Investigation of anomalous runoff response along the hundredth meridian: causes of behavior and potential amplification in a changing climate

UTD Geosciences

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Introduction

- MOPEX (1949 – 2002*)
  - Model Parameter Estimation Experiment
  - 431 stream gauge locations
- CAMELS (1981 – 2014*)
  - Catchment Attributes and Meteorology for Large-sample Studies
  - 671 stream gauge locations
- Variables in both datasets
  - Temperature (T)
  - Runoff (Q)
  - Precipitation (P)
  - Potential evapotranspiration (PET)
  - Actual evapotranspiration (ET) calculated using water balance
    - ET = P – Q
- Anomalous ≈ low runoff

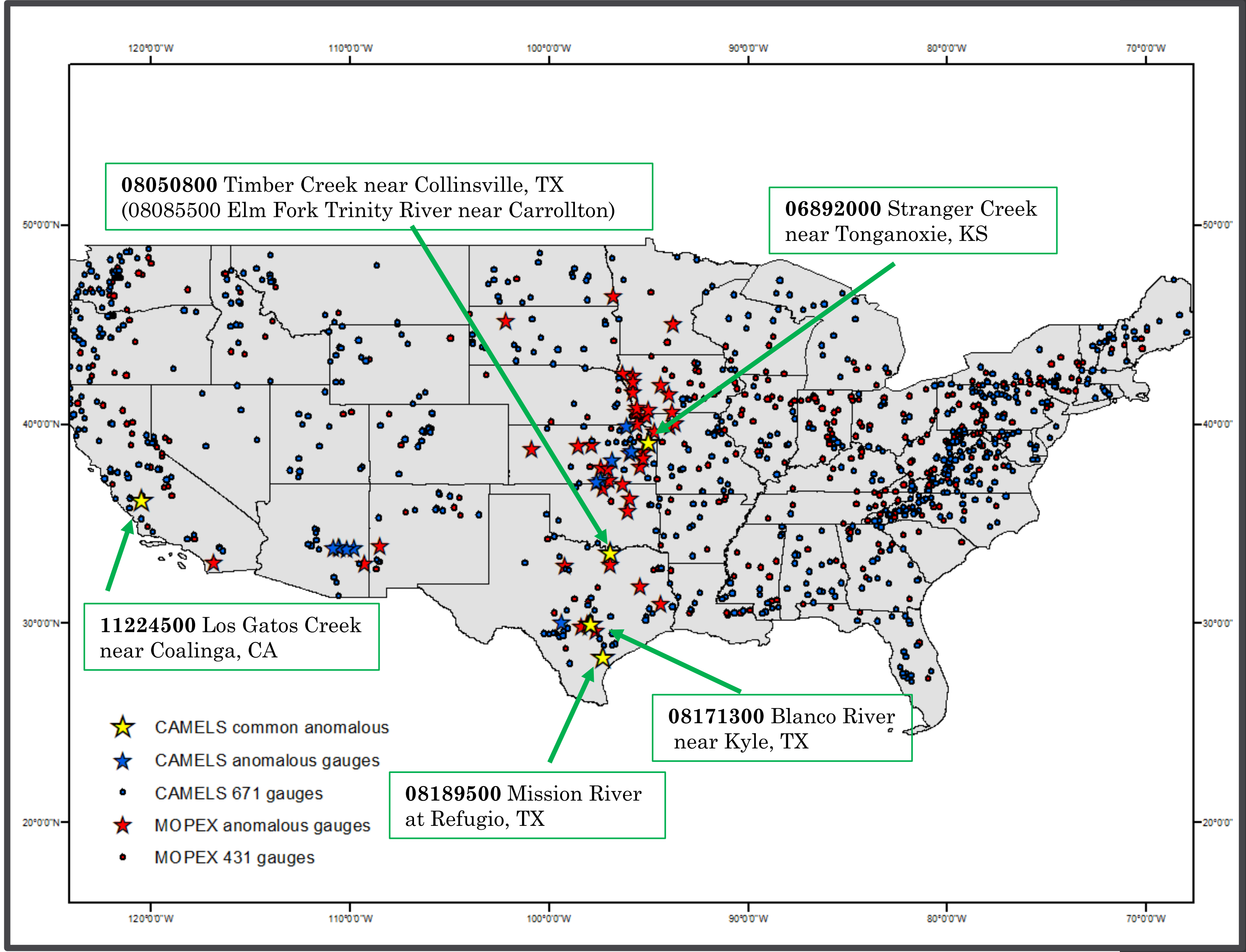


Figure 1: Gauge locations for MOPEX and CAMELS datasets.[1]

*** Water years (October 1 – September 30)**
1) Figure created in ArcMap using MOPEX and CAMELS data
CAMELS (Addor et al, 2017) - https://ral.ucar.edu/solutions/products/camels
MOPEX (Schaake et al, 2006) - https://hydrology.nws.noaa.gov/pub/gcip/mopex/US_Data/Documentation/

