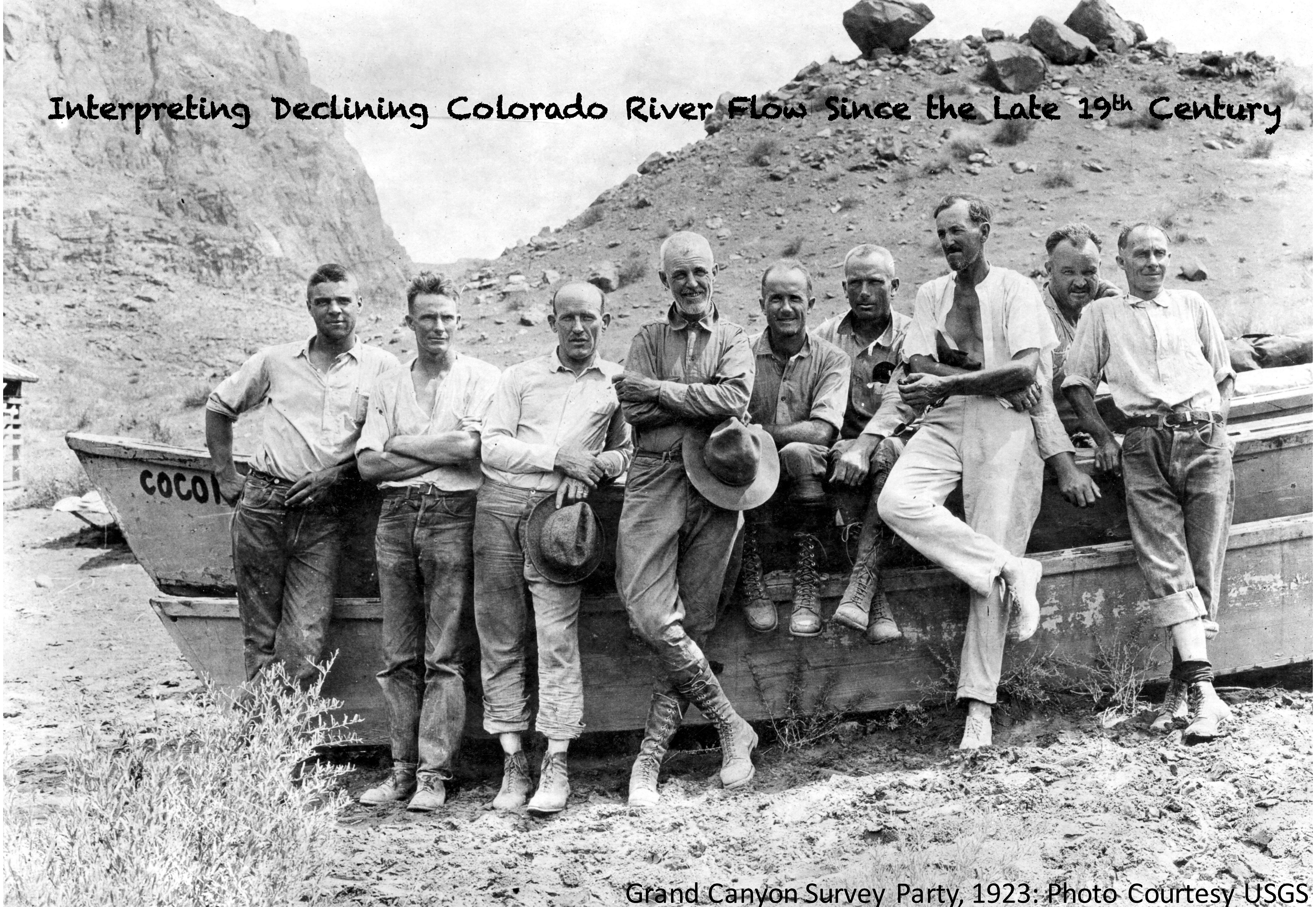
Interpreting Declining Colorado River Flow Since the Late 19th Century



Grand Canyon Survey Party, 1923: Photo Courtesy USGS

What Has Happened?

The first two decades of the 21st century have witnessed large water supply depletion on the Colorado River.

Why Has it Happened?

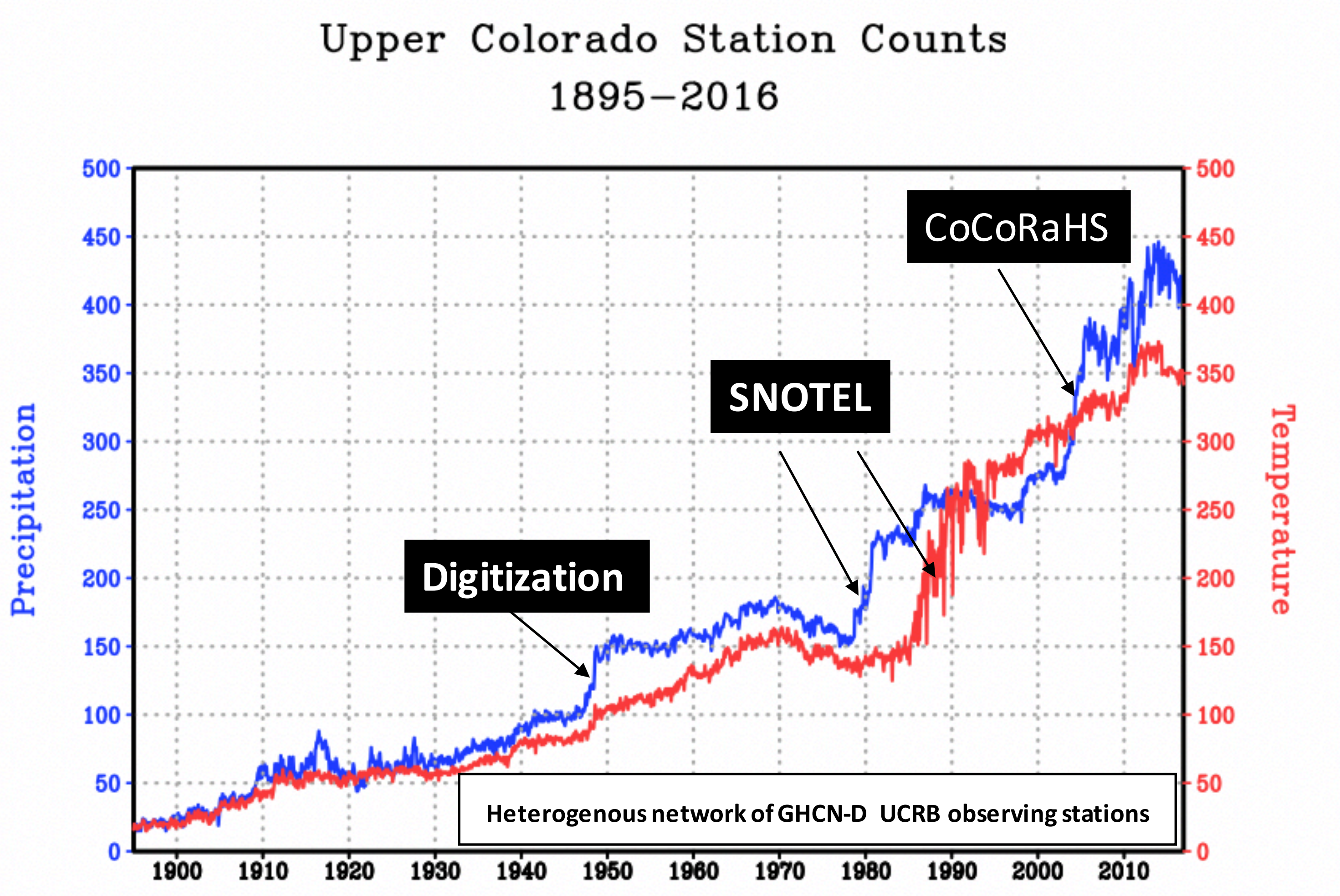
Record-setting temperature *is believed to be* the principal driver of low Colorado River flow.

What are the Implications?

It is feared that continued temperature rise ensures further water supply decline, regardless of pcpn changes.

Data Issues Cloud Empirical Interpretations of the Causes for Colorado River Flow Declines*

• *Actual pcpn change is not well-known*; • *True Q sensitivity to temperature cannot be reliably estimated from the instrumental record*



* *Figure* based on a draft manuscript Barsugli et al. 2018*;* see also Milly and Dunne 2002.

Method

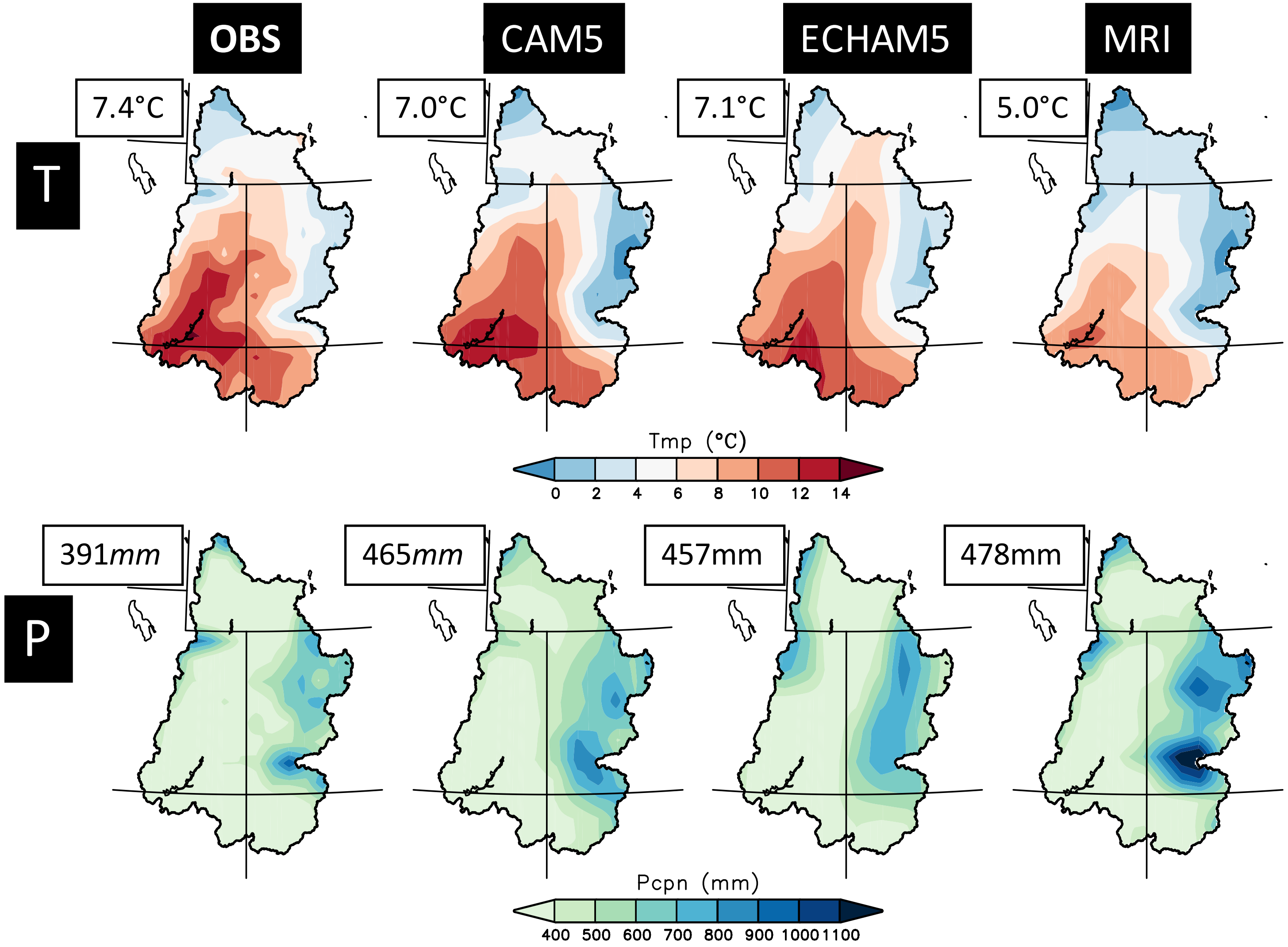
- **High Resolution (*~50km*) Atmospheric Climate Modeling (AGCM)**

