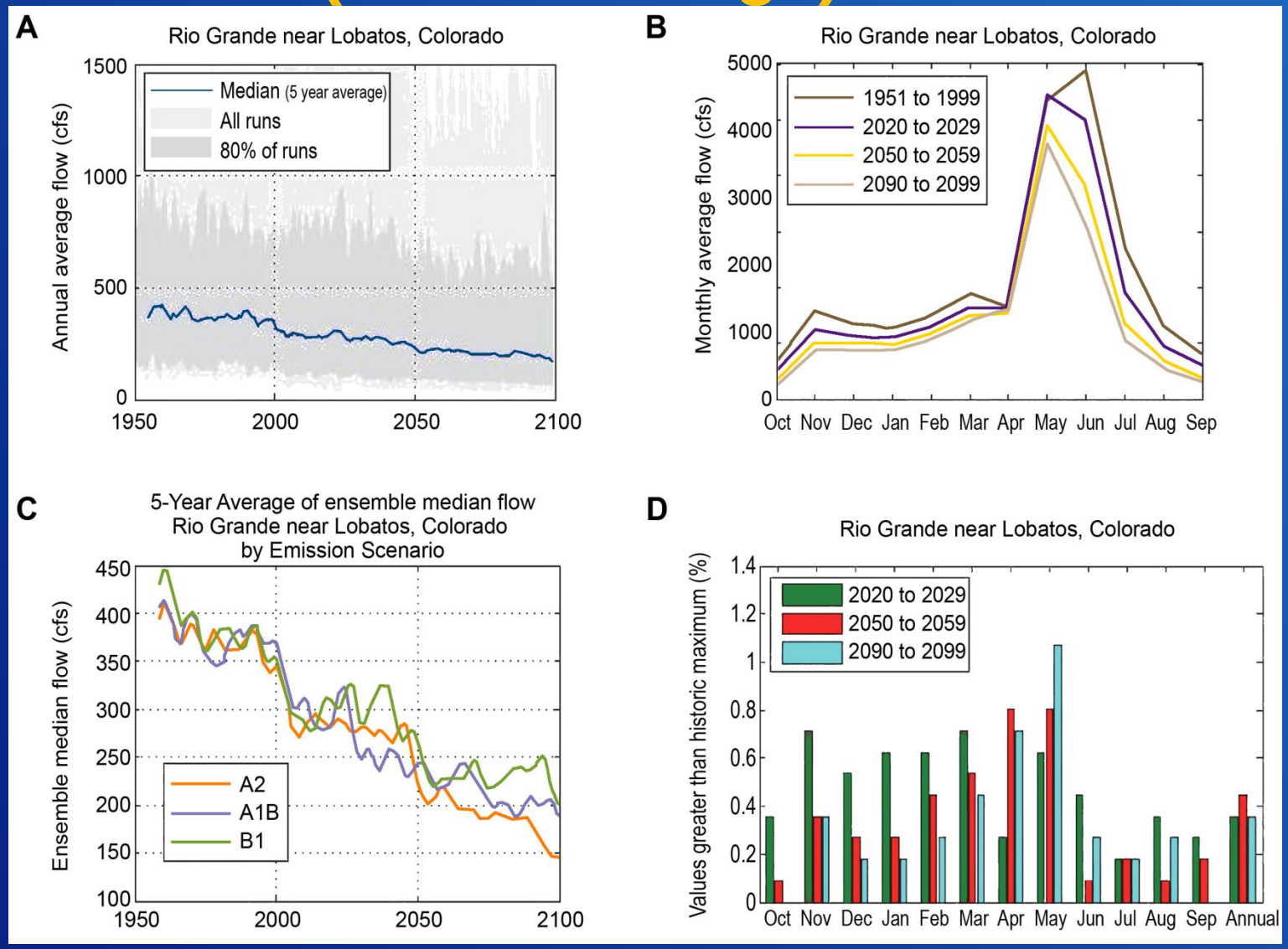
Summer Monsoons…?

Some evidence suggests that the summer monsoons on the Rio Grande may intensify under warmer conditions.
Available climate models are not yet able to simulate the monsoons accurately, so this remains a significant unknown.

The GCM's used in the IPCC's 5th Assessment Report have a finer spatial resolution, and seem to depict an increase in monsoonal precipitation.