Precipitation and aridity

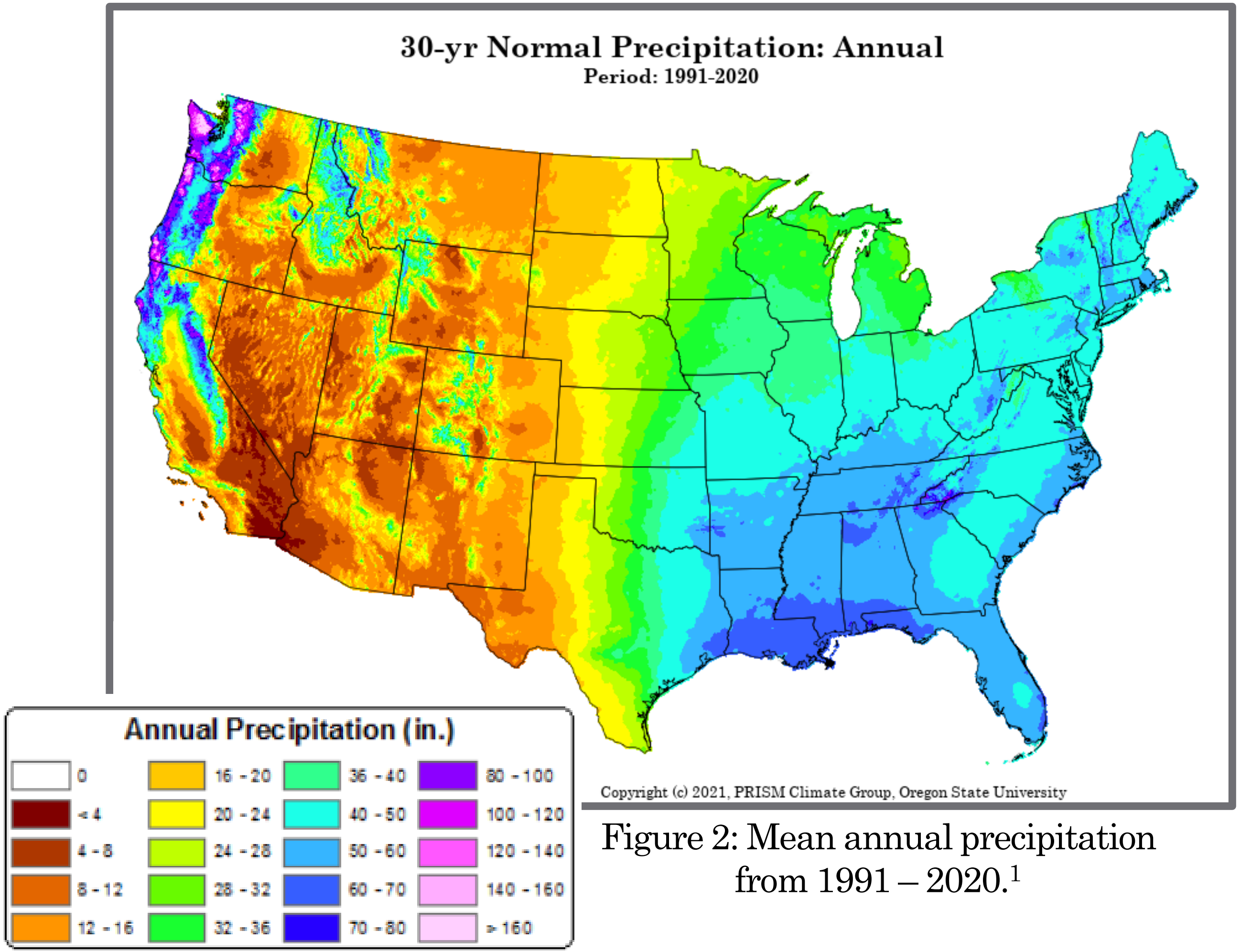


Figure 2: Mean annual precipitation from 1991 – 2020.[1]

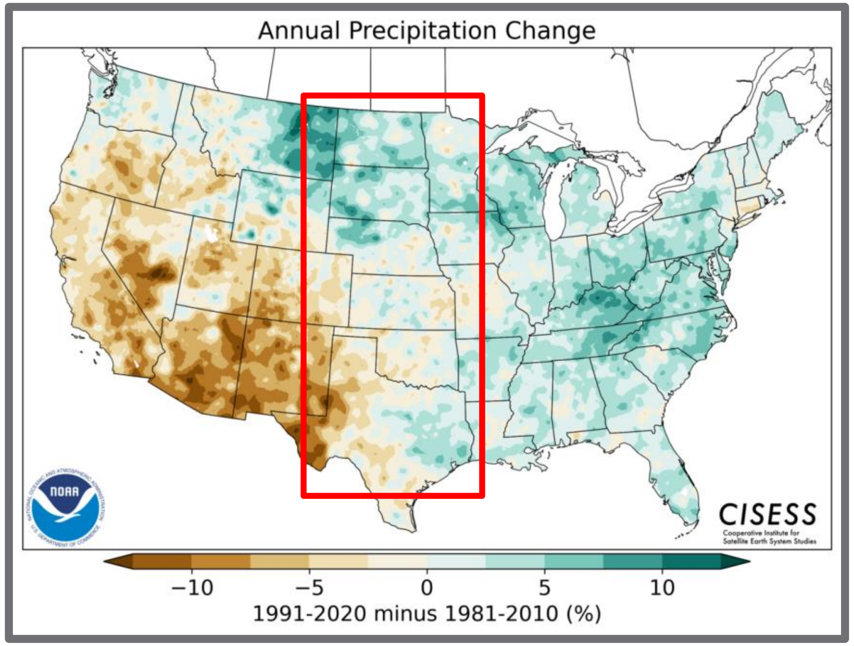


Figure 3: Annual precipitation change for 1991 – 2020 relative to 1981 – 2010.[2]