- **Two Driving Scenarios**

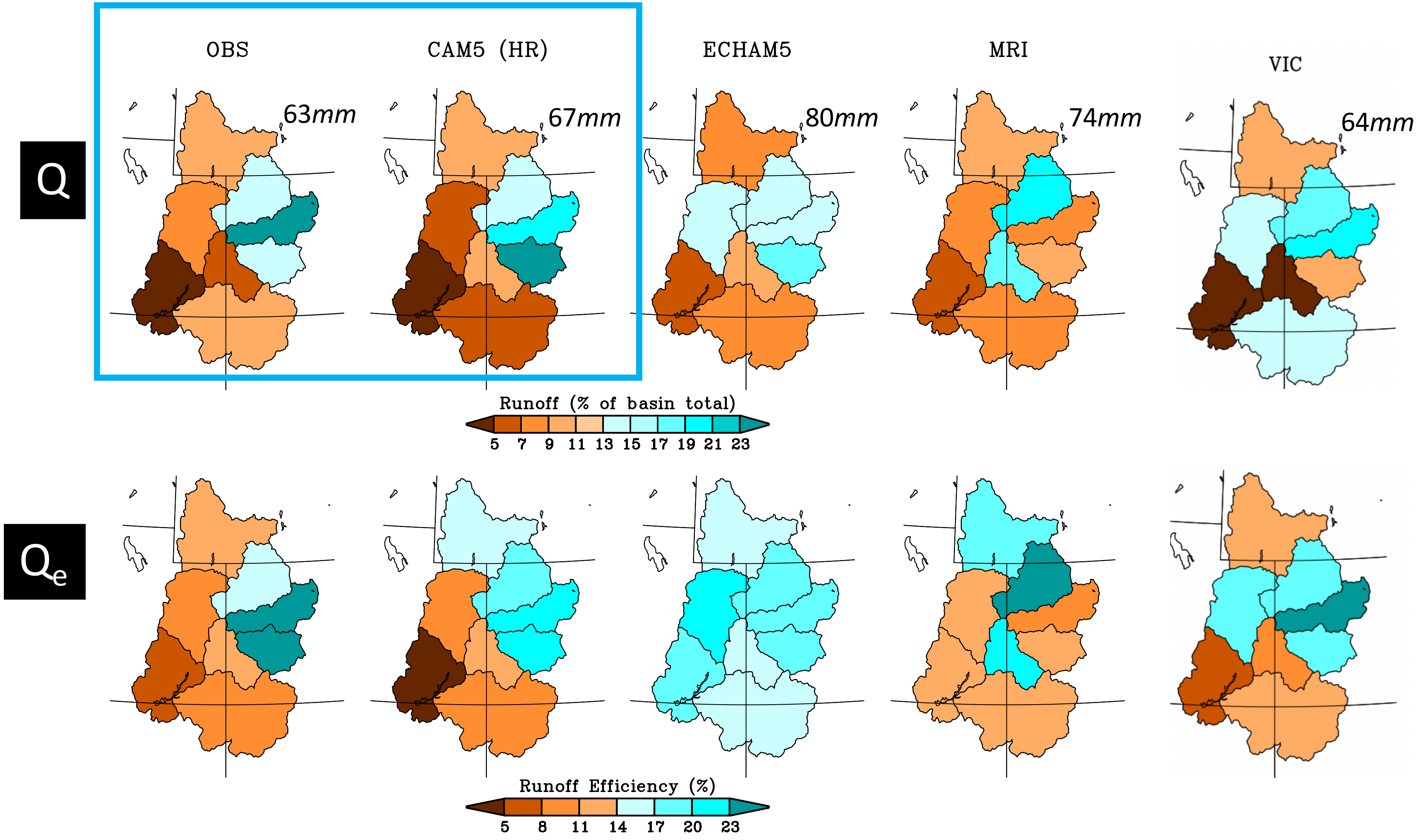
  --- Current Climate Forcing (OBS SSTs/SIC and GHG & aerosols 1979-2016)
  --- Late 19th Century Climate Forcing (Sun et al. 2018, WACE)
  --- Multiple models, multiple simulations (140)

AGCM Hydroclimate for the UCRB

Water-Year Temperature (T) and Precipitation (P) Climatology

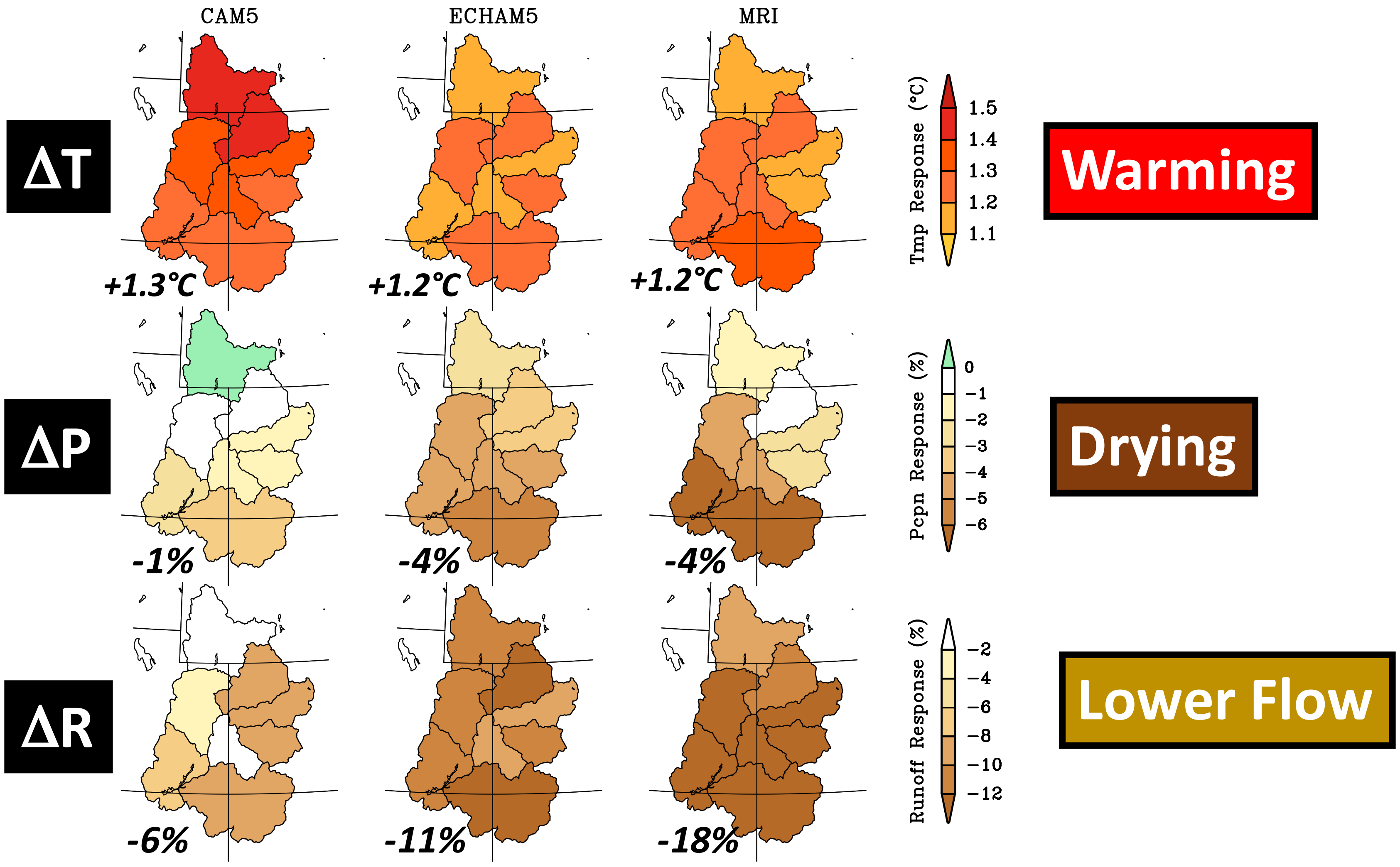


Water-Year Runoff (Q) and Runoff Efficiency (Q/P)



