Linking Evaporative Demand Surplus and Precipitation Deficits to Multi-Year Streamflow Drought in California


Nevada and Vernal Falls on the Merced River
Source: Wiki Commons

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Yosemite National Park, CA

Western Regional Climate Center
Providing climate services since 1986

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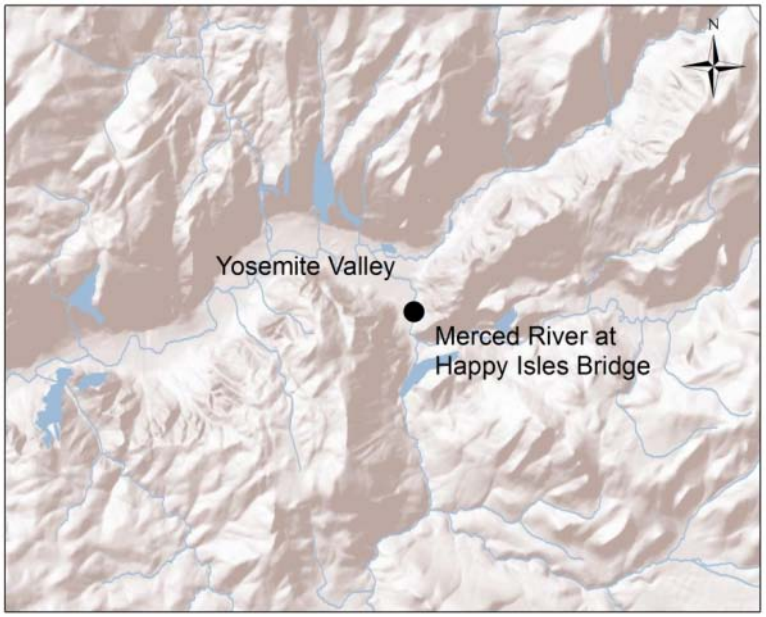
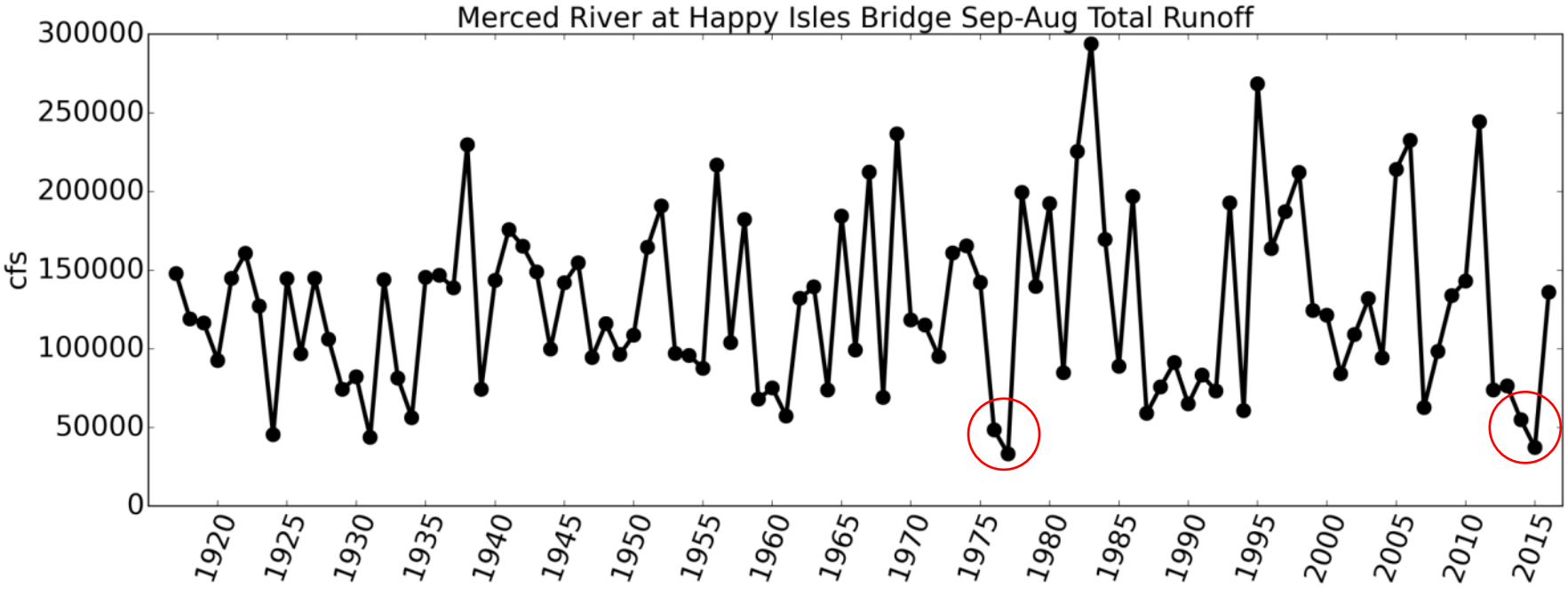
California Streamflow as a Drought Indicator

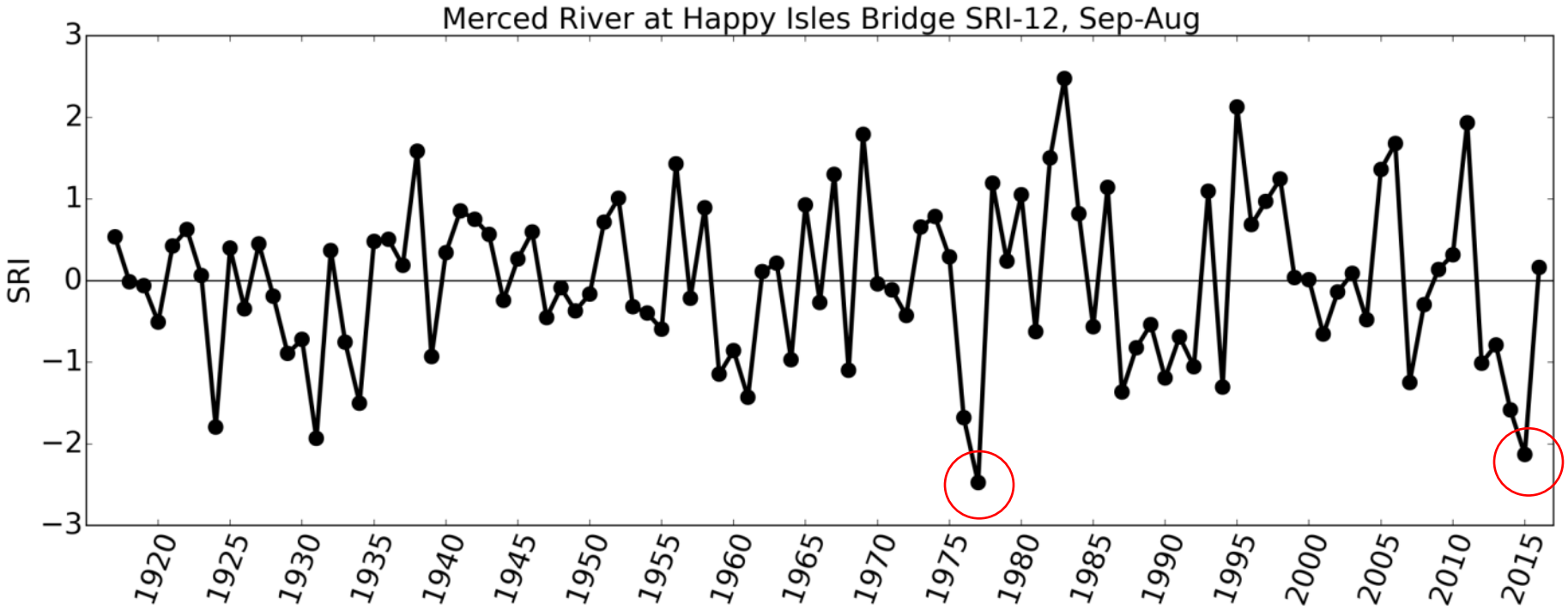
- Long climate records
- Reflects the combined effect of several climate and hydrologic variables: temperature, precipitation, snow water equivalent, evapotranspiration, and evaporative demand