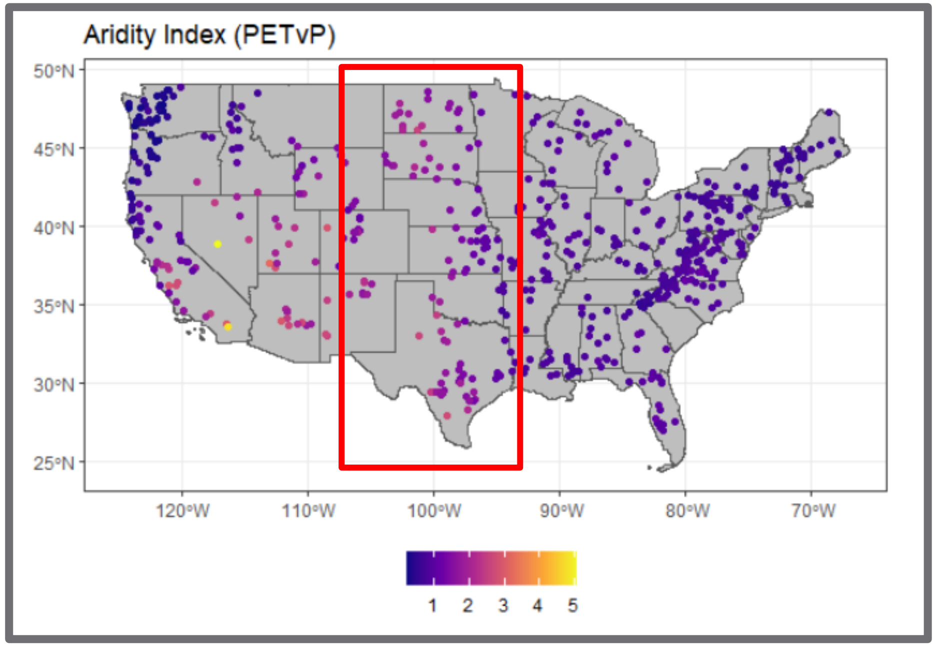


Figure 4: Aridity index (PET/P) for 1981 – 2014.[3]

1) PRISM https://prism.oregonstate.edu/normals/
2) NOAA https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals
3) CAMELS dataset (Addor et al, 2017), figure created in R

Runoff efficiency and elasticity

- Runoff efficiency (coefficient, ratio)
  - Amount of precipitation that becomes runoff
  - Runoff/precipitation (Q/P)
  - Decreased efficiency (≤ 0.2)
- Runoff elasticity[1] (sensitivity), ε
  - Quantifies change in Q based on change in X (i.e. P)
    - Percent change in Q is ε times percent change in P
    - If $\varepsilon > 1.0$, then change in Q is > change in P and Q is elastic (sensitive) to P
  - Highly responsive to changes in P (≥ 2)

$$\text{Precipitation elasticity of streamflow, } \varepsilon = \frac{\partial Q/Q}{\partial P/P}$$

How sensitive runoff is to changes is in precipitation

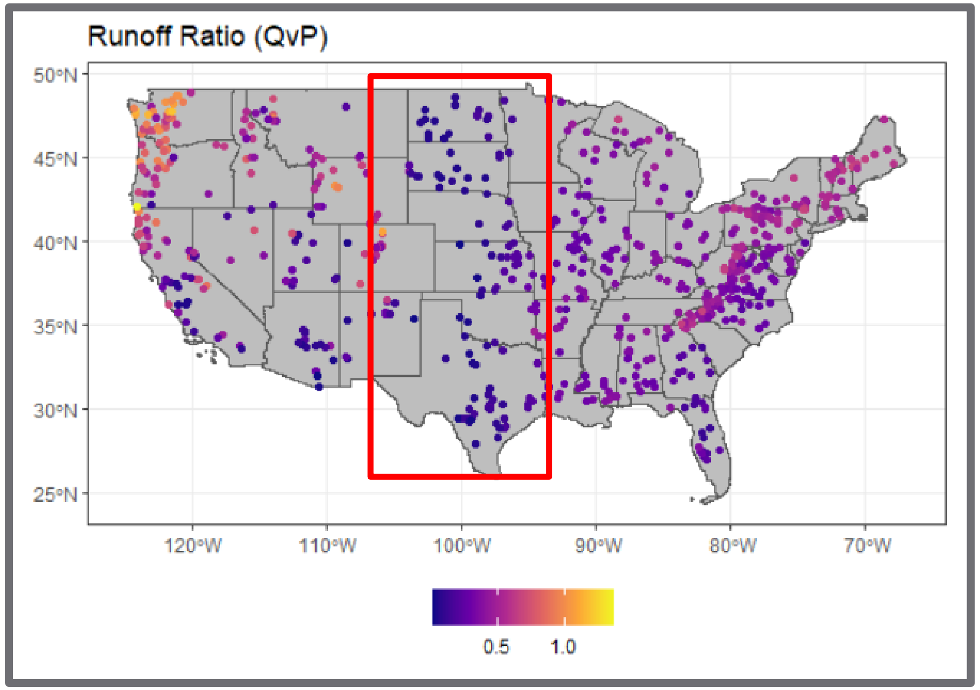


Figure 5: Runoff efficiency (Q/P) for 1981 – 2014.[2]