AGCM Hydroclimate Response for the UCRB

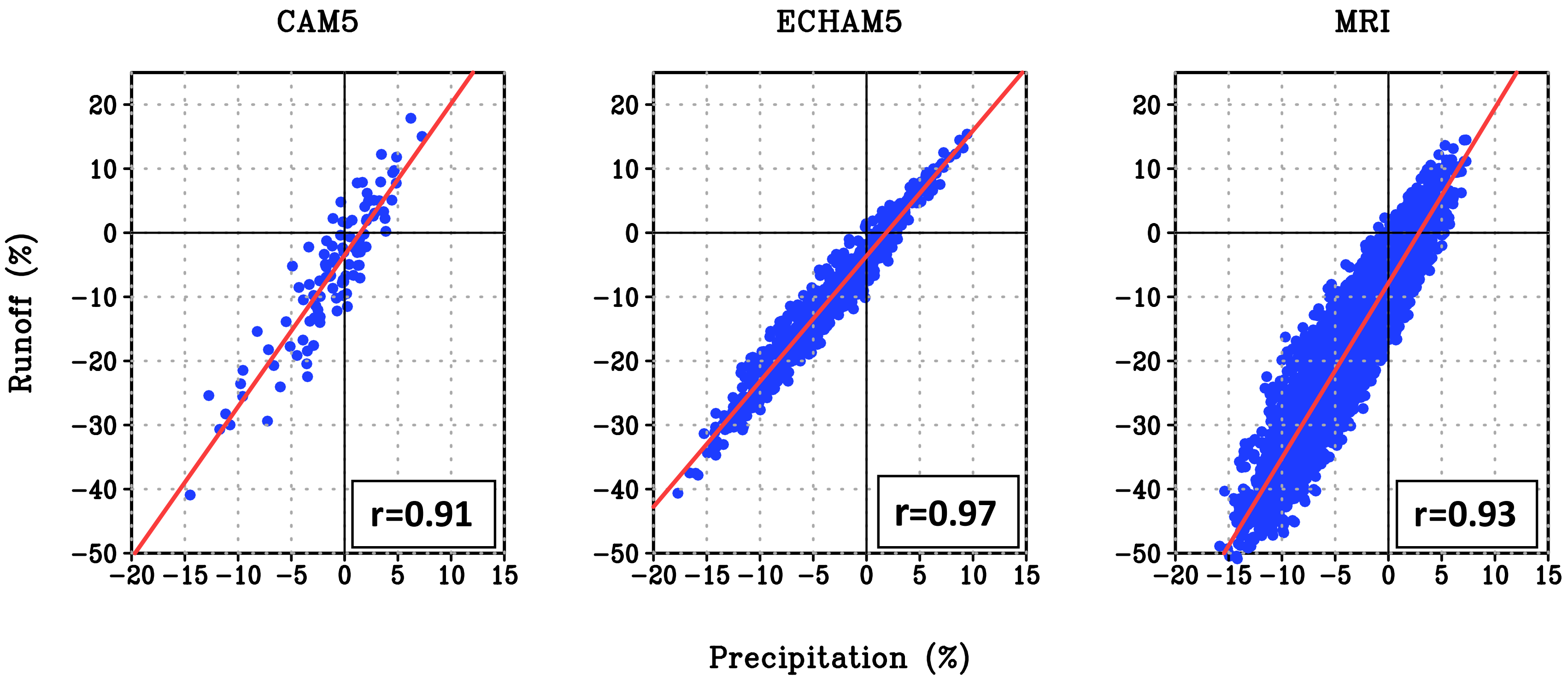
Temperature and Precipitation Response



Physics of UCRB Runoff Response

Runoff Sensitivity to Temperature and Precipitation Change

$$\Delta Q/Q = \varepsilon_p \, \Delta P/P + \varepsilon_T \Delta T$$



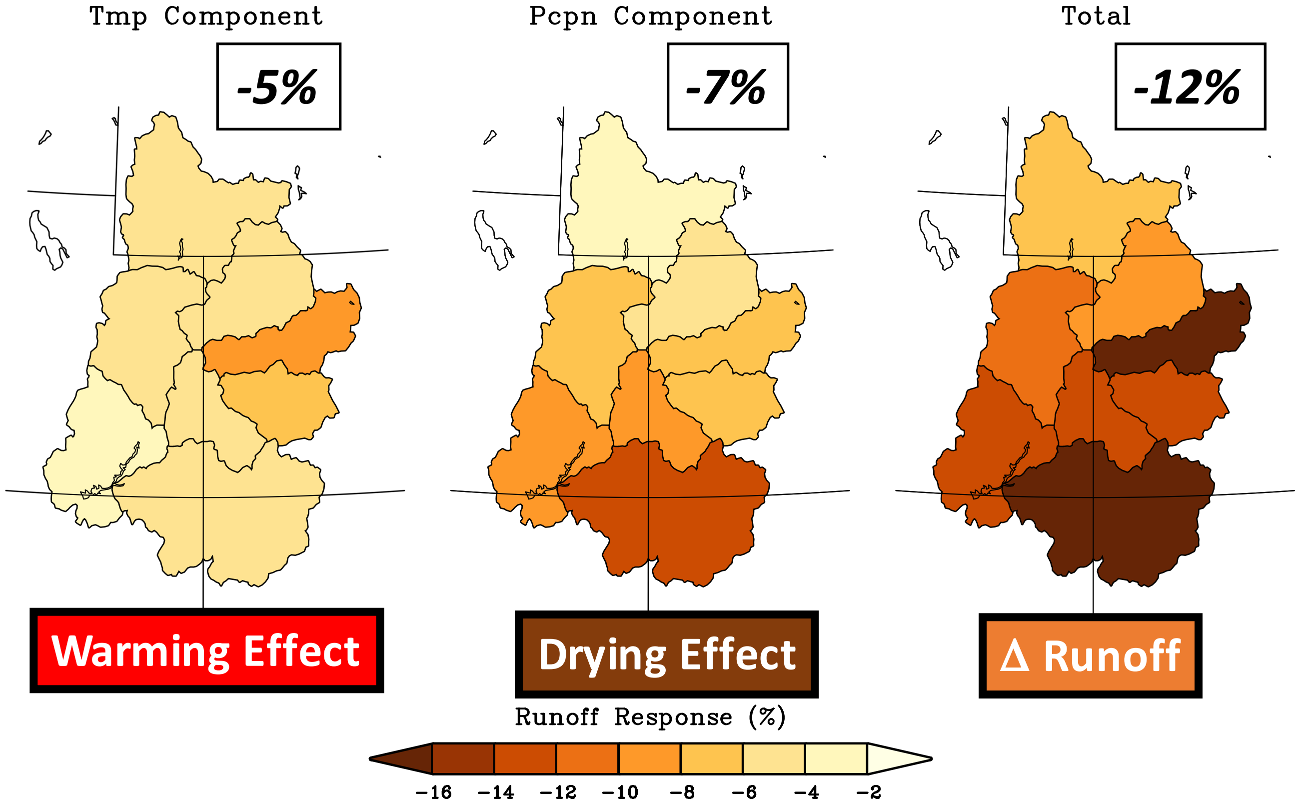
$\varepsilon_p = 2.4$
$\varepsilon_T = -2.5\%/°C$

$\varepsilon_p = 2.0$
$\varepsilon_T = -3.0\%/°C$

$\varepsilon_p = 2.7$
$\varepsilon_T = -6.5\%/°C$

Runoff Response to Climate Change Since Late 19th Century

Multi-model



Summary of Our Principal Findings

- Our results indicate a climate change UCRB runoff signal of *-12% (+/- 4%)* since the late 19thC.
- The underlying effect of climate change has been to increase T *(~1.2°C)* and reduce P *(~-3%)*.
- Temperature sensitivity of Colorado River flow is on the low end of prior estimates (~ *-3%/°C*).
- Reduced P, not increased T, has mostly caused climate change-induced flow decline to date.
- Large precipitation increases are not required to offset warming-induced flow decreases.

Implications of Our Results for the Debate on Megadrought Risk on the Colorado River

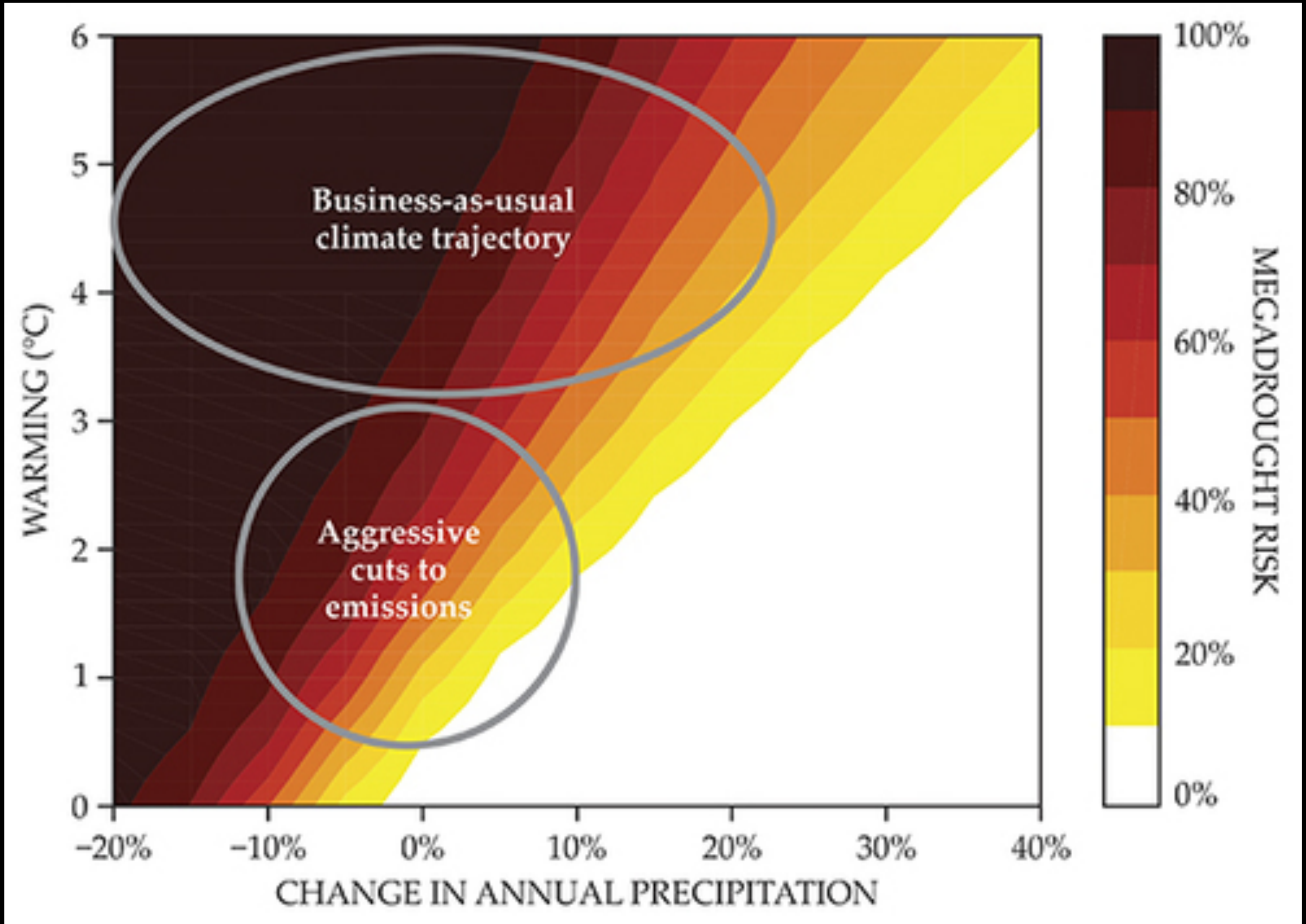


Figure 4 from Ault and George, Aug 2018; *Physics Today*

Implications of Our Results for the Debate on Megadrought Risk on the Colorado River