RECLAMATION

Rio Grande at the Colorado-New Mexico State Line (Lobatos Gage)



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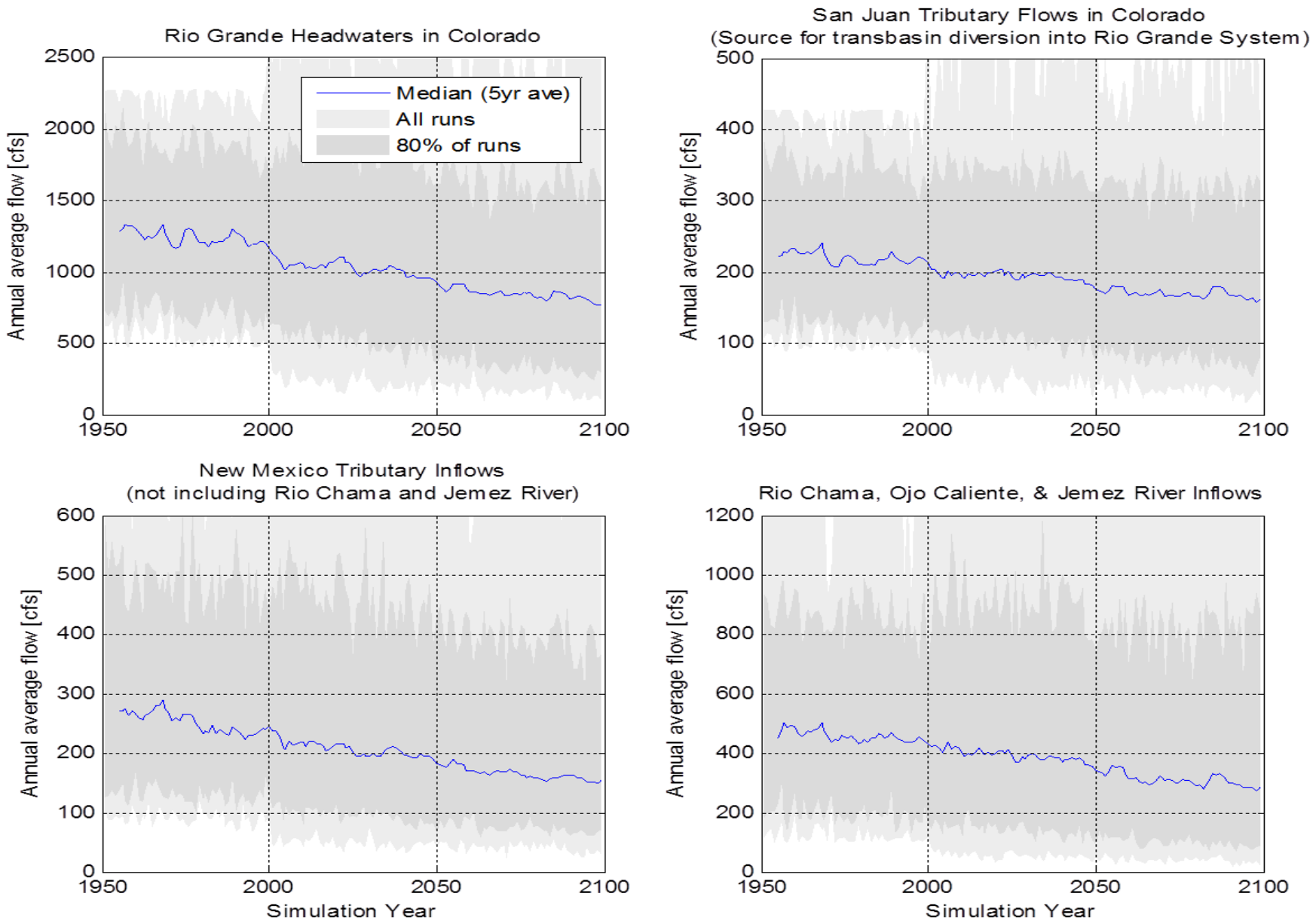