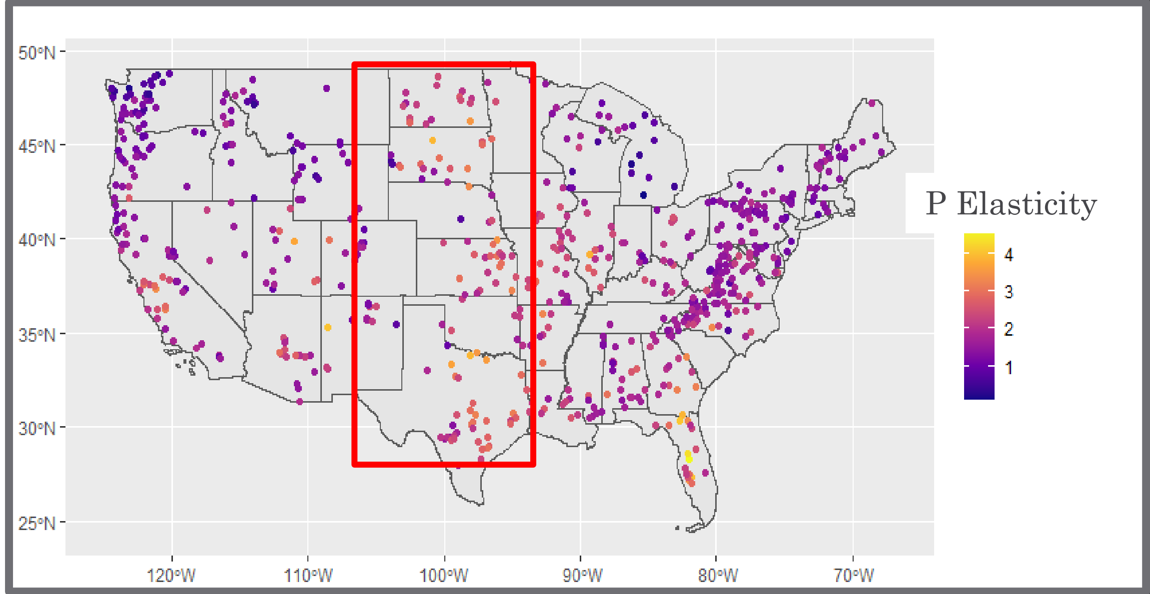


Figure 6: Precipitation elasticity of streamflow for 1981 – 2014.[2]

1) Schaake (1990)
2) CAMELS dataset (Addor et al, 2017), figures created in R

Budyko framework

- Budyko (1974)
  - Fraction of P that becomes ET is controlled by available water (P) and energy (PET)
    - Supply (water) and demand (energy)
  - Functional relationship between ET and two climate variables PET and P
    - $\frac{\mathrm{ET}}{\mathrm{P}} = \mathrm{f}\left(\frac{\mathrm{PET}}{\mathrm{P}}\right)$
  - Evaporative index (actual ET/P)
  - Aridity index (PET/P)

Budyko equation (1974)

$$\frac{ET}{P} = \left\{\frac{PET}{P} \tanh\left(\frac{PET}{P}\right)^{-1}\left(1 - \exp\left(-\frac{PET}{P}\right)\right)\right\}^{0.5}$$

sun = energy (PET)