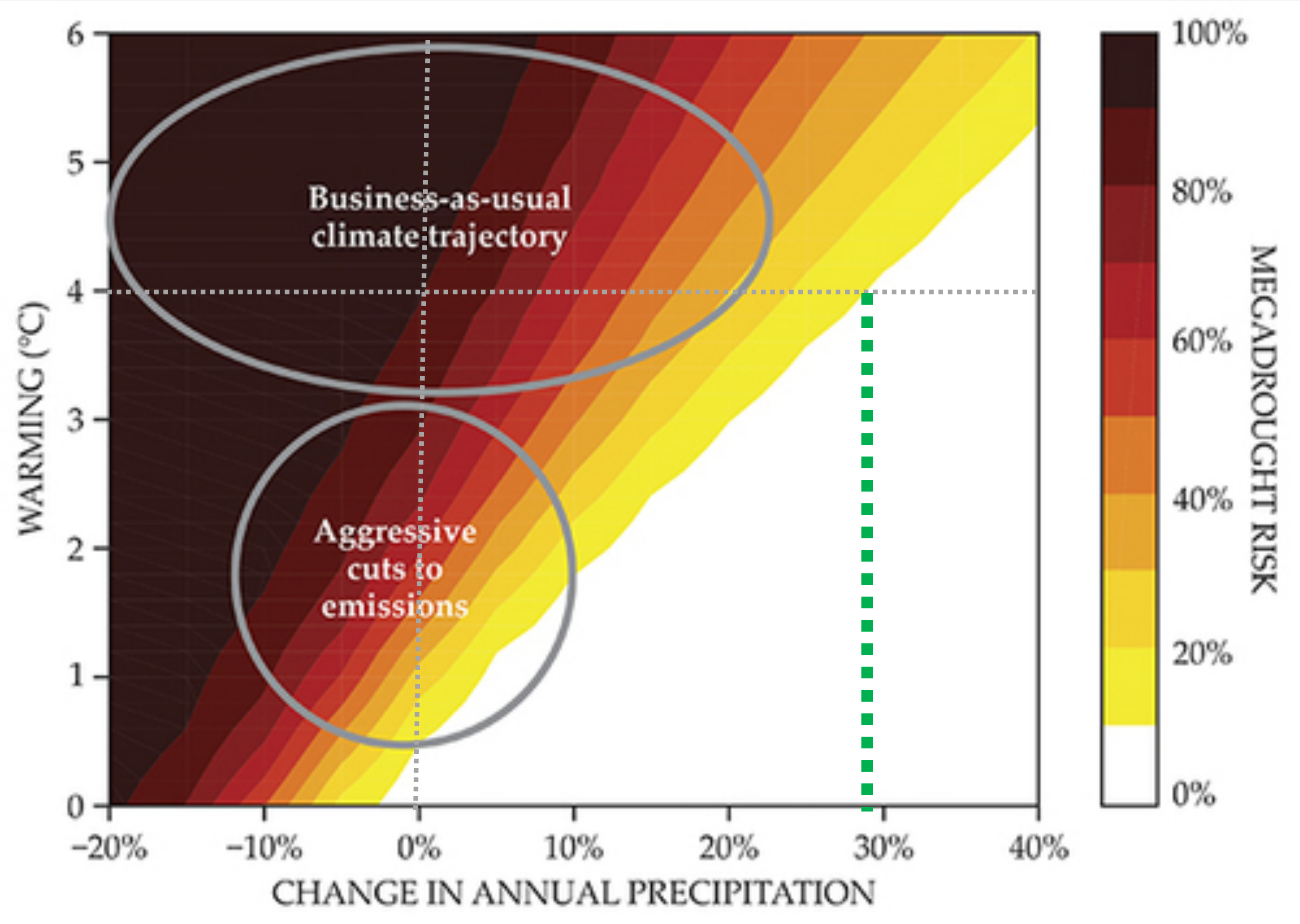


Figure 4 from Ault and George, Aug 2018; *Physics Today*

Implications of Our Results for the Debate on Megadrought Risk on the Colorado River

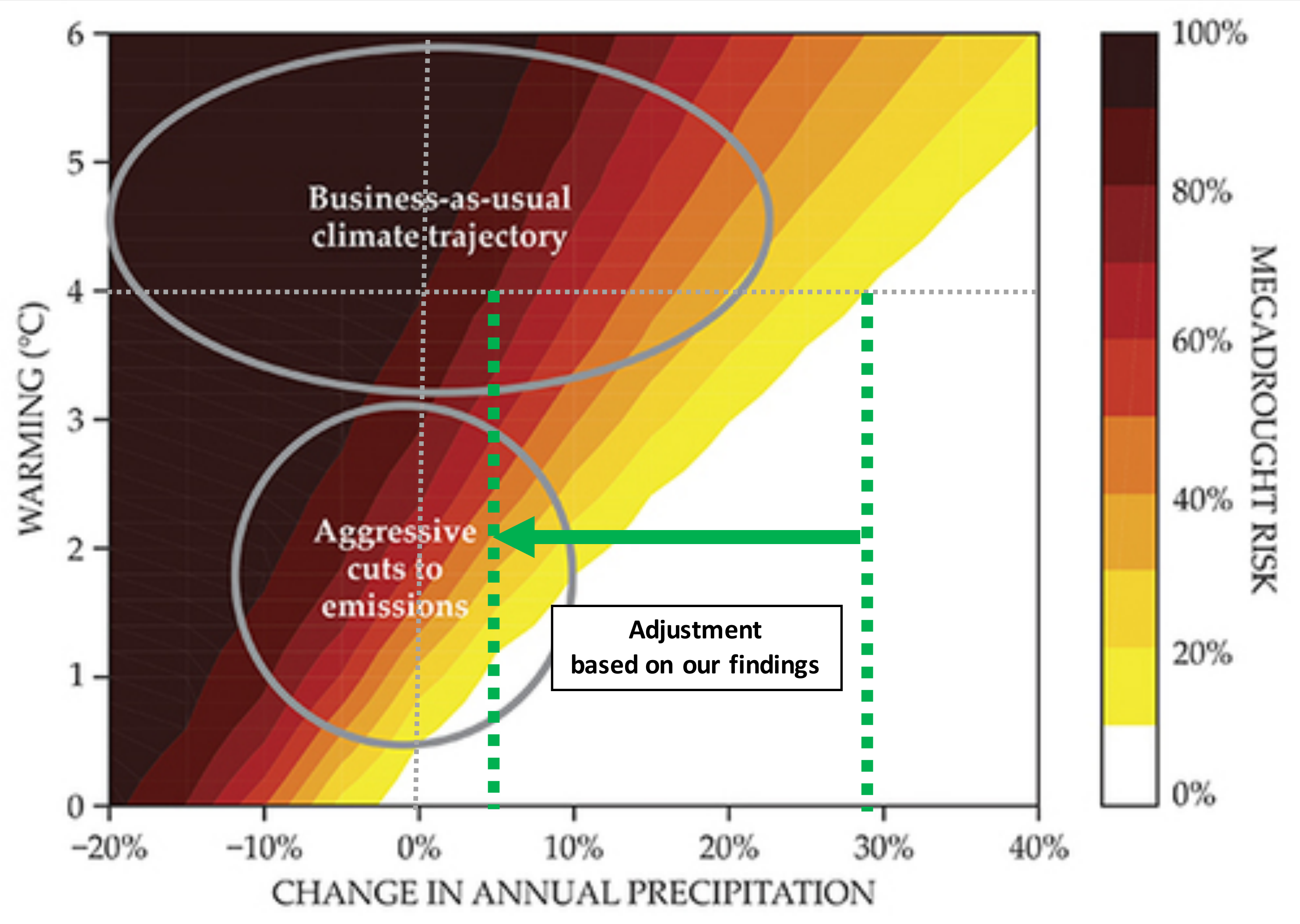
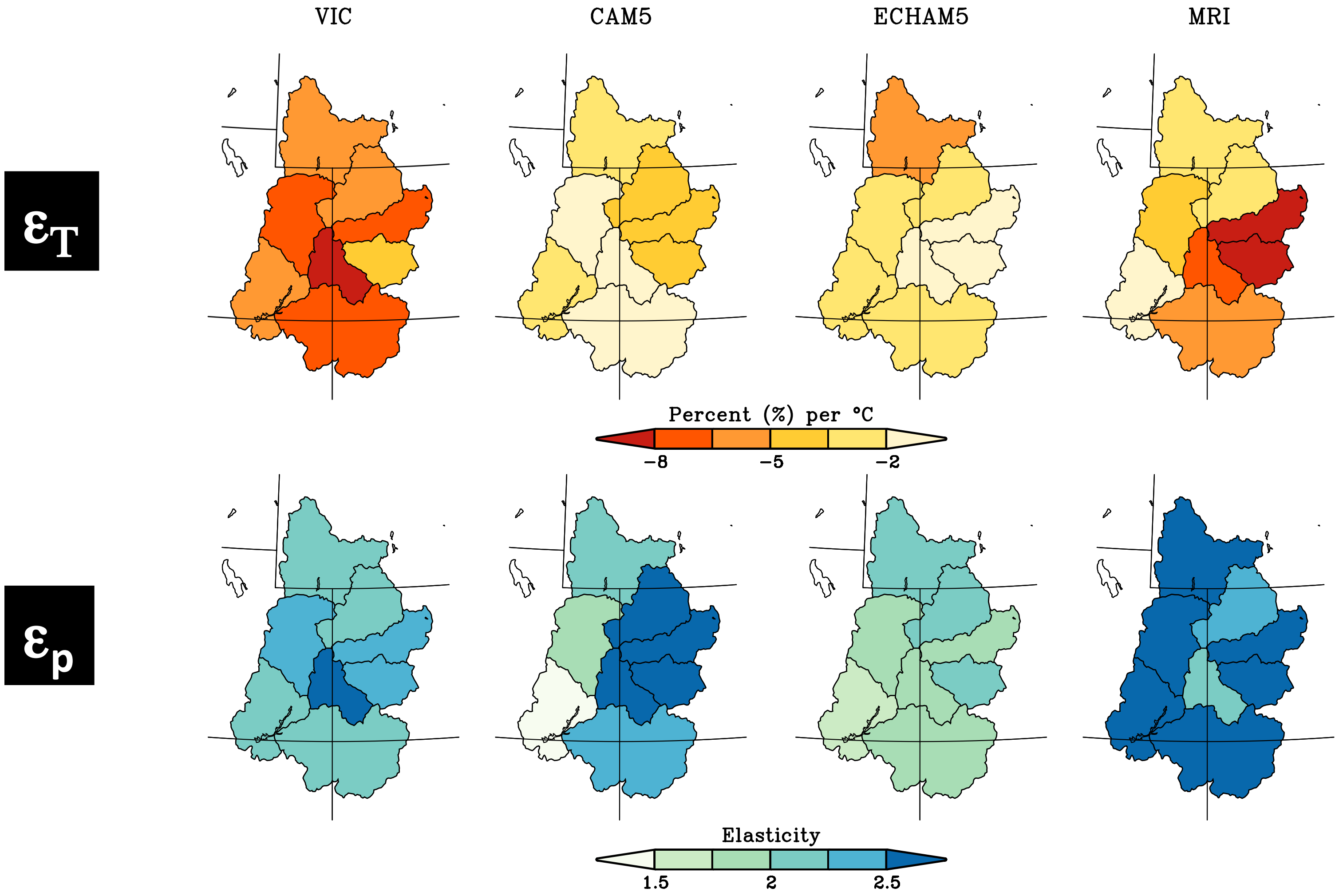