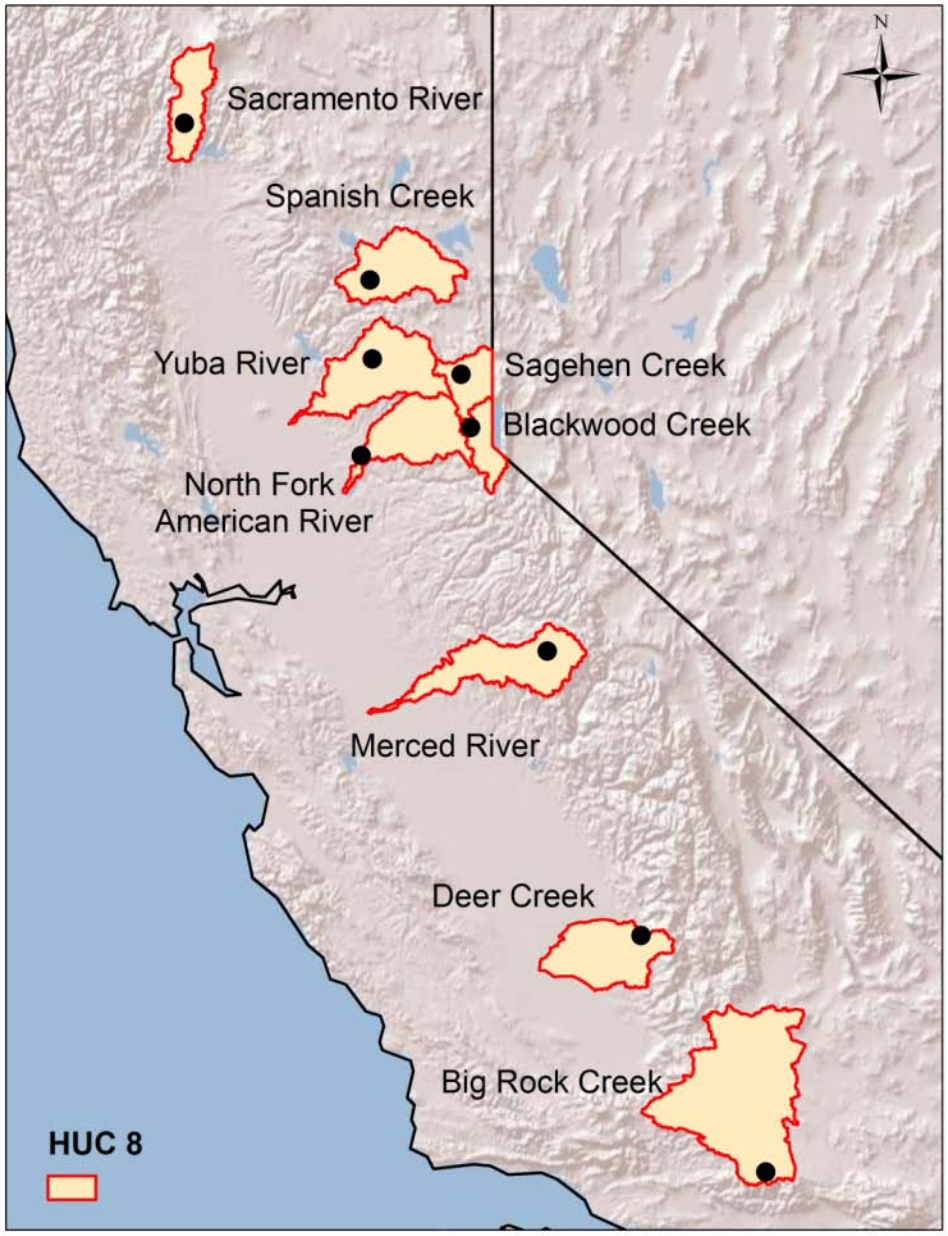


Standardized Runoff Index

- Shukla and Wood, 2008, GRL
- Follows Standardized Precipitation Index methodology:
  1. Accumulate streamflow at given time scale (i.e., 1, 6, or 12 month running mean)
  2. Estimate cumulative probability based on a parametric or **empirical** distribution
  3. Cumulative probability is converted to standard normal deviate (zero mean and one standard deviation

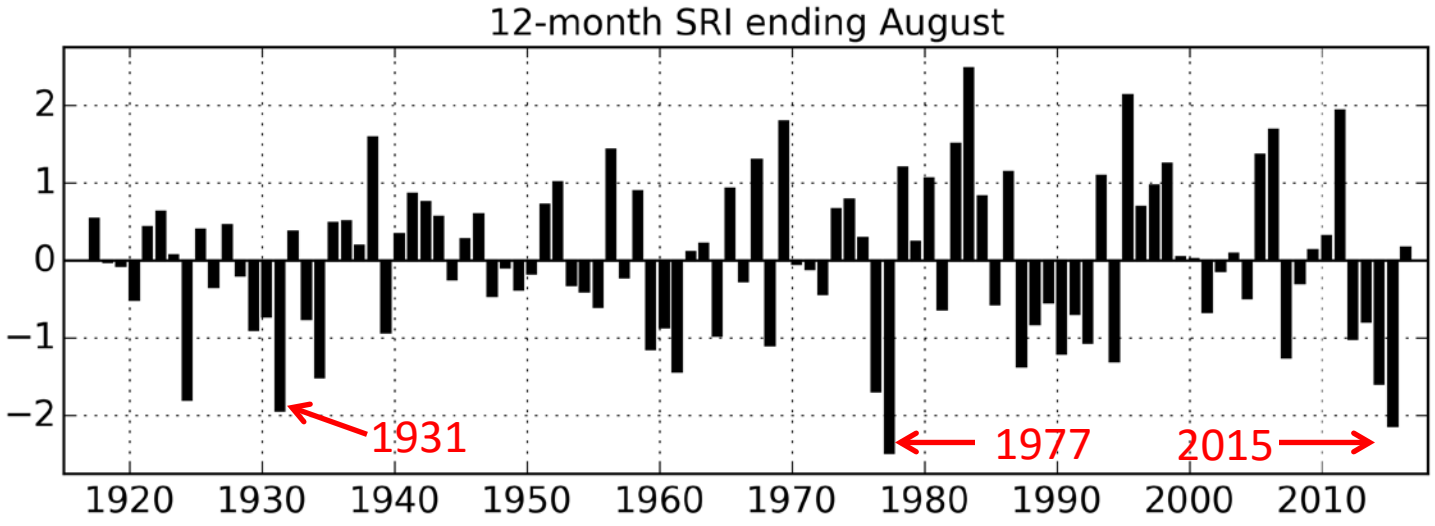


Standardized Runoff Index



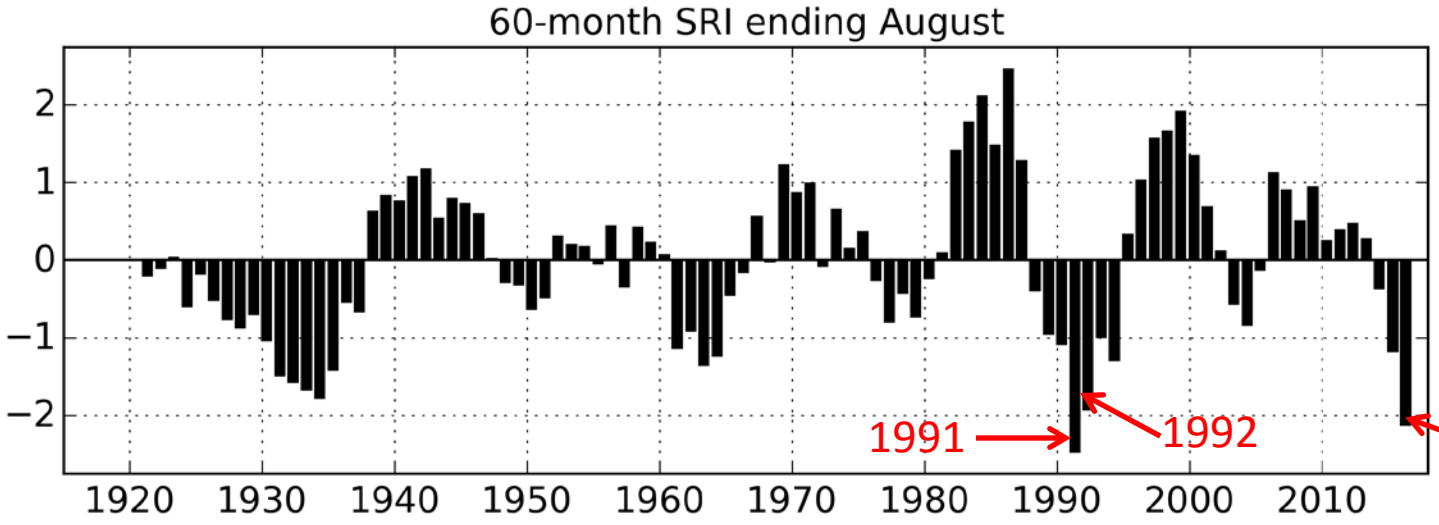
- 9 USGS streamflow gauges
- Water year SRI…slightly modified as September – August so 2016 could be used
- 12, 24, 36, 48, and 60 month SRI
- Full period: each gauge has different record length
- Climate data (gridMET) record: **1980-2015**

SRI at Merced River



12-months ranks:

1. 1977
2. 2015
3. 1931

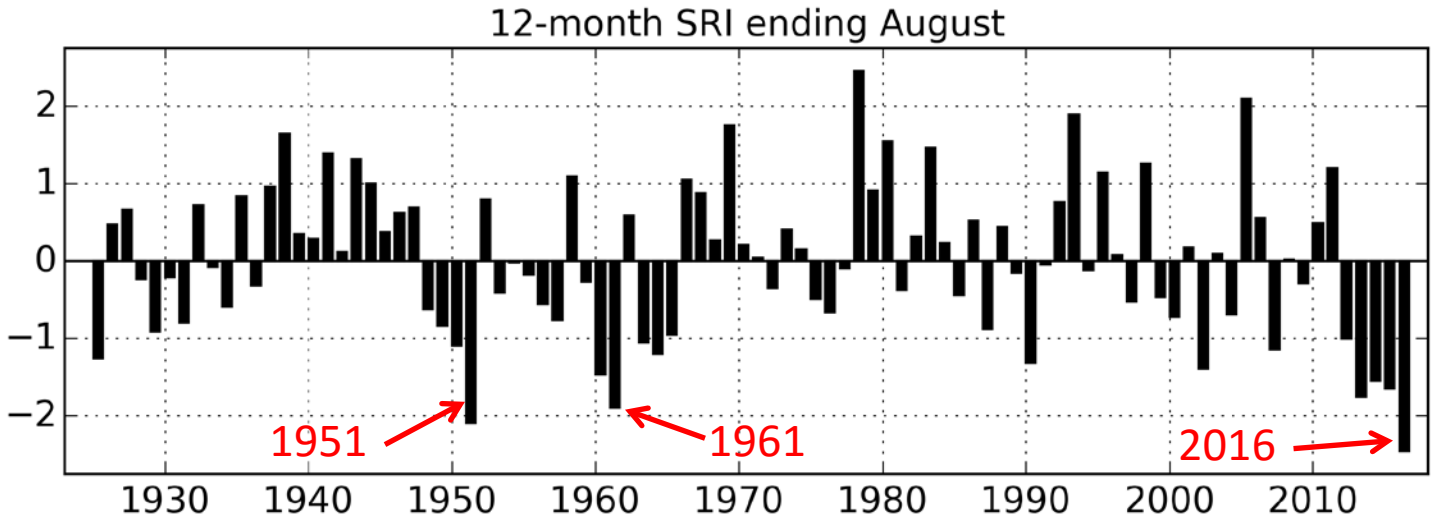


60-months ranks:

1. 1991
2. 2016
3. 1992

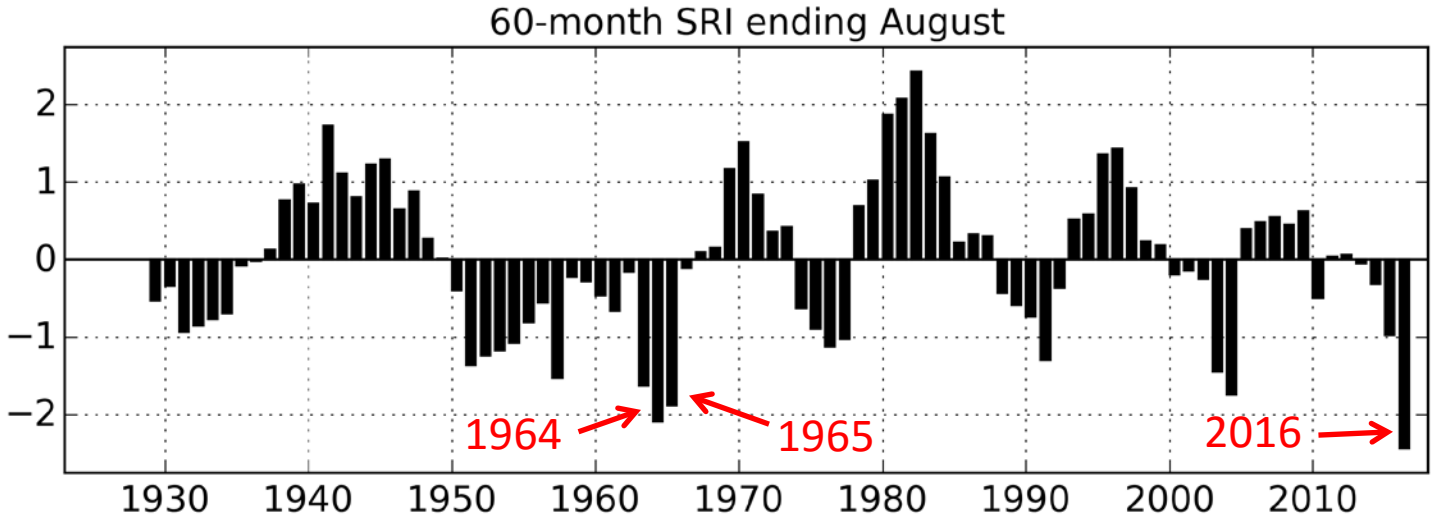
SRI at Big Rock Creek

- San Gabriel Mountains, northeast of Los Angeles



12-months ranks:

1. 2016
2. 1951
3. 1961



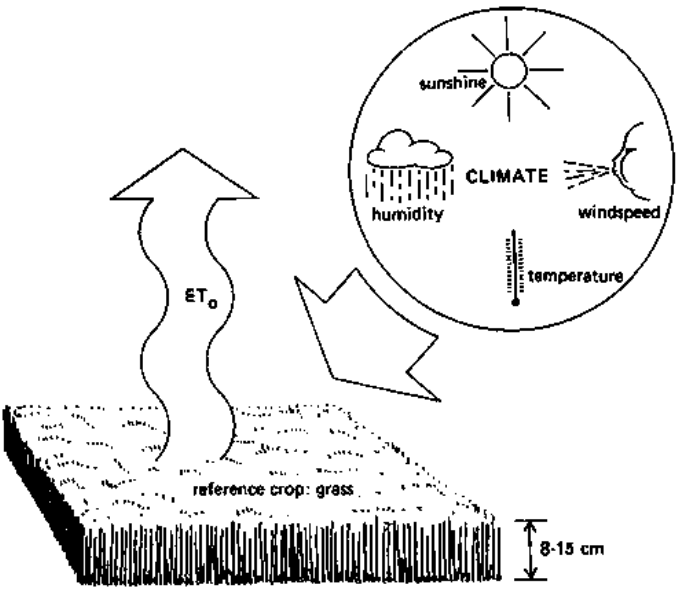
60-months ranks:

1. 2016
2. 1964
3. 1965

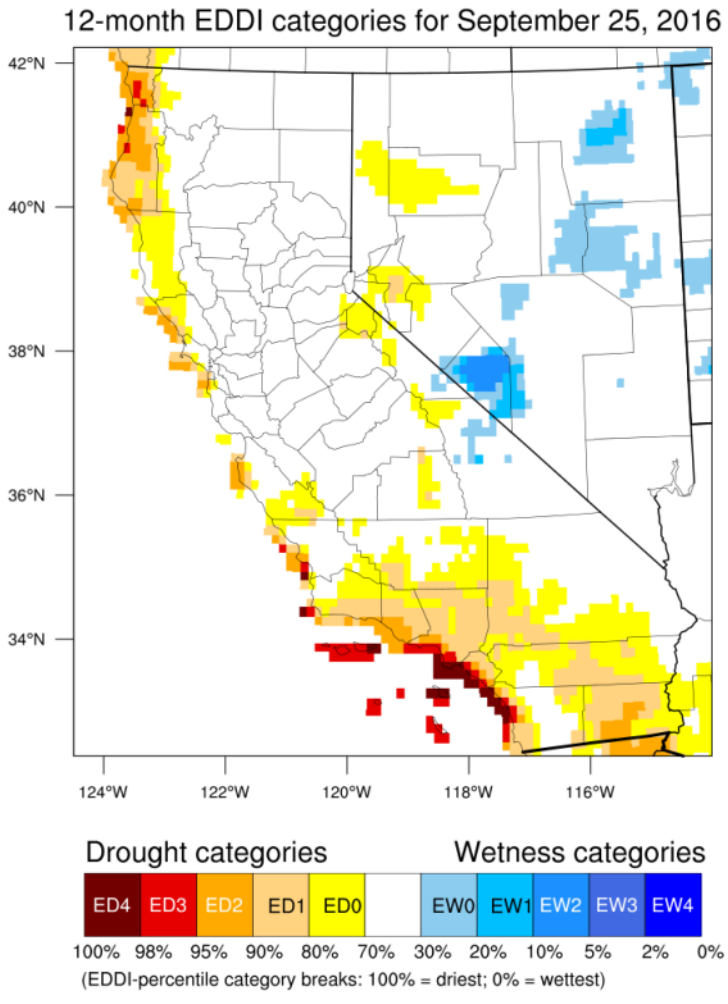
Evaporative Demand Drought Index (EDDI)

- Hobbins et al. 2016: Theory and formulation
- McEvoy et al. 2016: Comparison against other drought indices
- Accumulated evaporative demand only (Penman-Monteith [ET_o])
- No precipitation!
- Same methodology SRI

"Atmospheric Thirst"



- Temperature
- Humidity
- Solar Radiation
- Wind Speed



ftp://ftp.cdc.noaa.gov/pub/Public/mhobbins/EDDI/

ASCE Standardized Penman-Monteith (ET_o)

$$ET_o = \frac{\Delta}{\Delta + \gamma(1 + C_d U_2)} \frac{R_n - G}{\lambda} + \frac{\gamma}{\Delta + \gamma(1 + C_d U_2)} \frac{C_n}{T + 273} U_2 (e_s - e_a)$$