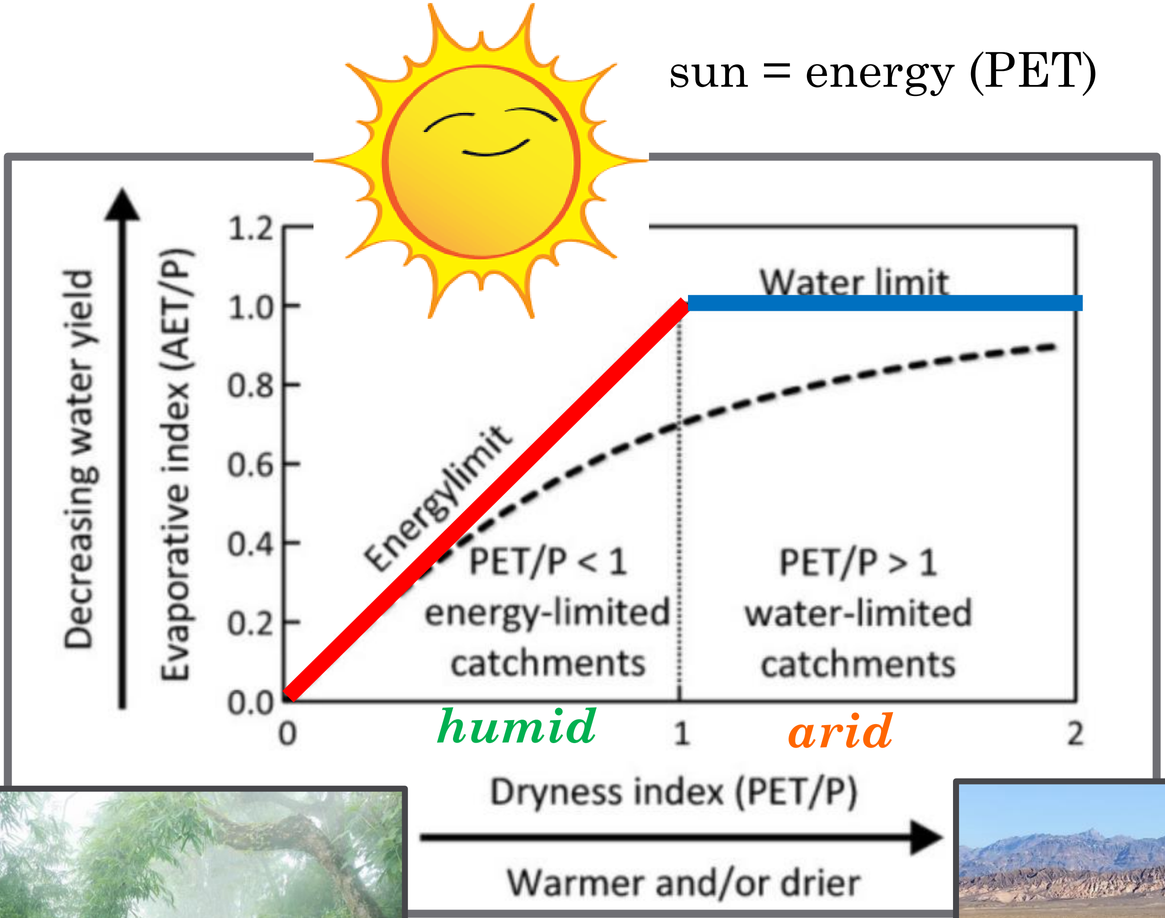


Figure 7: Illustration of the general Budyko curve.[1]