Figure 4 from Ault and George, Aug 2018; *Physics Today*

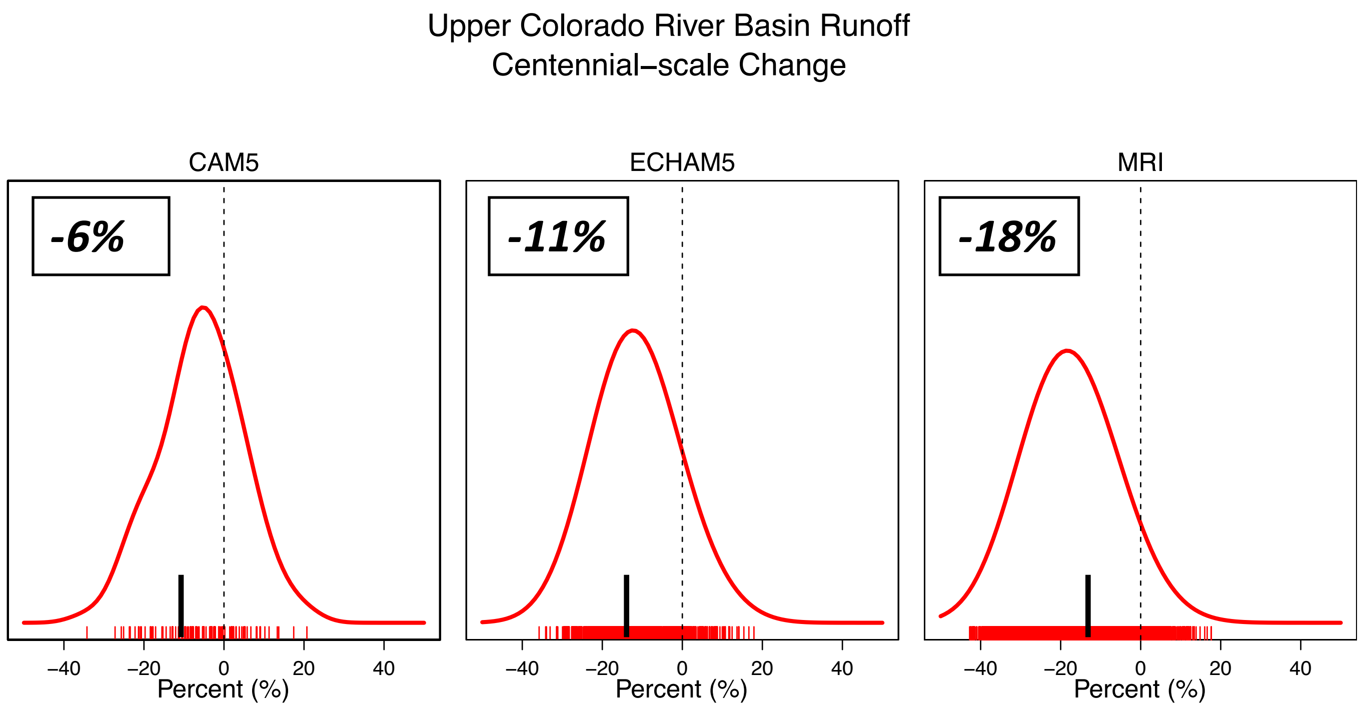

Thank You

Extra Slides

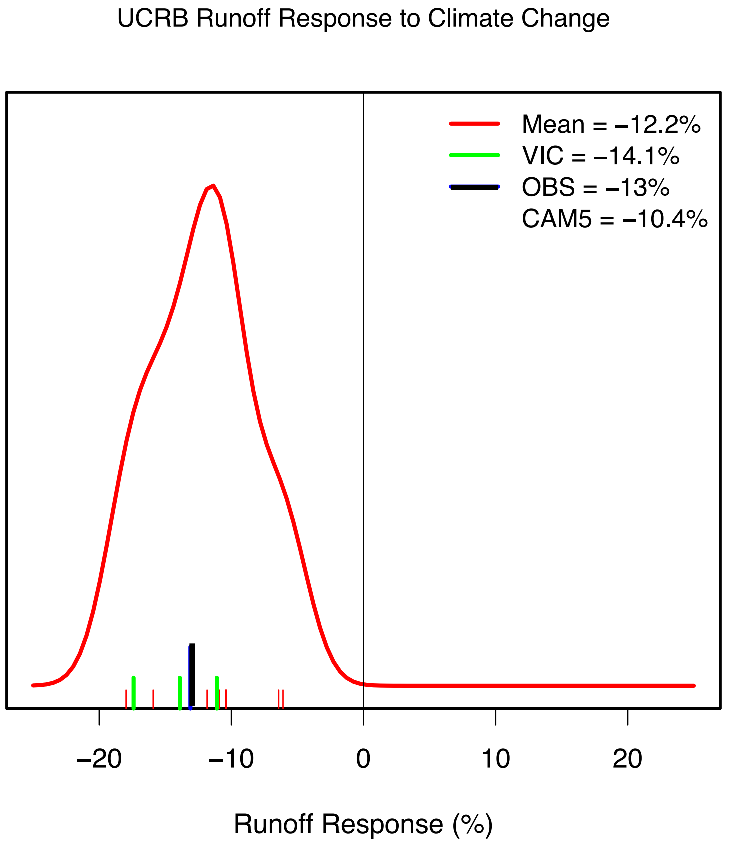
Runoff Sensitivity within the UCRB



Runoff Response (%)



Runoff Response to Climate Change Since Late 19th Century



Empirical Evidence for *High Temperature Sensitivity* of Colorado River Flow

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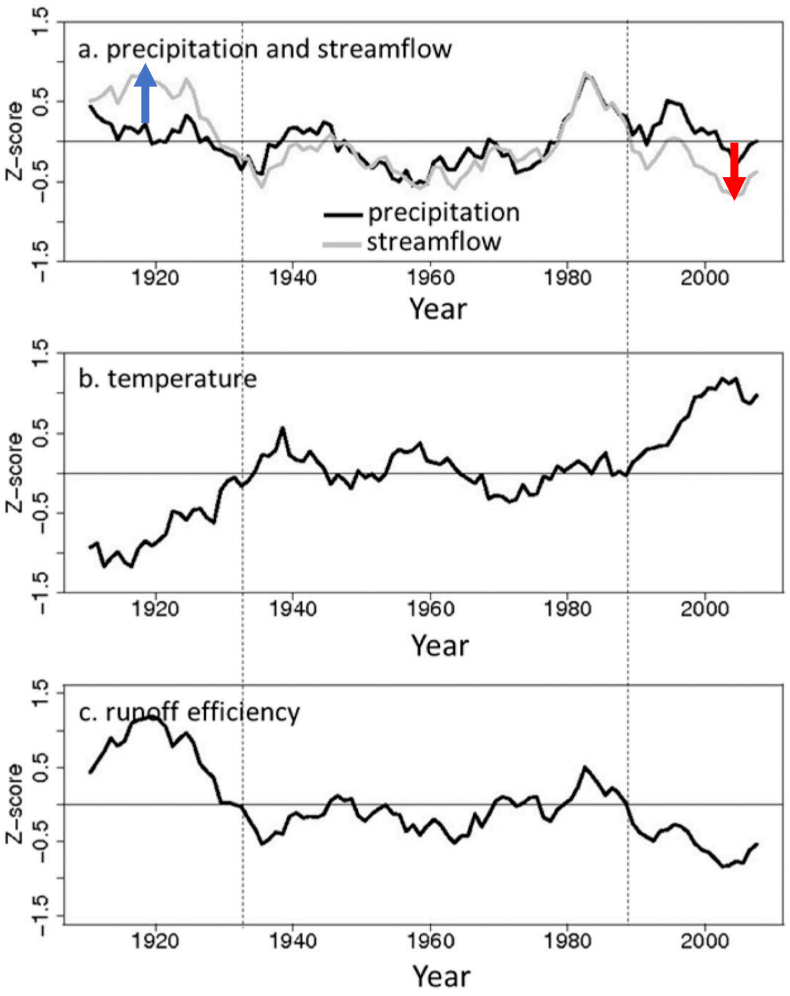