Physically based equation

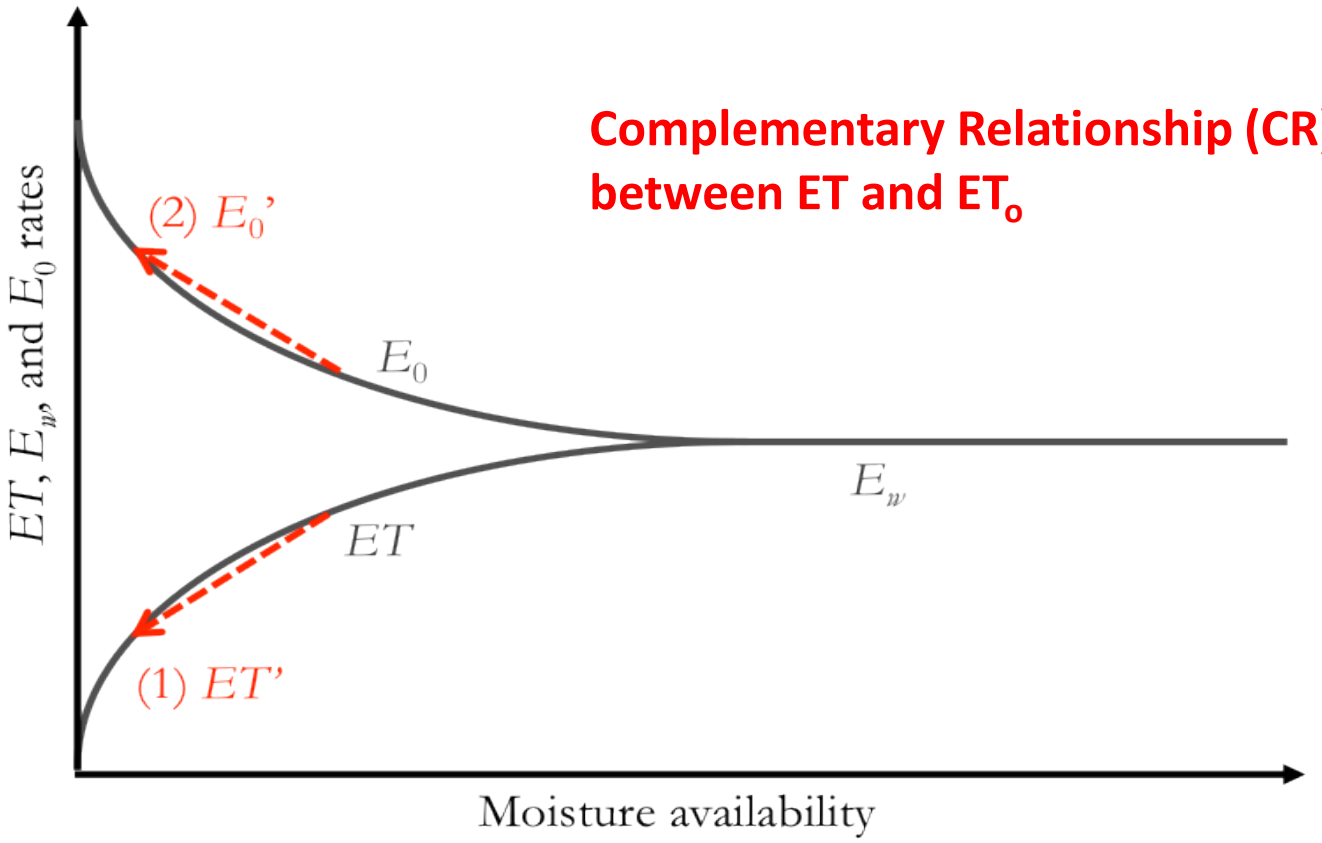
Advective component:
- Temperature
- Wind Speed
- Humidity

Radiative component:
- SW radiation
- LW radiation
- Ground heat flux

R_n = net radiation (shortwave + longwave)
G = ground heat flux (assumed to be zero)
T = mean daily temperature
U_2 = mean daily wind speed at 2-m
e_s = saturation vapor pressure ((e_{s_tmax}+e_{s_tmin})/2)
e_a = actual vapor pressure (from q and surface pressure)
λ = latent heat of vaporization
Δ = slope of saturation vapor pressure-temperature curve
γ = psychrometric constant
C_n = 900 (grass reference)
C_d = 0.34 (grass reference)

(Allen et al. 1998, 2005)

ET_o as a Drought Indicator

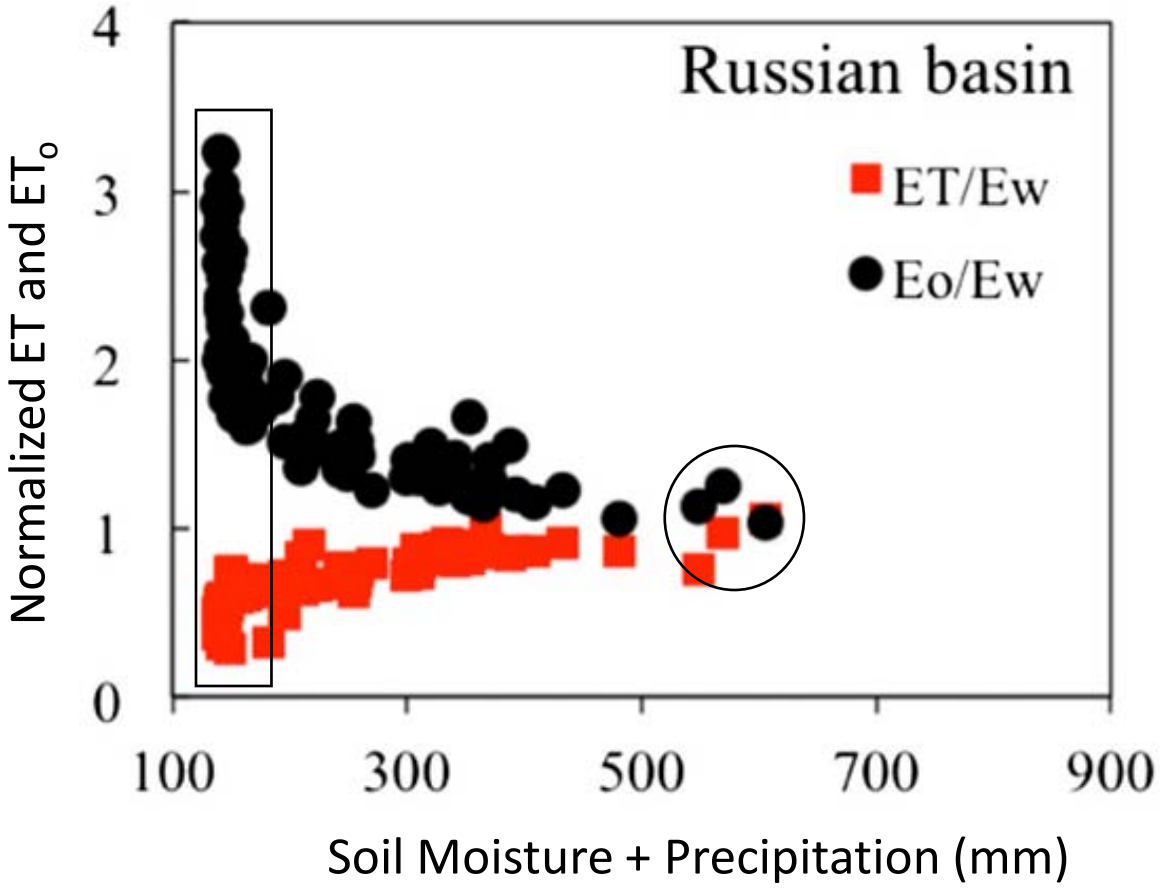


Complementary Relationship (CR) between ET and ET_o

- Under water limited conditions: ET and ET_o vary in opposing directions
- CR: R. J. Bouchet, 1963