PET/P < 1

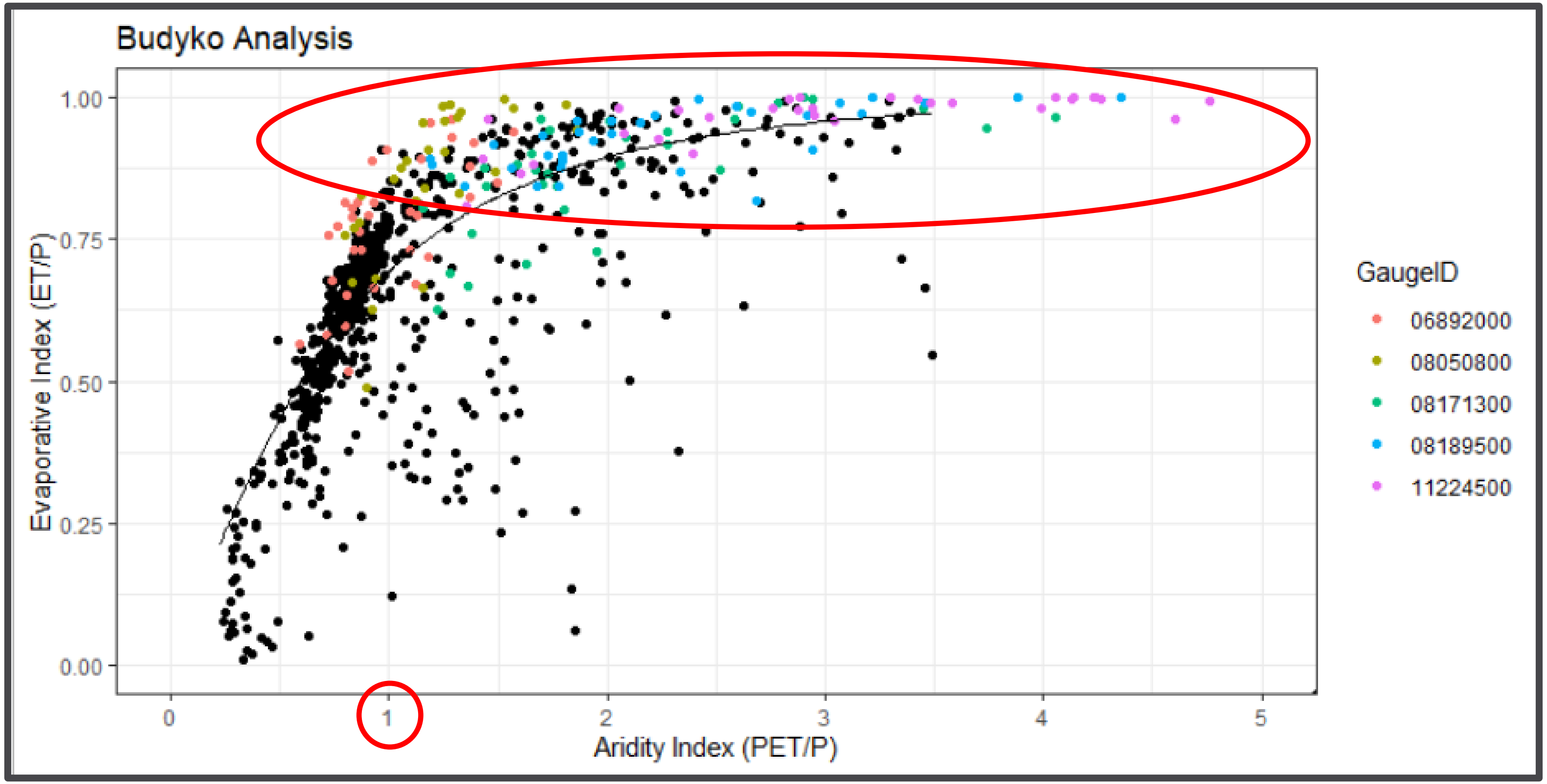
PET/P > 1

1) After Figure 2, Hasan et al. (2018)

Budyko equation (1974)

$$\frac{ET}{P} = \left\{\frac{PET}{P} tanh\left(\frac{PET}{P}\right)^{-1}\left(1 - exp\left(-\frac{PET}{P}\right)\right)\right\}^{0.5}$$

Anomalous basins



Tonganoxie, KS
Collinsville, TX
Kyle, TX
Refugio, TX
Coalinga, CA

Figure 8: Aridity index vs evaporative index for all 671 CAMELS gauges (1981 – 2014[1])
Annual values plotted for 5 common gauges.

1) CAMELS dataset (Addor et al., 2017), figure created in R

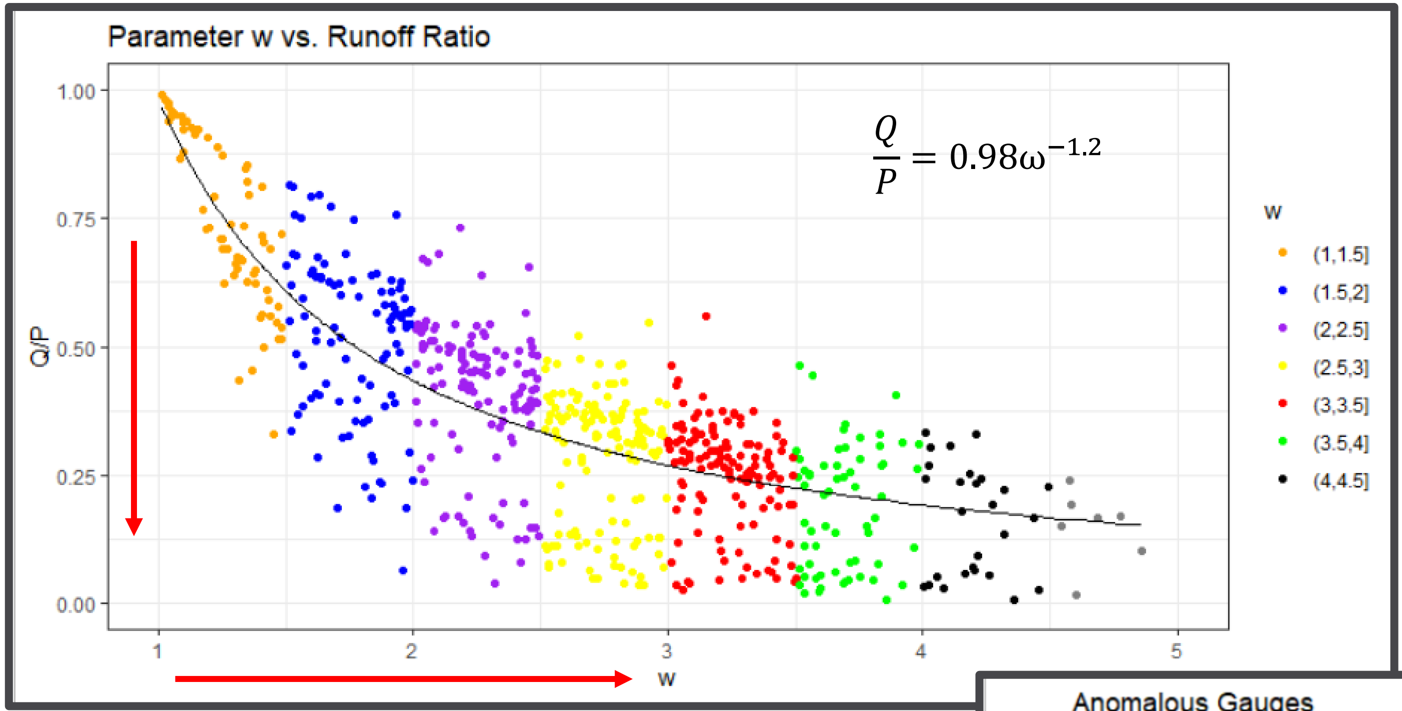


Figure 9: Runoff ratio (Q/P) vs theoretical fit parameter, w, calculated for each basin[1]