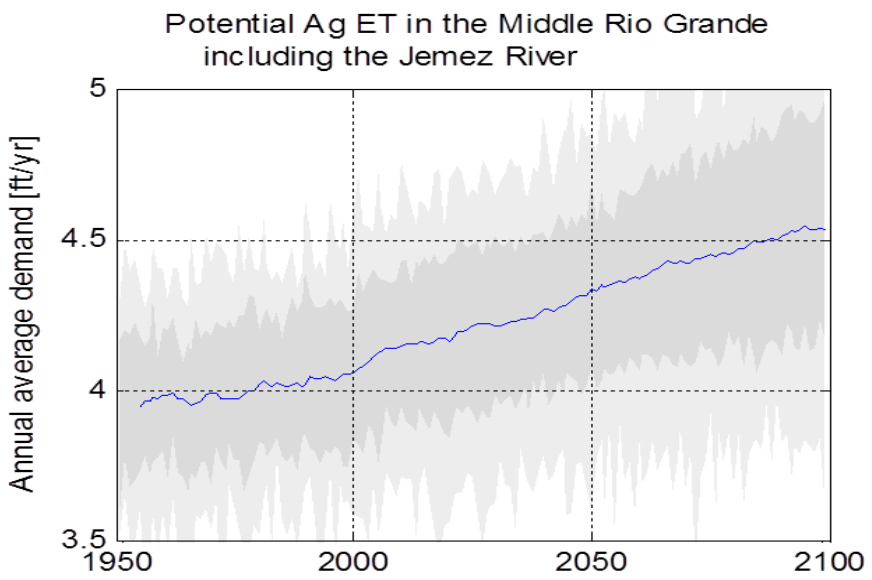
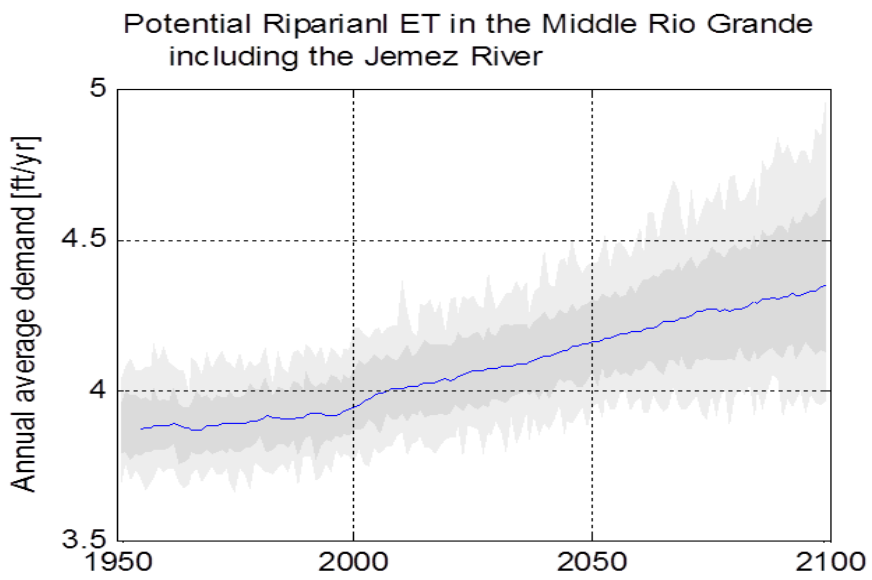
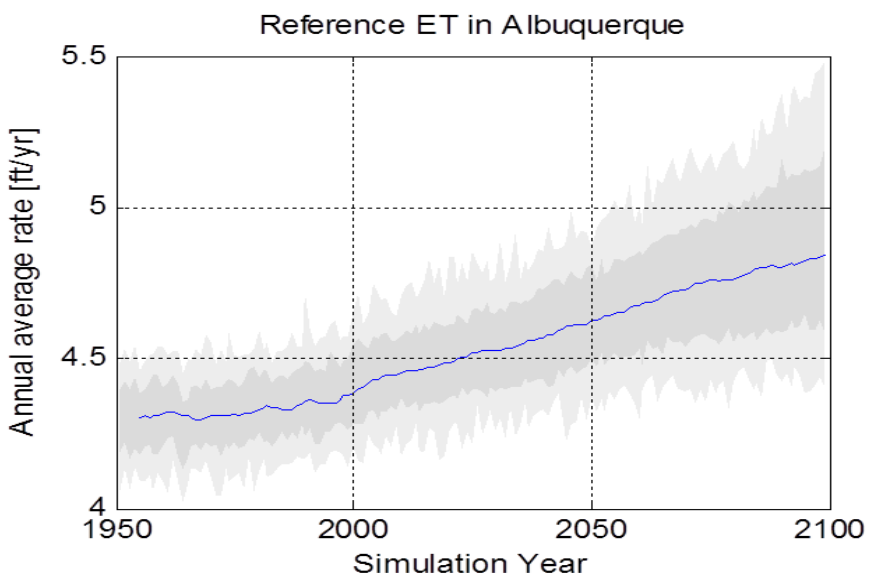
Models Project Reduced System Inflows