Figure 2. The 10-yr moving averages of *Z* scores of upper Colorado River basin (a) water-year precipitation and streamflow, (b) water-year temperature, and (c) runoff efficiency. The dotted vertical lines demark an early twentieth-century cool period (1906–33), a near-average temperature period (1934–87), and a late warm period (1988–2012).

from McCabe et al, 2017, *Earth Interactions*

McCabe et al (2017) interpret the historical data to indicate that reductions in flow (since late 1980s) arise *because of increasing temperatures.*

"These … are the largest documented temperature-related reductions since record keeping began*. It is expected that as warming continues, the negative effects of temperature…on streamflow will become more evident and problematic"

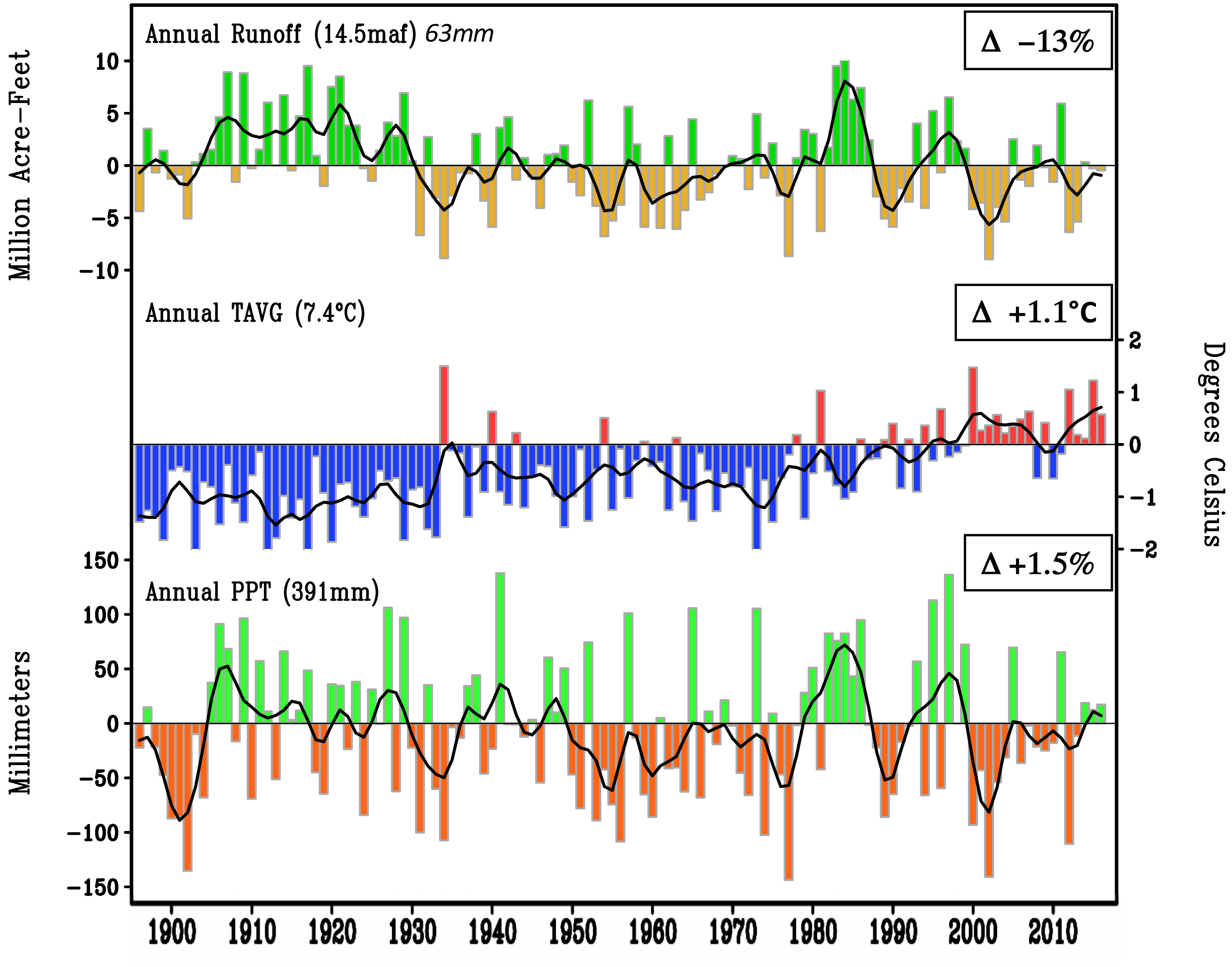
- implied runoff sensitivity ~ -10% per °C warming

13% decline in Lees Ferry flow and a 1.1°C temperature rise in the UCRB since late 19th C

Various empirical studies argue for high temperature sensitivity of Lees Ferry flow (10%-15% decline per °C warming)

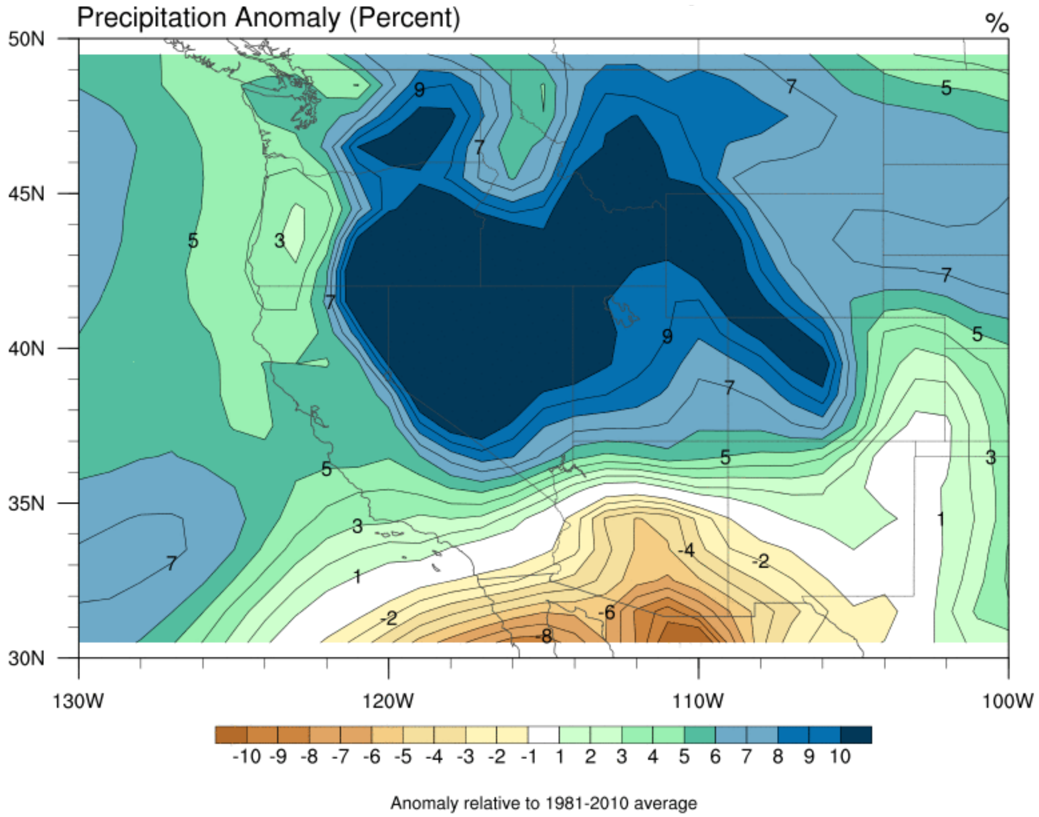
Stockton & Boggess 1979; Revelle & Wagonner 1983; Nowak et al. 2012; Woodhouse et al 2016; Udall & Overpeck 2017; McCabe et al. 2017

Upper Colorado River Basin

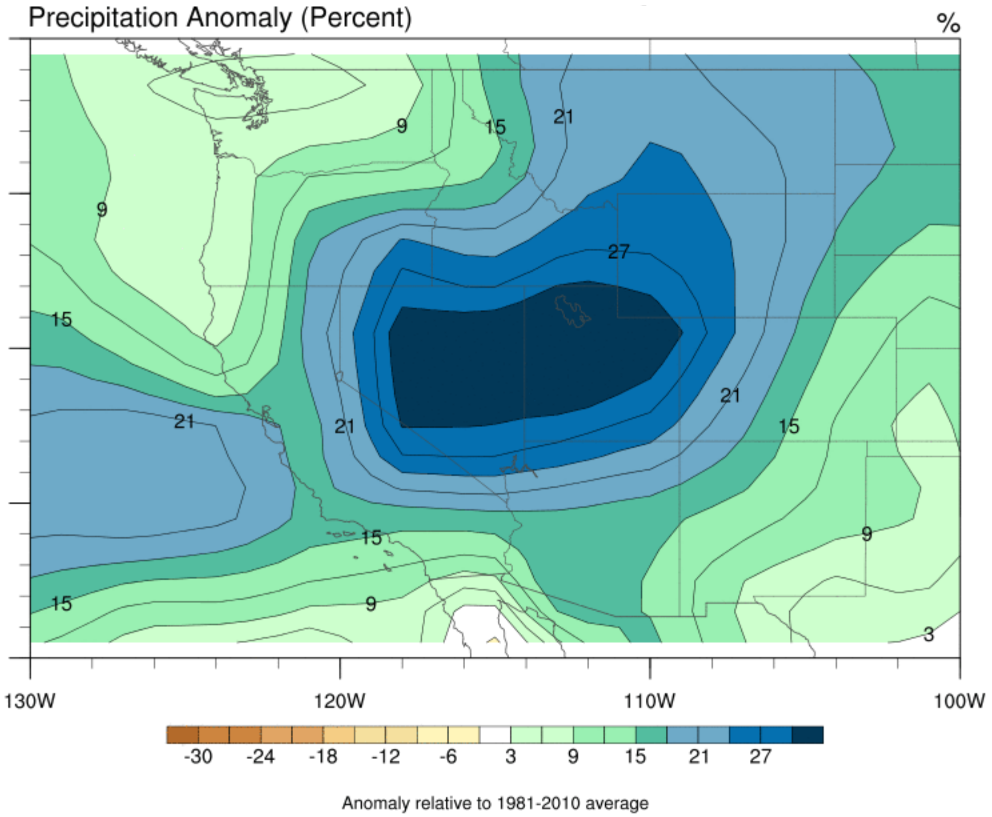


Northern Hemisphere Projection

(2051-80) vs (1981-2010)