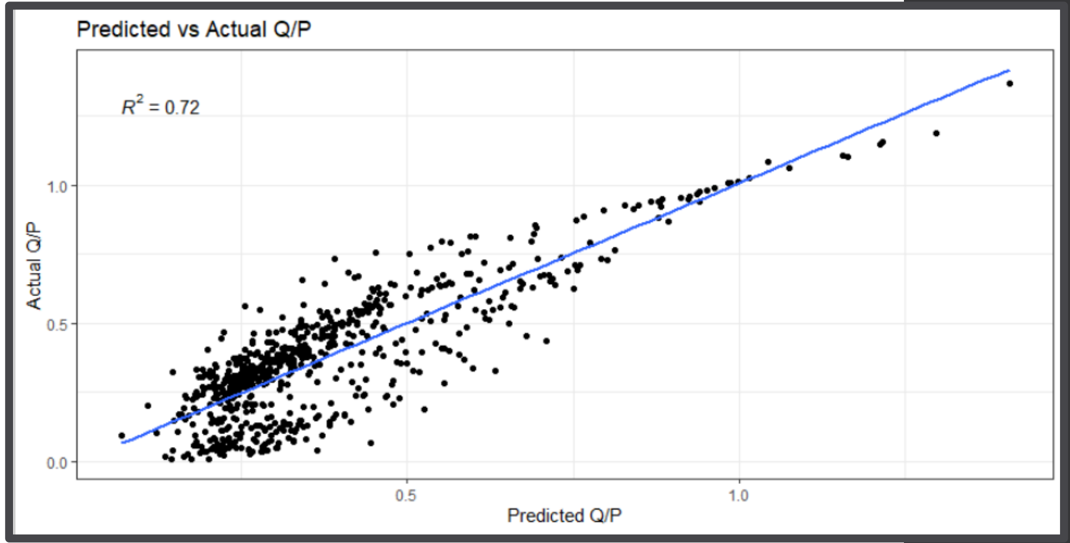


Figure 10: Actual vs predicted runoff ratio, goodness of fit determined[1]

Fu equation (1981)

$$\frac{ET}{P} = \left\{1 + \left(\frac{P}{PET}\right)^{\omega}\right\}^{\frac{1}{\omega}}$$

***Parameter w** represents climate (i.e., rate of precipitation) and catchment characteristics (i.e., vegetation, soil, topography)*

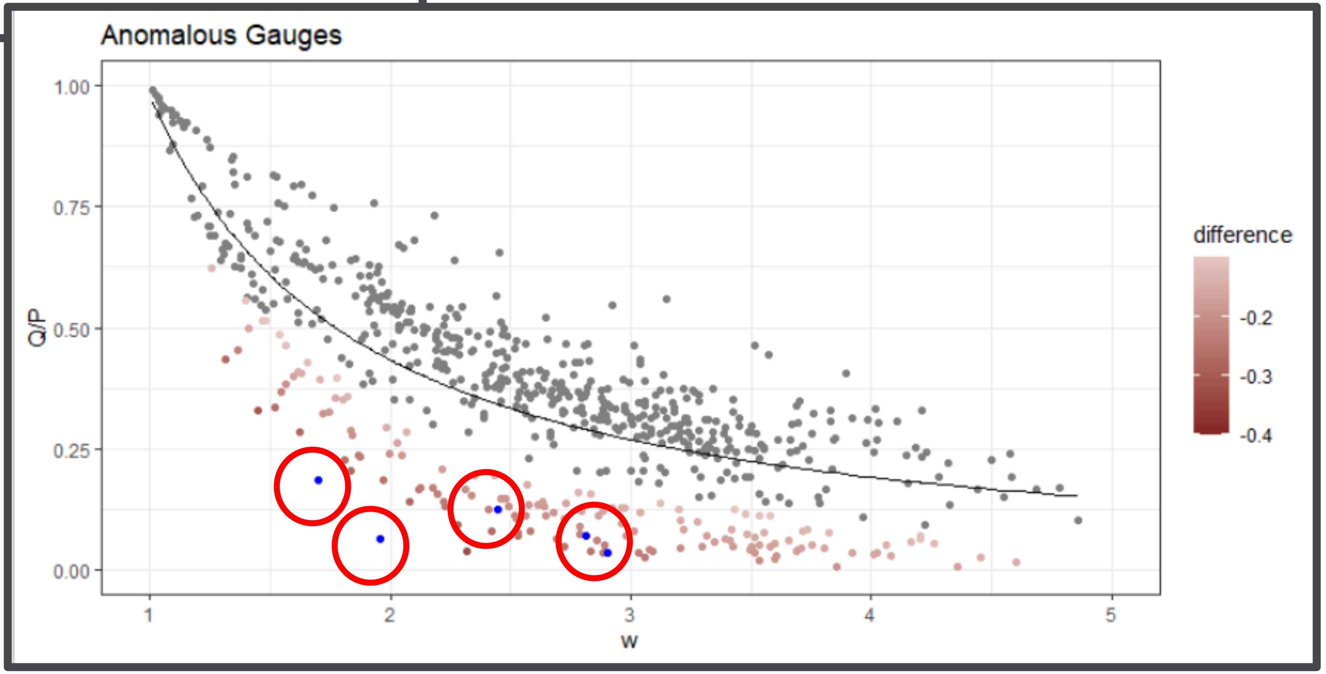


Figure 11: Gauges with difference of >= 10% from best fit line. 159 gauges out of 671. 5 common gauges shown in blue[1]