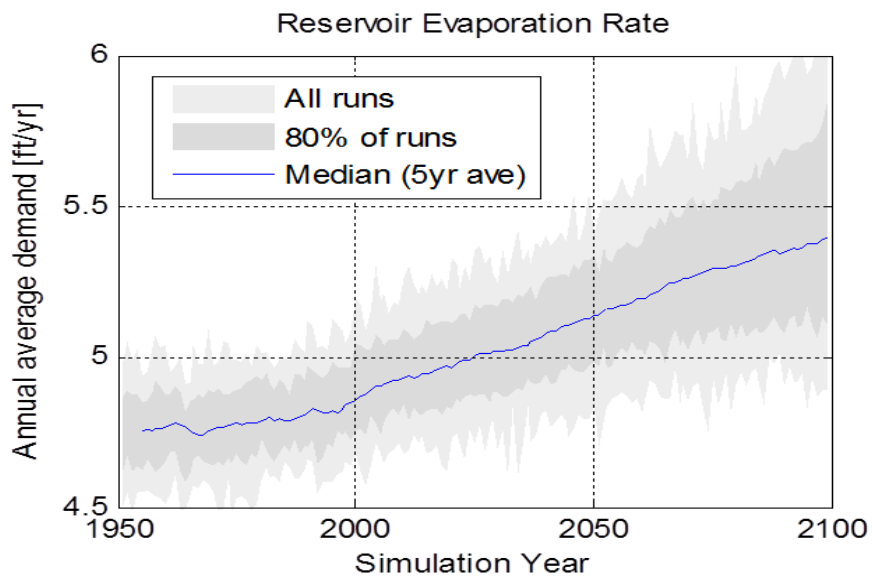


Models Project Increases in Demand: Agricultural, Riparian, and Reservoir Evaporation