Complementary Relationship in California

Apr – Sep, Russian River Basin, CA

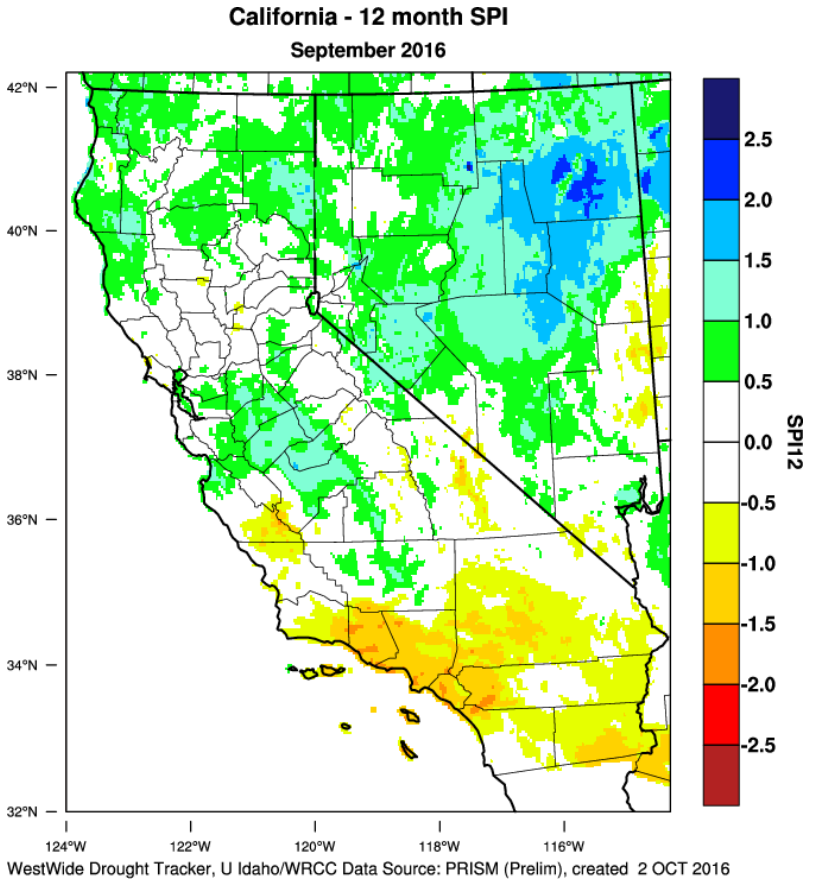


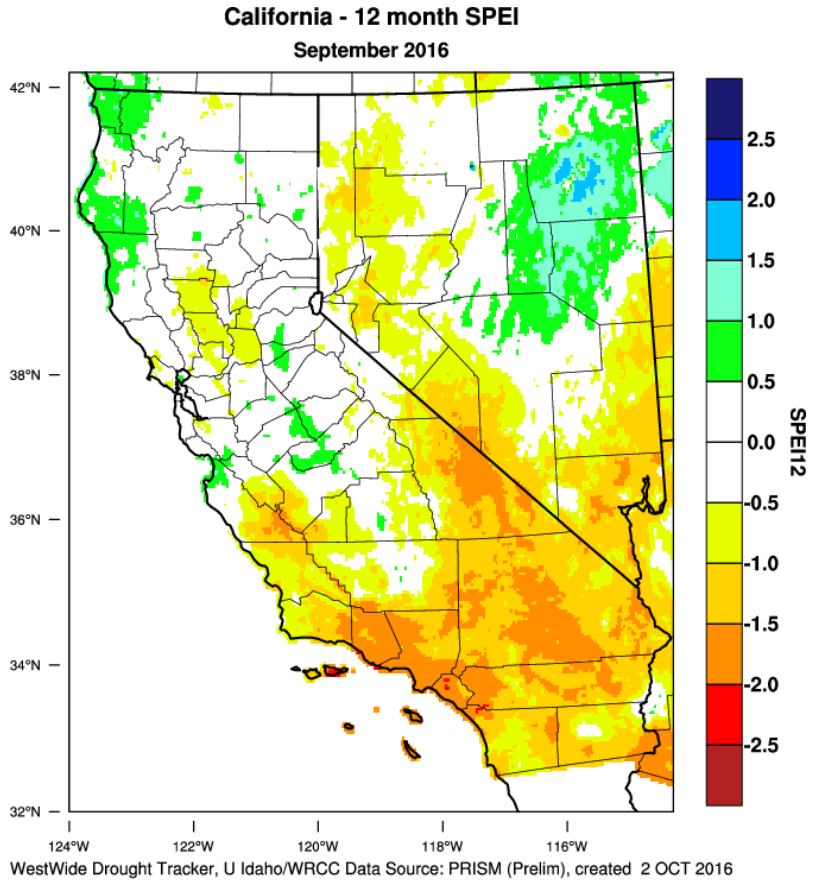
- Wet years: ET and ET_o very close to each other
- Dry years: ET and ET_o much more separated
- ET_o anomalies can be used as a drought indicator similar to precipitation anomalies
- ET_o easier to estimate than actual ET with confidence

[Hobbins et al., 2016]

SPI and SPEI

- SPI: Standardized Precipitation Index, precipitation only
- SPEI: Standardized Precipitation Evapotranspiration Index [P – PET]
- Accumulated precipitation or [P – PET]
- Same methodology as SRI and EDDI





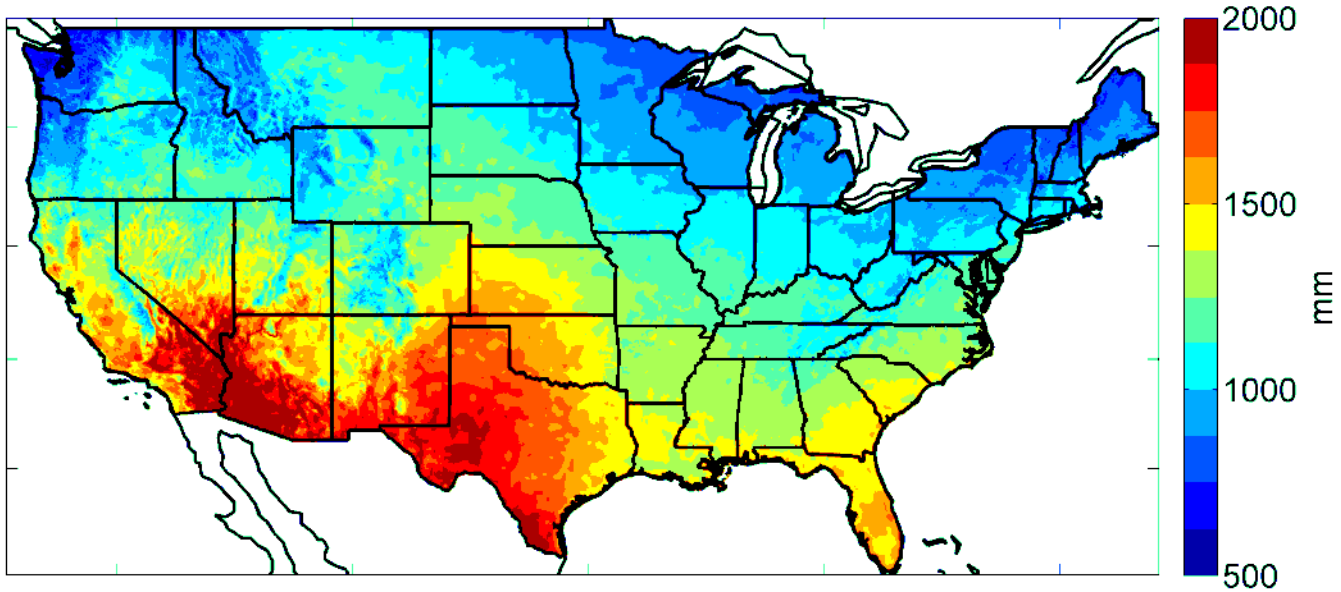
[SPI, McKee et al. 1993]

[SPEI, Vicente-Serrano et al. 2010]

Drought Index Data and Analysis

- University of Idaho gridMET (http://metdata.northwestknowledge.net/)
  - Daily temporal resolution, CONUS-wide, 4km spatial resolution, 1979-present
  - Combines NLDAS-2 and PRISM for near real-time updates (2-3 day latency)
  - Temperature, specific humidity, wind speed, downward shortwave radiation, and precipitation
- Lag correlation analysis between EDDI/SPI/SPEI and water year SRI (12-month ending in August)