1) CAMELS dataset (Addor et al., 2017), figures created in R

- Spatial distribution of all anomalous CAMELS gauges
  - All lie west of 95˚W
- Basins in regions of decreasing P but also in the transition zone where P is remaining constant or even increasing

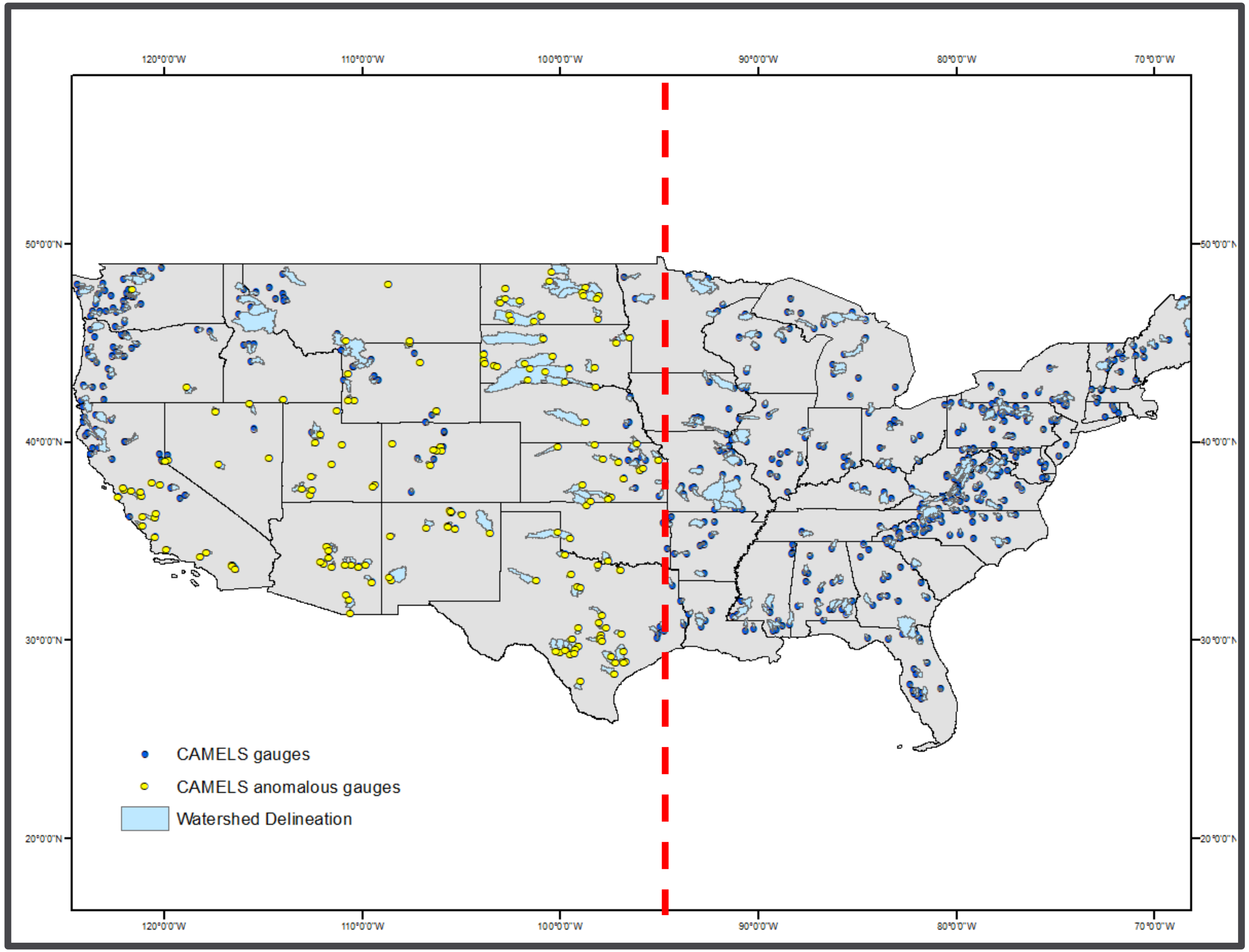


Figure 12: Location of CAMELS 671 gauges. Anomalous basins shown in yellow, identified from Budyko analysis.[1]

1) **Figure created in ArcMap using CAMELS data set (Addor et al., 2017)**

Continued work

- Additional climatic variable comparisons
- Temporal evaluations
  - Seasonal, monthly, annual timescales
- Spatial evaluations
  - Land use
  - Vegetation, soil
  - Topography
  - Human aspect
- Decomposition methods to identify climate vs human impact on changes in runoff
- Identify cause(s) of decreased runoff
  - Confirm with Community Land Model

Figure 13: Satellite image of 2001 Dallas/Fort Worth, Texas. Lewisville Lake (north), Lavon Lake (northeast), Lake Ray Hubbard (east).