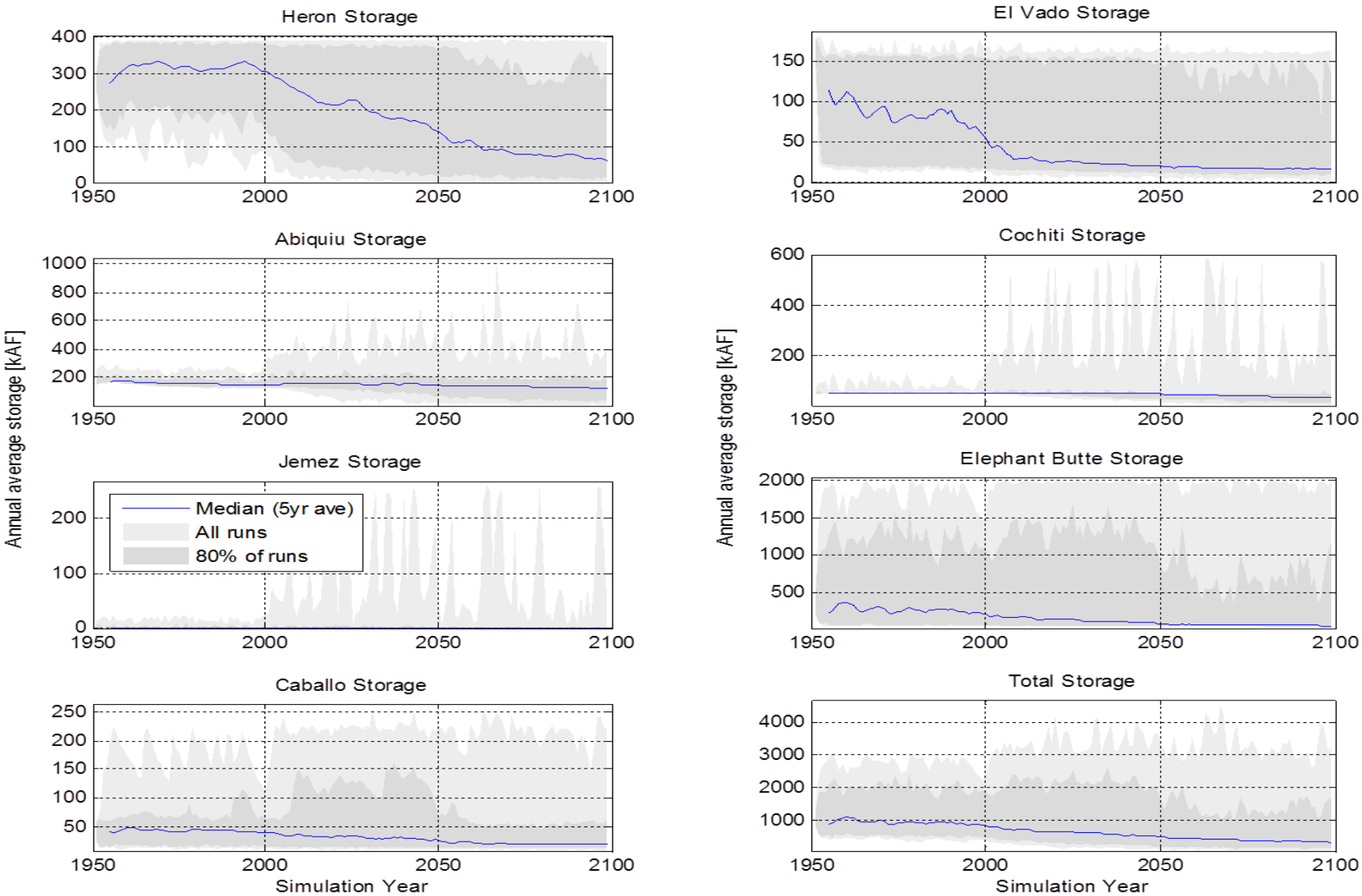








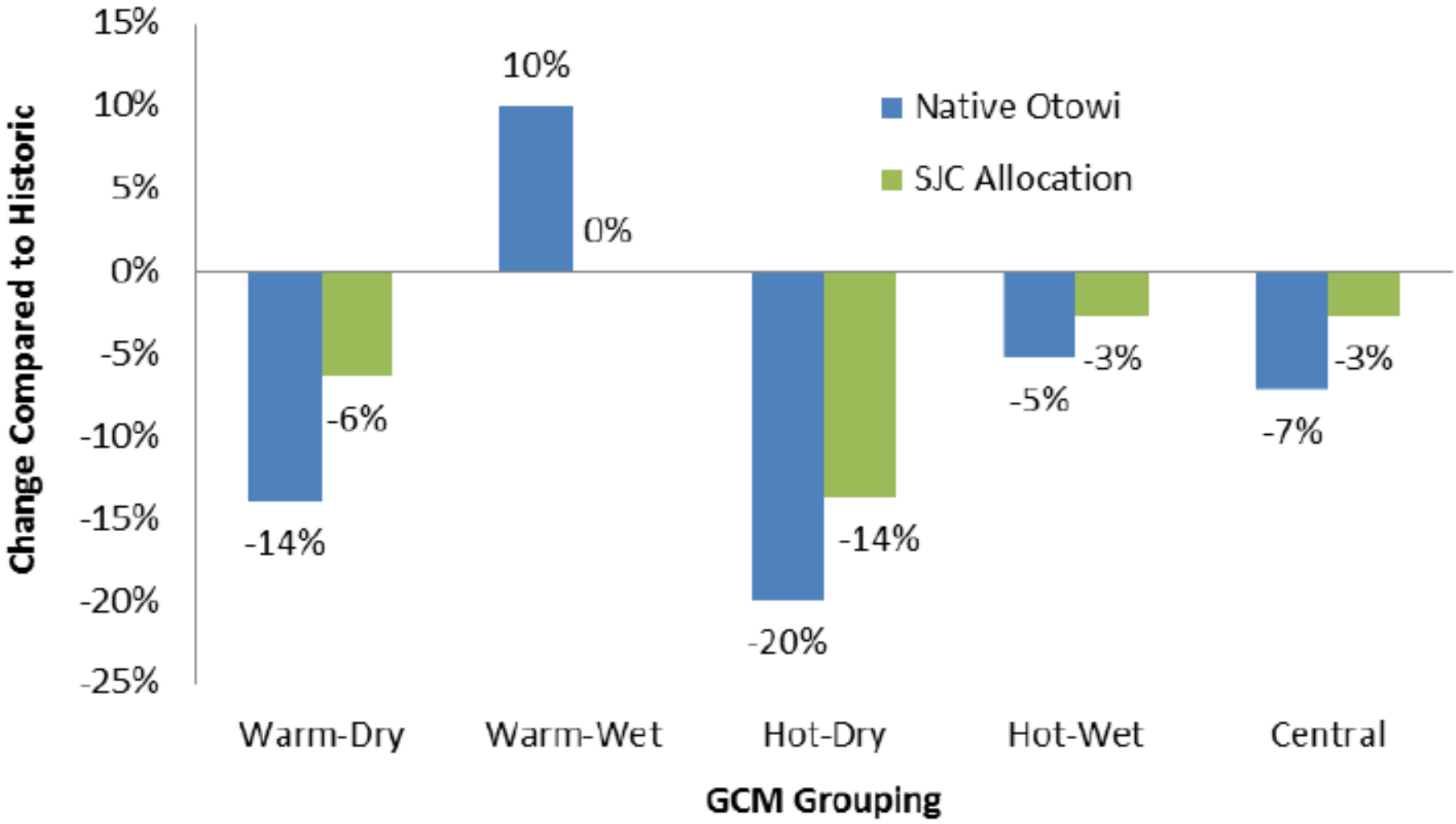
Models Project Decreases in Reservoir Supply