gridMET annual average ETo: 1981-2010

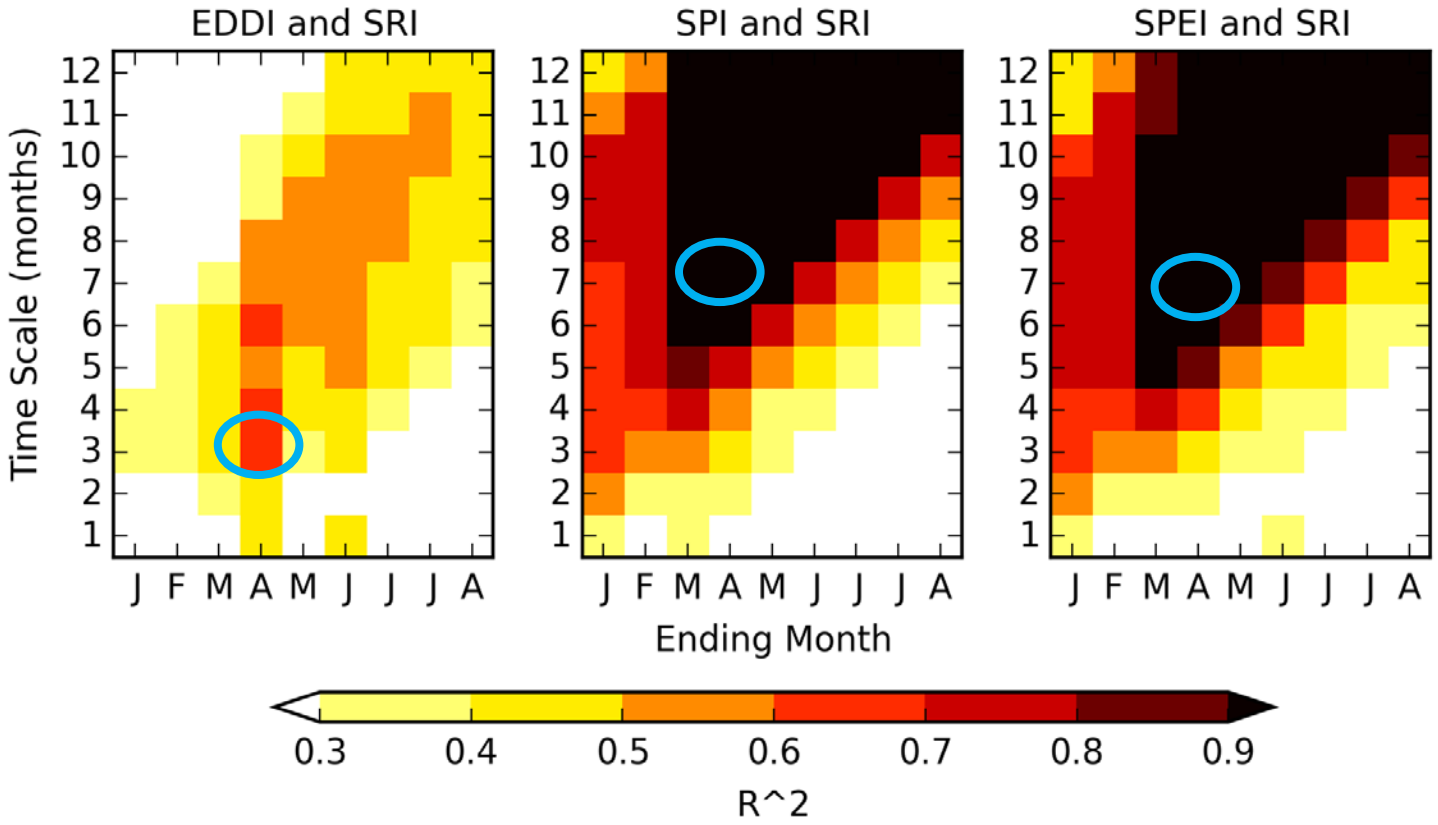


[gridMET; Abatzoglou 2013]

Merced River Drought Index Correlations

- 12-month SRI ending in August
- 1-12 month EDDI, SPI, and SPEI at Jan-Aug ending months