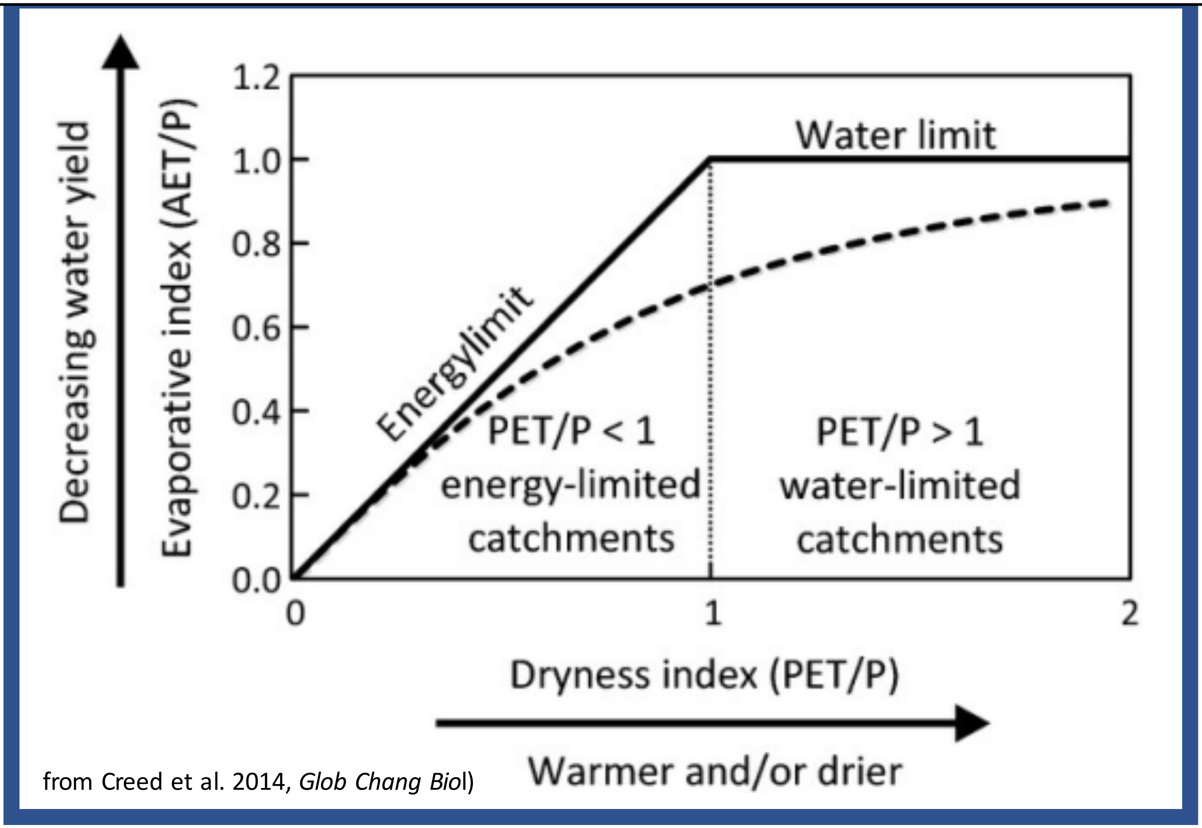
CESM1



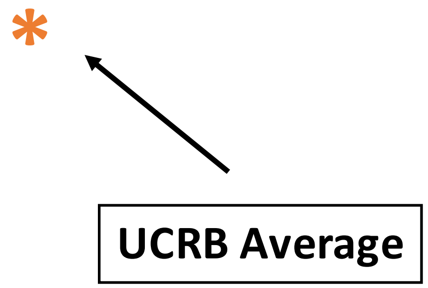
CanESM

Budyko (1974) framework for diagnosing physics of catchment hydroclimate

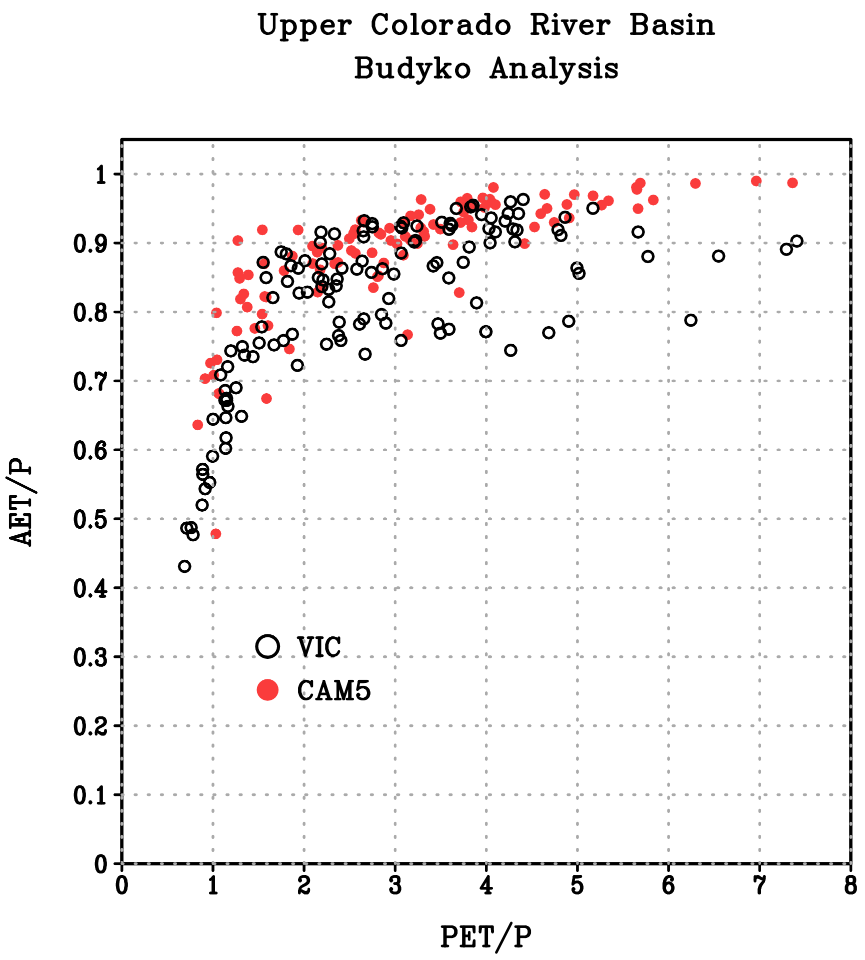
Budyko Hypothesis : AET/P = ϕ (PET/P)

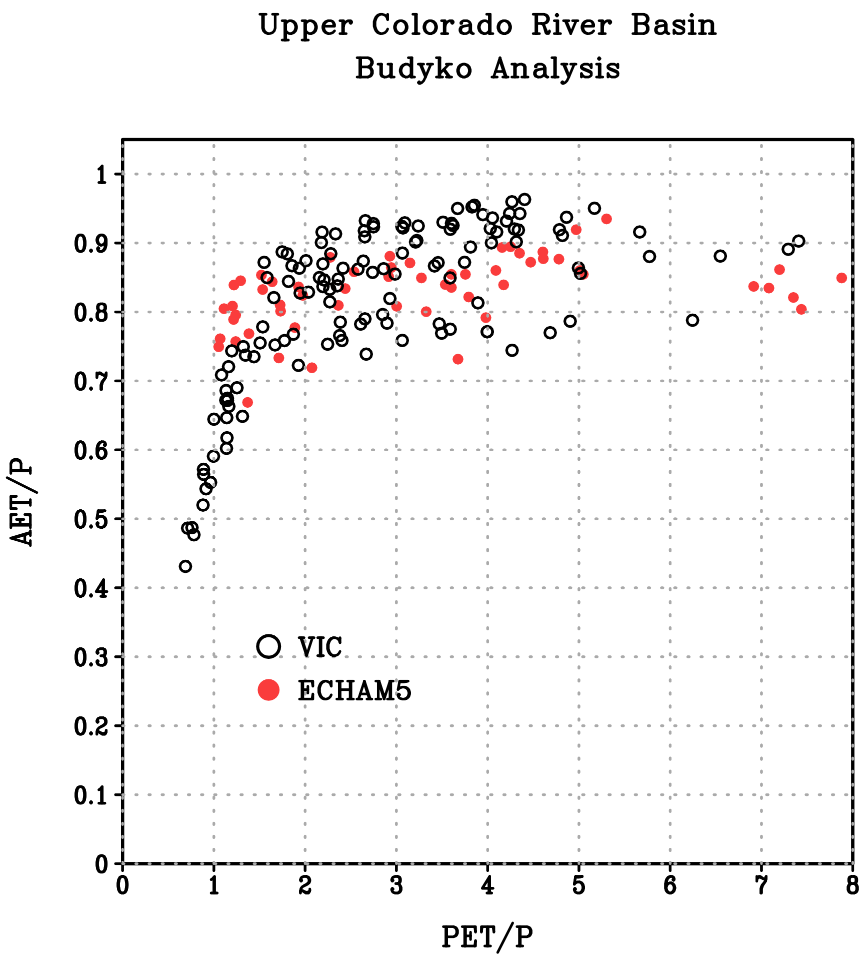


from Creed et al. 2014, *Glob Chang Biol*)