San-Juan Chama Trans-mountain Diversion

- 96,200 acre-feet per year of water that must be consumed in the Middle Rio Grande Valley.
- Has been used to supplement municipal, industrial, agricultural, tribal, and environmental supplies.
- Is projected to be more reliable than the native supply

Native (at Otowi) and SJC Water Availability in Rio Grande 2040 Compared to Historic by GCM Grouping

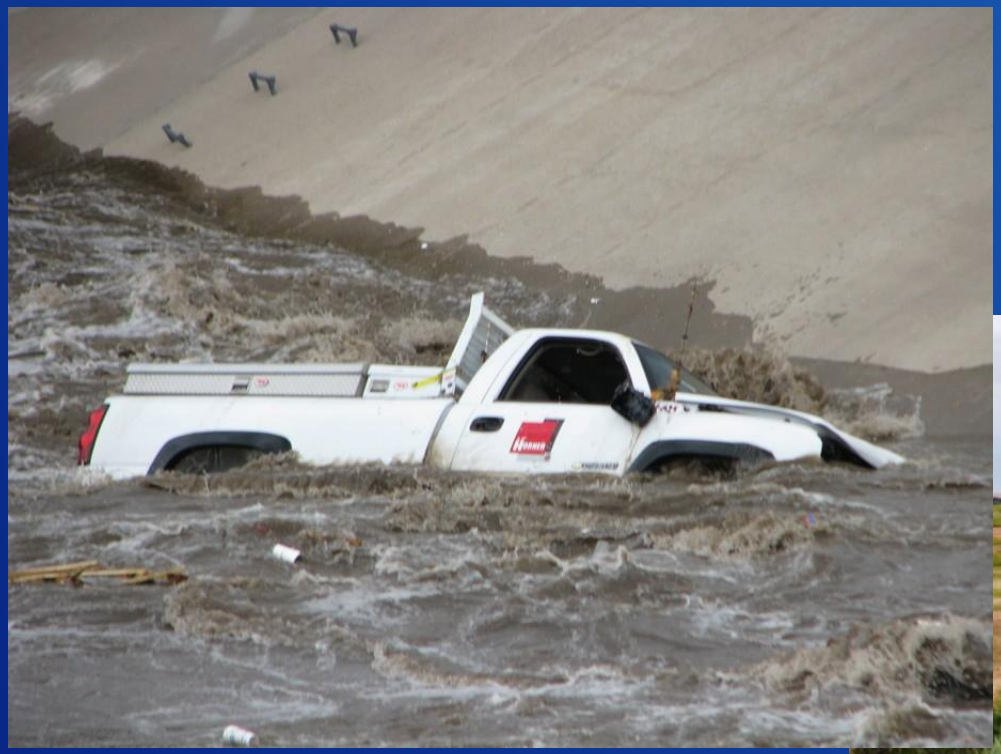


RECLAMATION

Futures 2040:
The Metropolitan Transportation Plan for the Albuquerque Metropolitan Planning Area