- Cold season precipitation and ET_o explain most of the streamflow variance



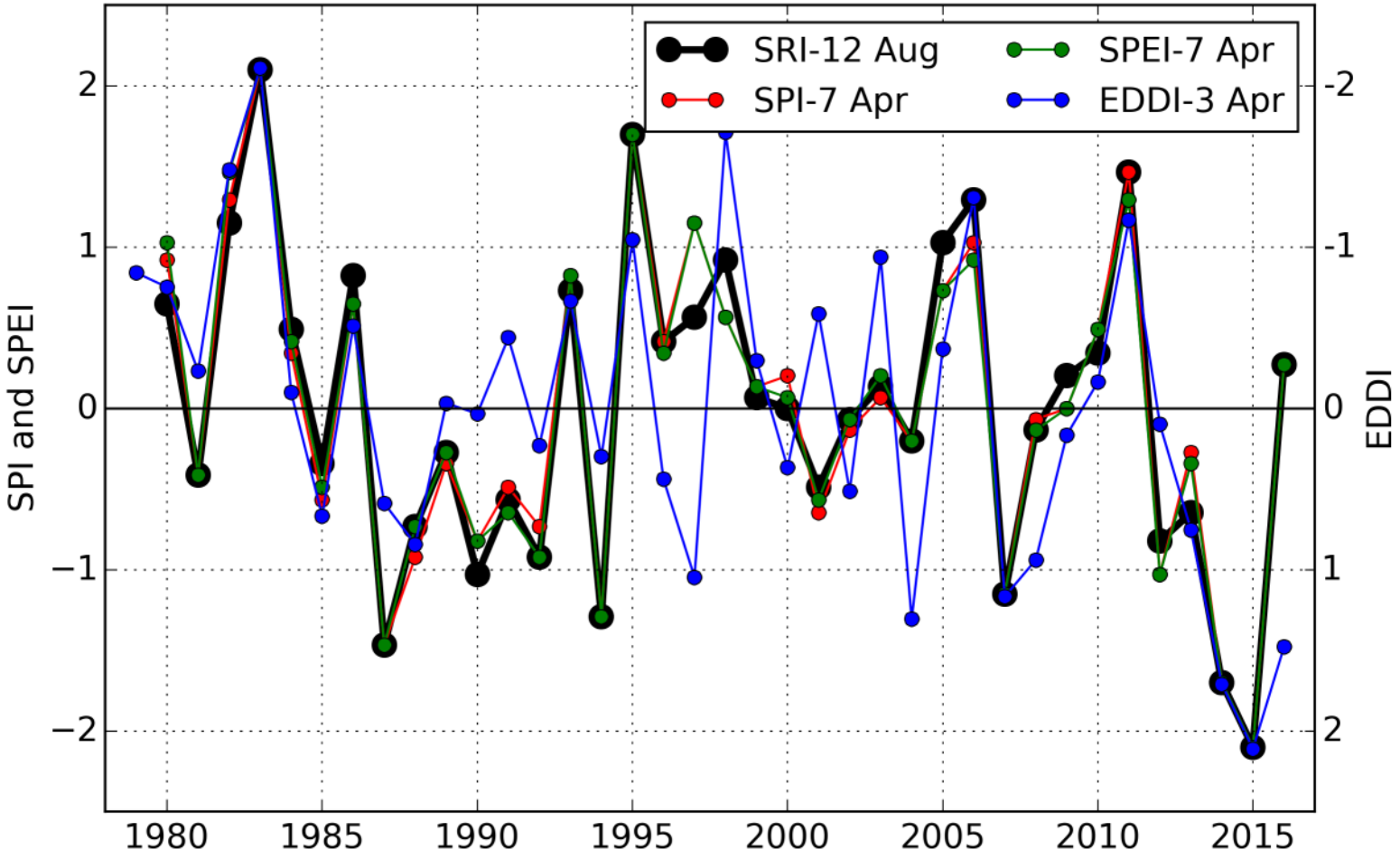
Max EDDI R^2:
0.61
April 3-month

Max SPI R^2:
0.96
April 7-month

Max SPEI R^2:
0.96
April 7-month

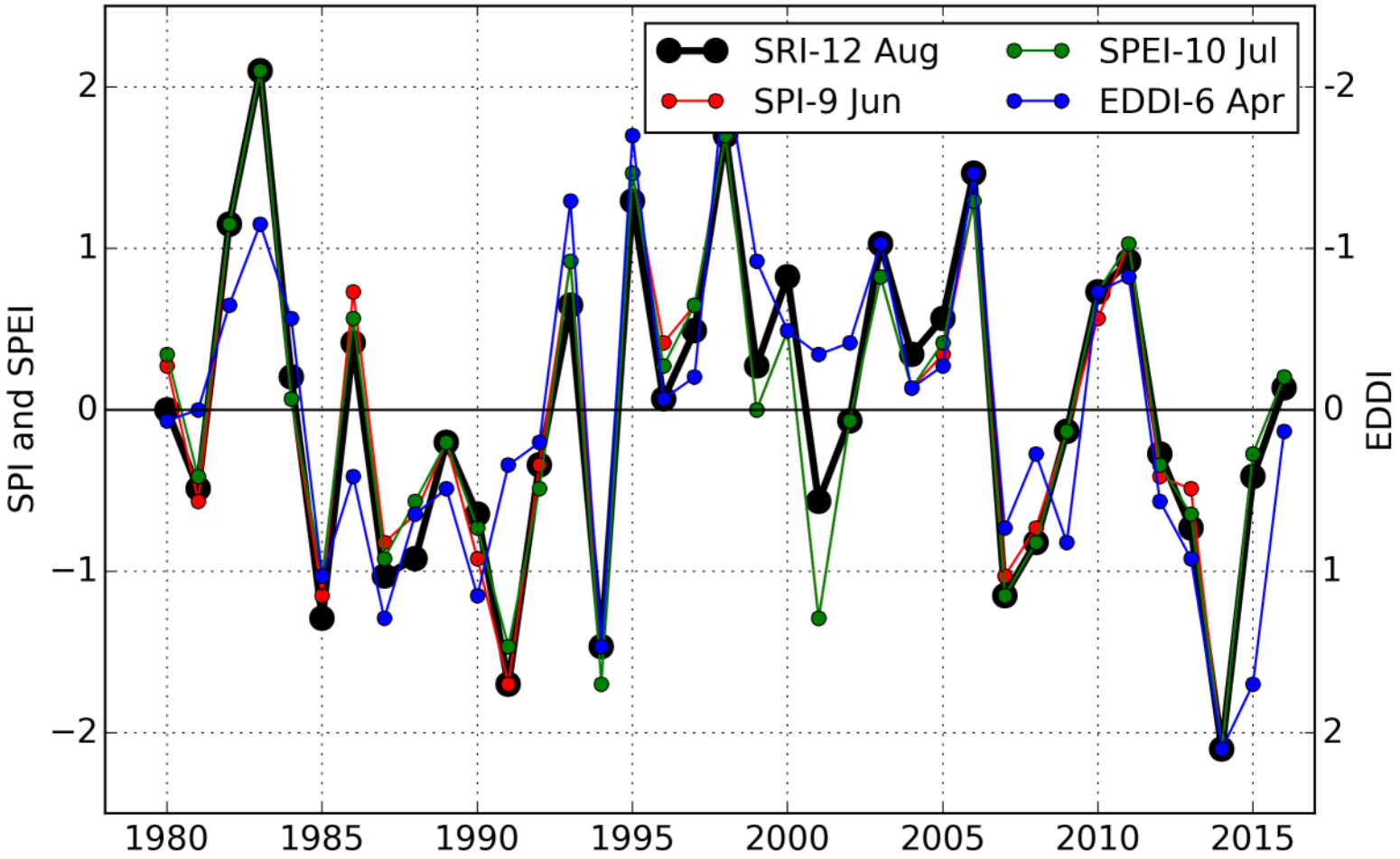
Merced River Drought Index Correlations

- All indices agree: 2014 and 2015 most severe droughts in record
- Warm + wet can still lead to ET_o surplus or high EDDI values: 1996, 1997, 2016
- Temperature not always dominant ET_o driver



Sacramento River Drought Index Correlations

- Strongest relationships between EDDI and SRI: $R^2 = 0.73$
- Better agreement on 1987-1992 drought
- ET_o sensitivity to drivers varies with region

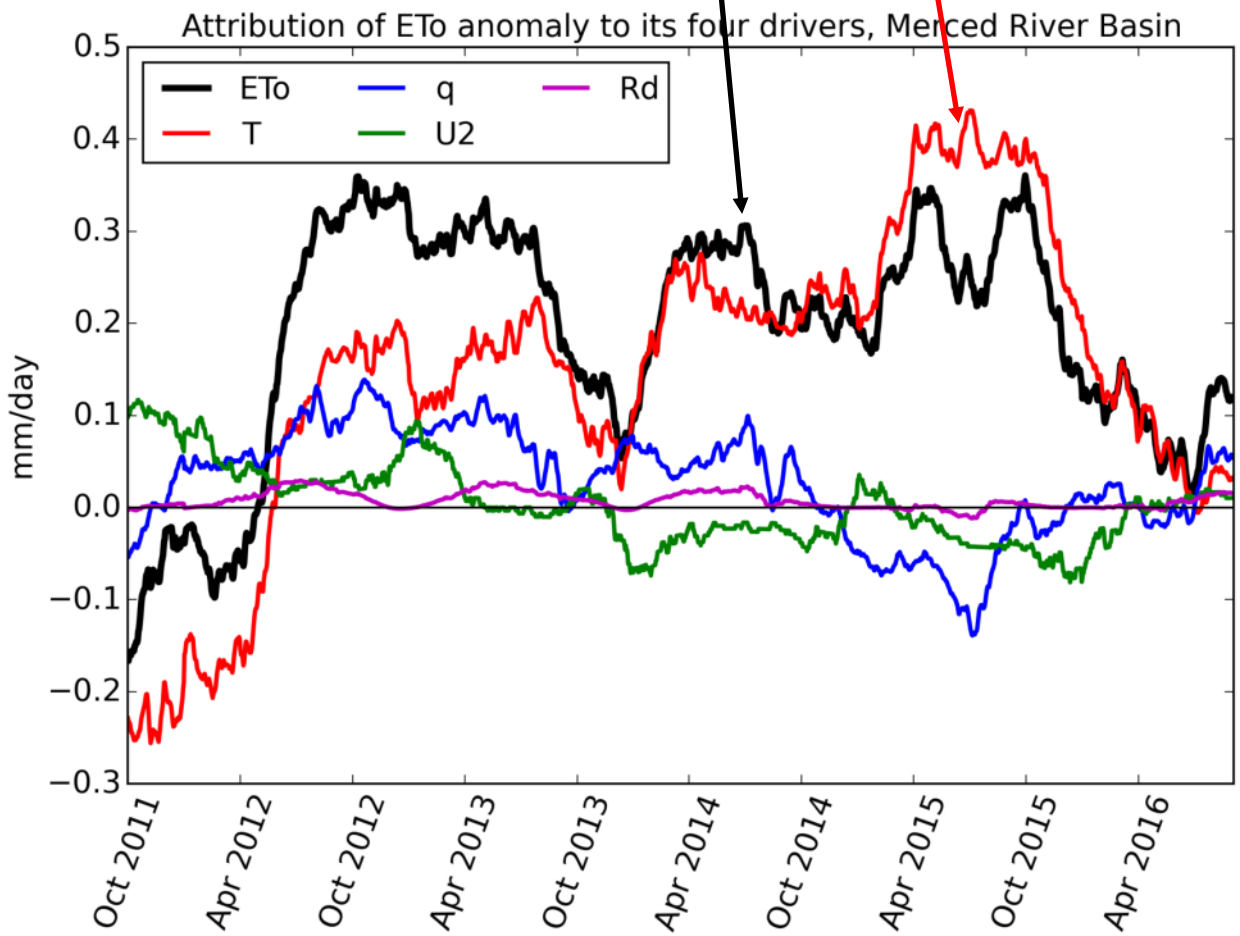


ET_o decomposition and attribution

12-month running mean ET_0 anomaly

$$\Delta E_0 = \frac{\partial E_0}{\partial T_{air}}\Delta T_{air} + \frac{\partial E_0}{\partial q}\Delta q + \frac{\partial E_0}{\partial R_d}\Delta R_d + \frac{\partial E_0}{\partial U_{10}}\Delta U$$

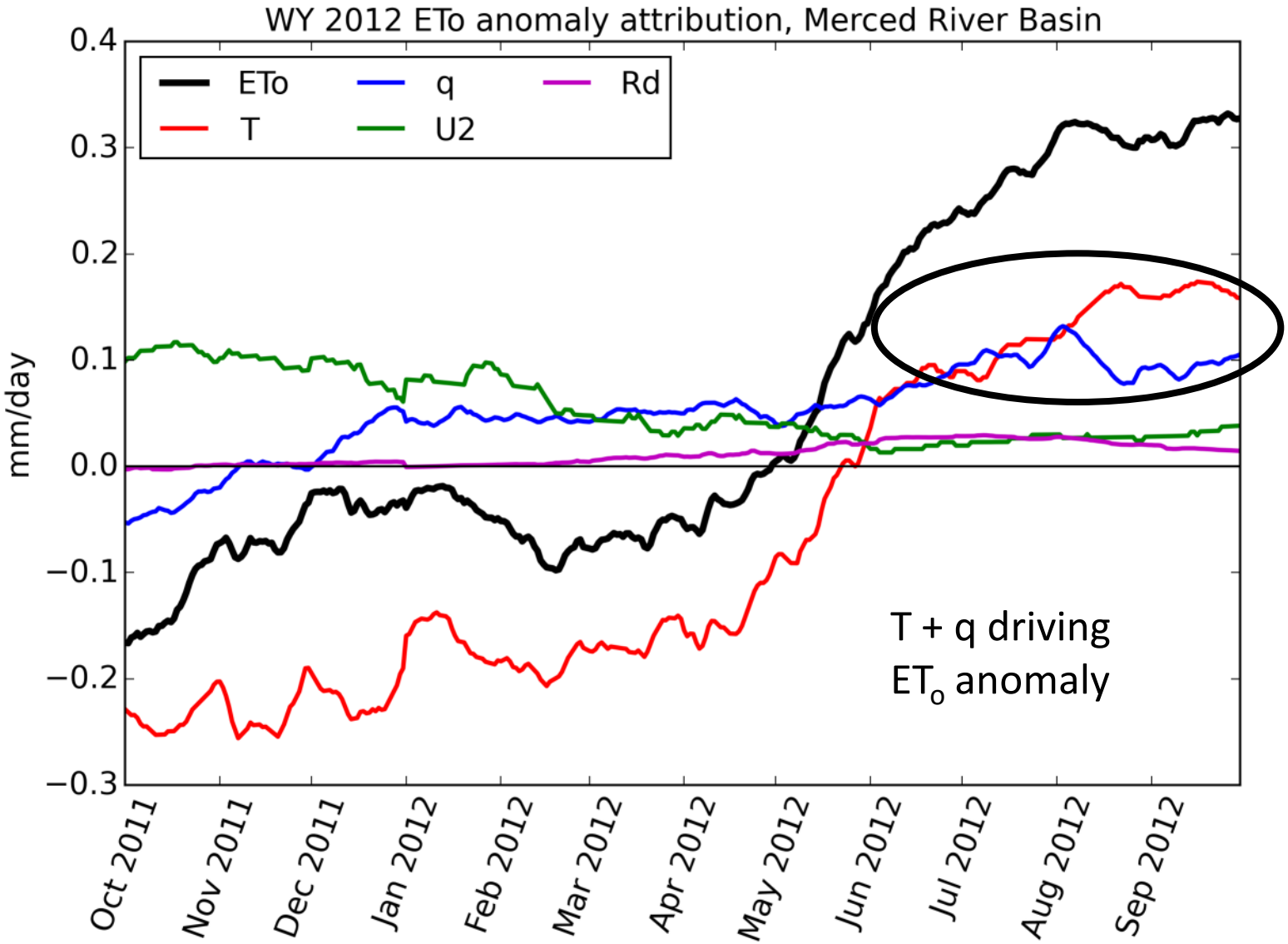
T sensitivity x T anomaly



- Sum of ET_o drivers = ET_o anomaly
- Positive ET_o anomaly since early 2012
- Shift to mostly temperature dominant late 2013