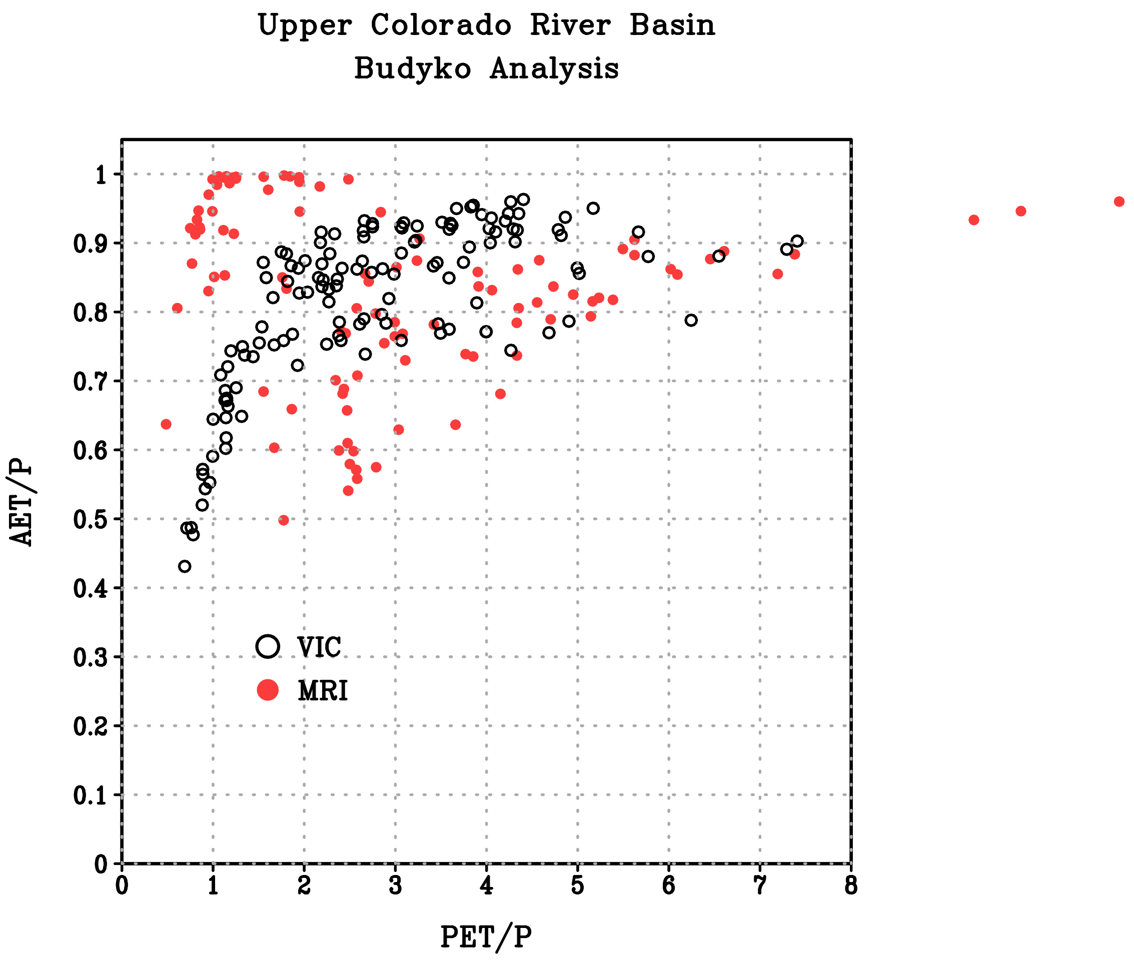


A spatial average of UCRB water/energy balances is unrepresentative of the physics which operate in that (small) portion of the cold/wet UCRB where most of the runoff originates.


Upper Colorado River Basin
Budyko Analysis
AET/P
PET/P
VIC
CAM5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
7
8



Upper Colorado River Basin
Budyko Analysis
AET/P
PET/P
VIC
ECHAM5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
7
8


Upper Colorado River Basin
Budyko Analysis
AET/P
PET/P
VIC
MRI
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
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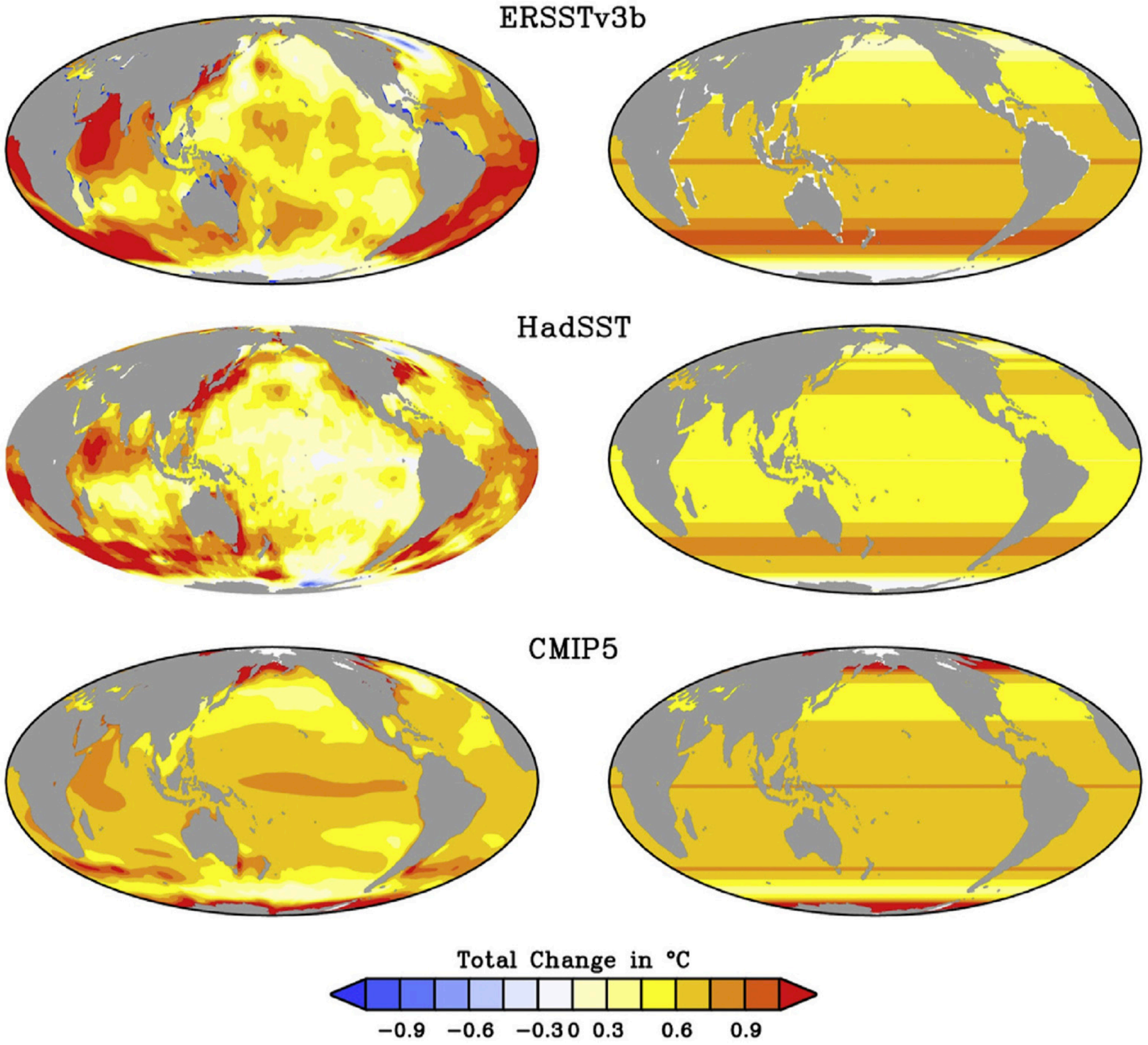
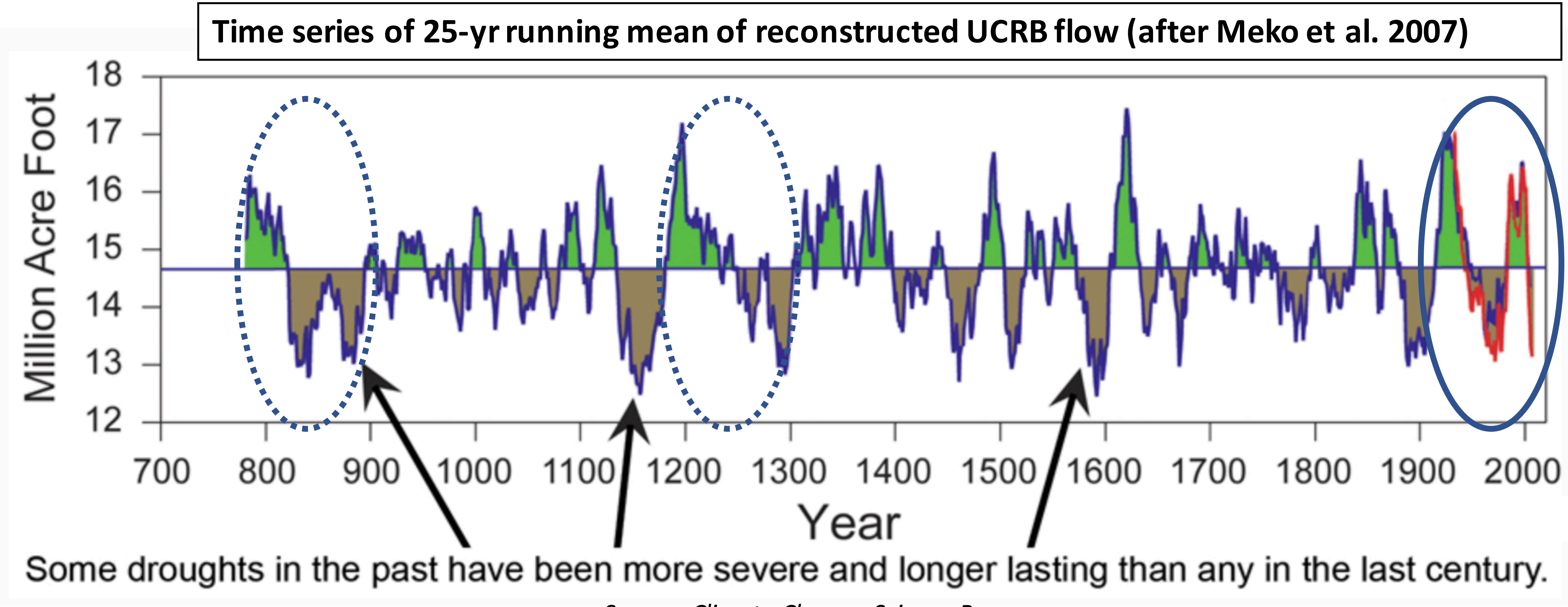


Fig. 2. 1880–2011 linear SST trend (°C) computed at each grid point (left) and zonal-average (right) from ERSSTv3b (top), HadiSSTv1 (middle) and ensemble mean of the 37 CMIP5 models subjected to "All Forcings" during historical period and RCP8.5 emission scenario after 2005 (bottom).

from Sun et al. 2018, WACE

An inherently volatile Colorado River



Source: Climate Change Science Program