RECLAMATION

The Southwest's variable hydrology



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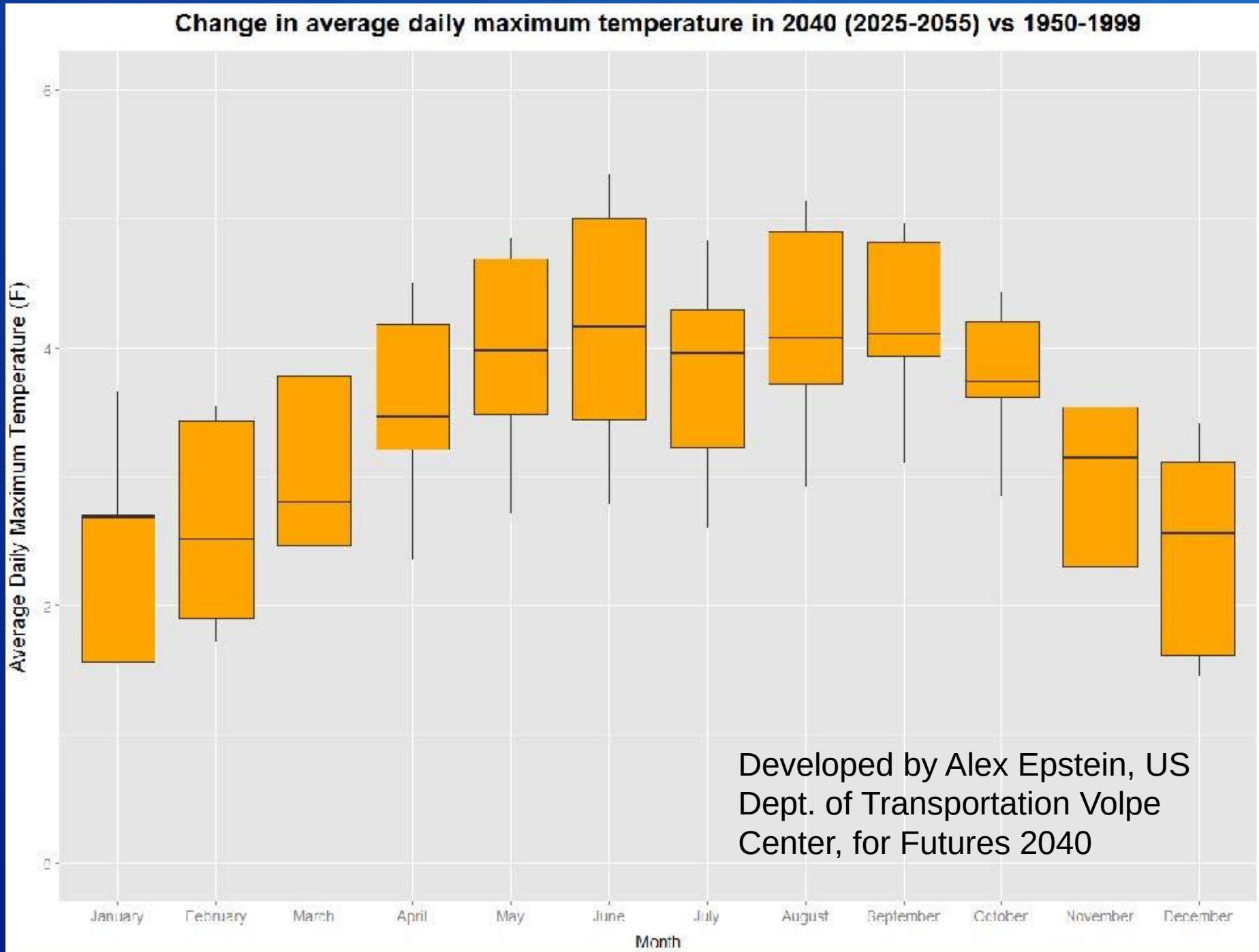
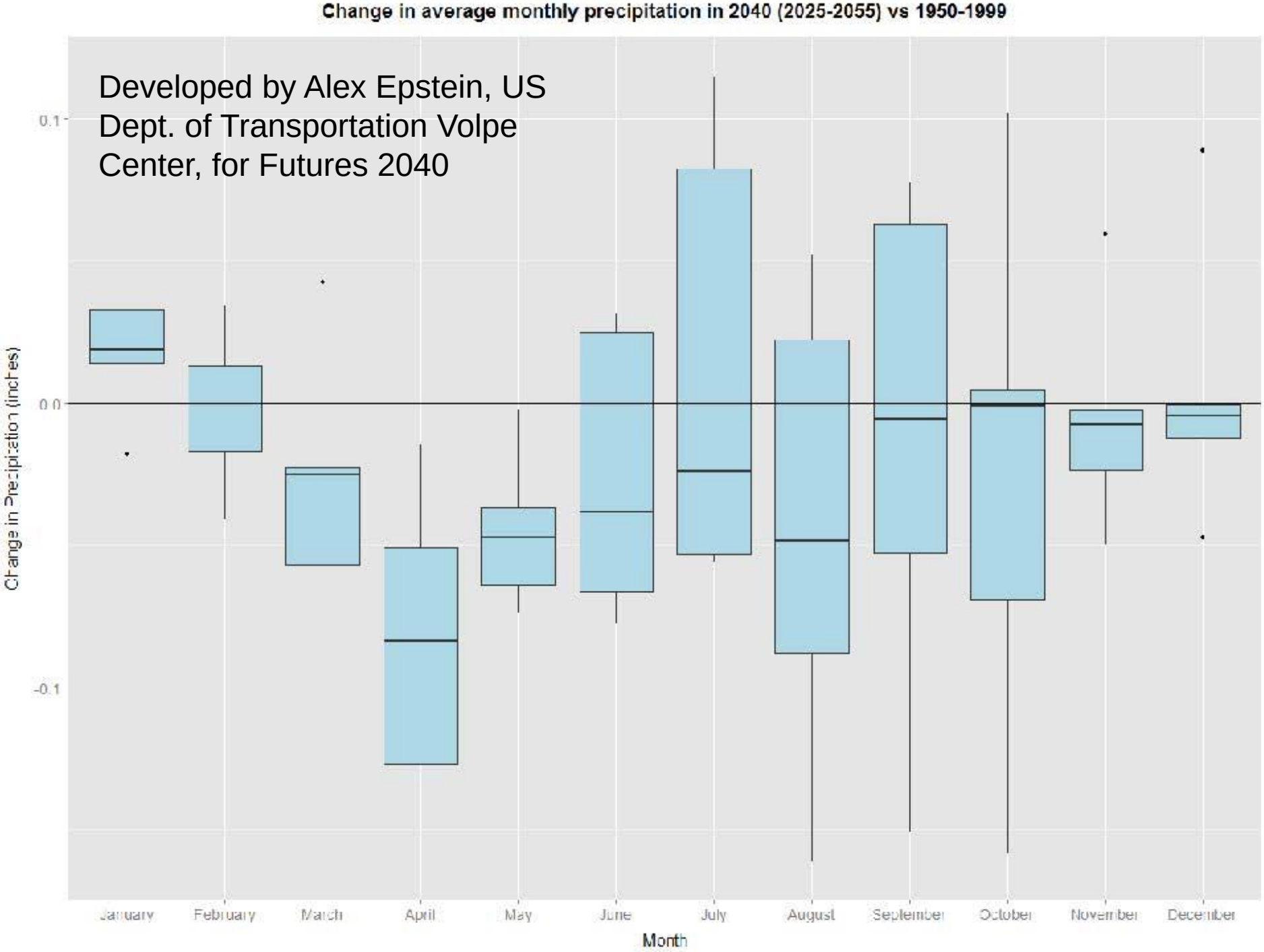


Developed by Alex Epstein, US Dept. of Transportation Volpe Center, for Futures 2040


Change in average monthly precipitation in 2040 (2025-2055) vs 1950-1999
Developed by Alex Epstein, US Dept. of Transportation Volpe Center, for Futures 2040
0.1
0.0
-0.1
Change in Precipitation (inches)
January
February
March
April
May
June
July
August
September
October
November
December
Month

Summary of Projected Impacts on Water Management Systems

- Water Infrastructure, Operations, and Delivery
- Hydropower Generation
- Flood Control Operations
- Water Quality
- Fish and Wildlife Habitat
- Endangered Species
- Flow- and Water-Dependent Ecological Resilience
- Recreation
- The Rio Grande Compact

Feedbacks and Cascading Impacts

Las Conchas and its aftermath

RECLAMATION

Overall Changes Projected in Southwestern Hydrology

- Our usable, manageable water supply will decline, especially winter snowpack; Monsoons remain a significant unknown.
- Our water supply will be subject to increased variability and uncertainty.
- There will be changes in spatial and temporal distribution of water.
- Feedbacks can lead to cascading impacts (as recently seen in New Mexico).
- Everything is confounded by all of the other things that humans do.

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RECLAMATION

Thanks for joining me in thinking about insoluable problems.

If you aren't part of the solution, you are part of the precipitate!