[Hobbins, 2016; results courtesy of Mike Hobbins]

ET_o decomposition and attribution



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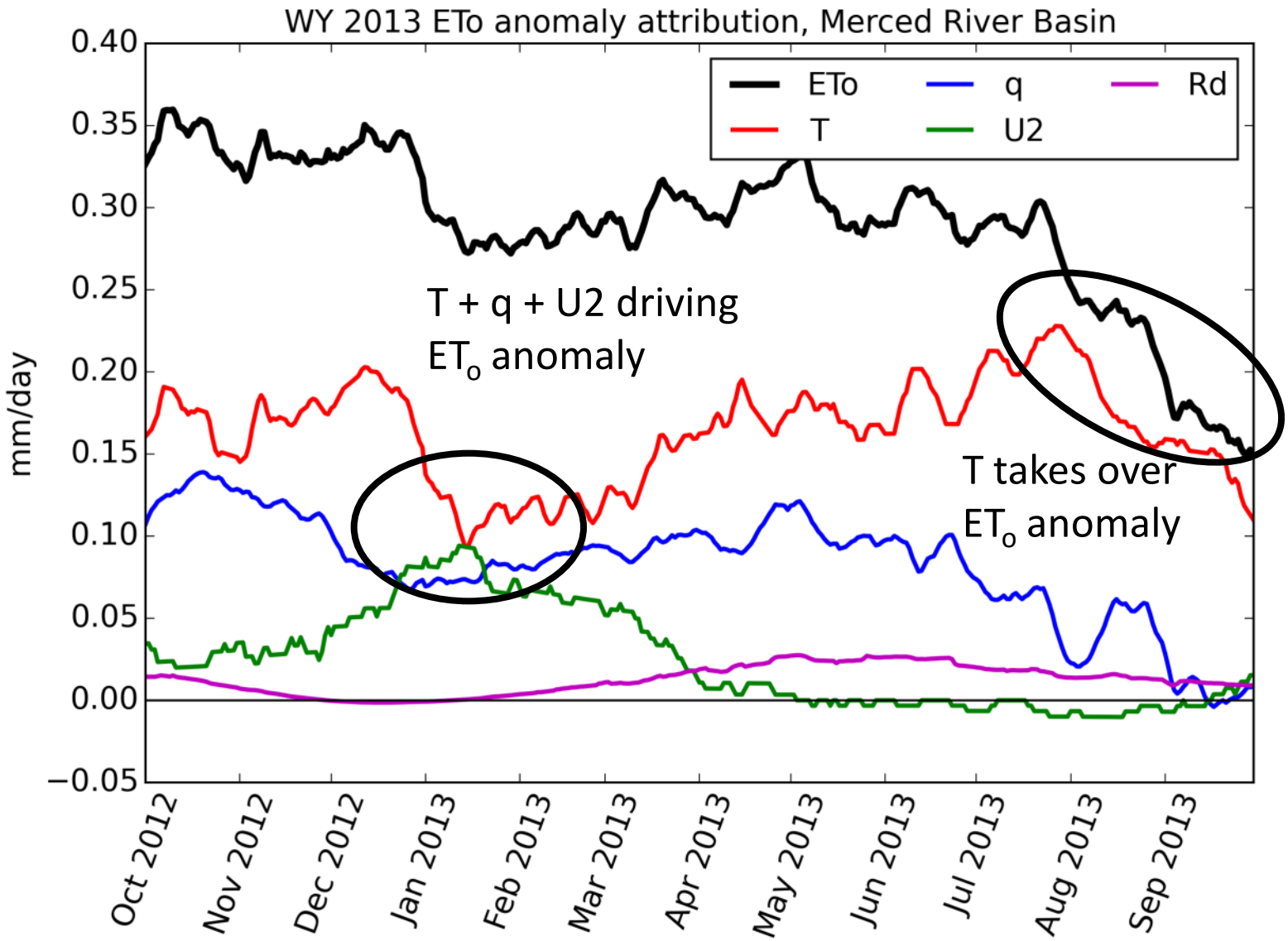

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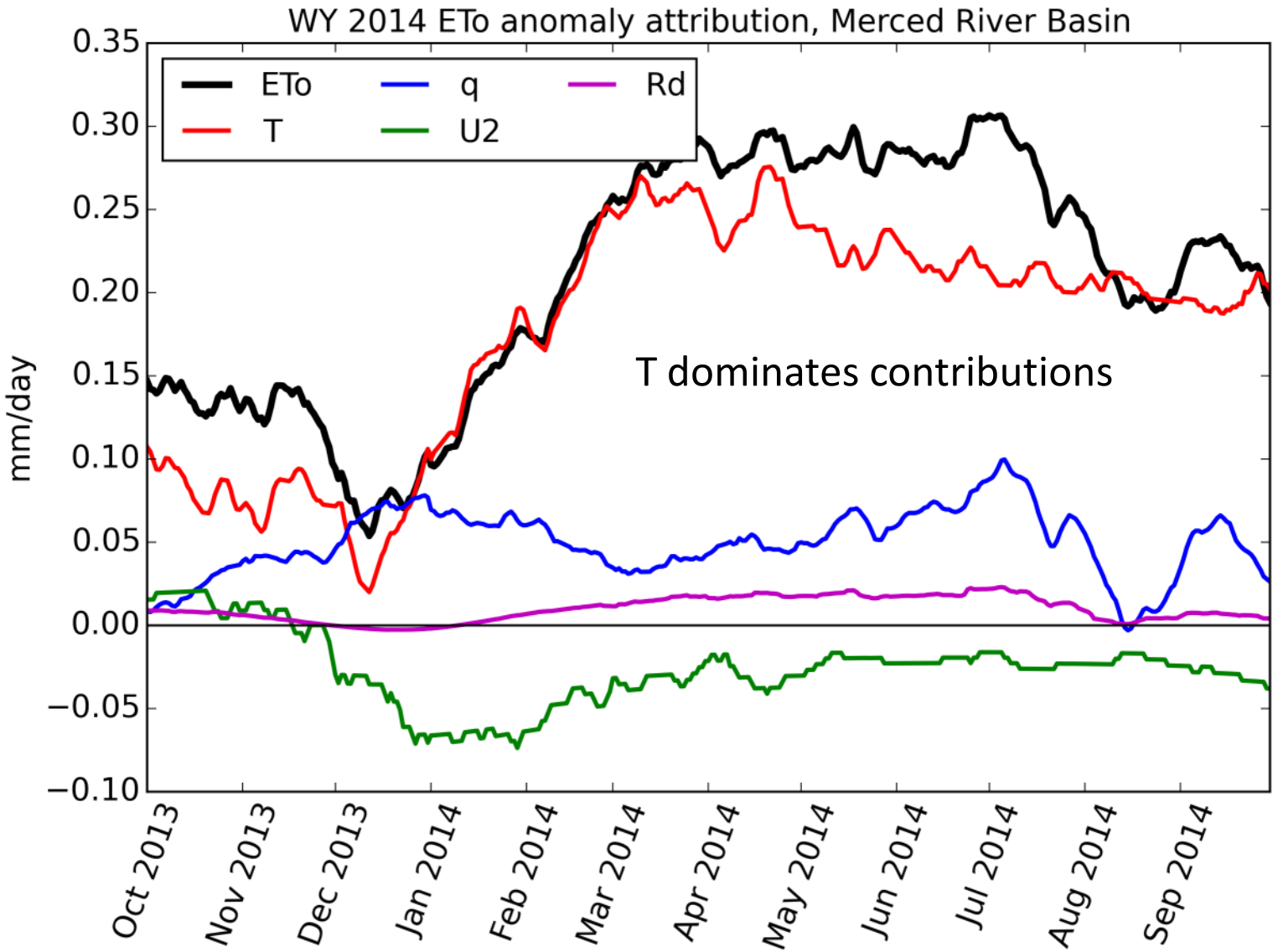

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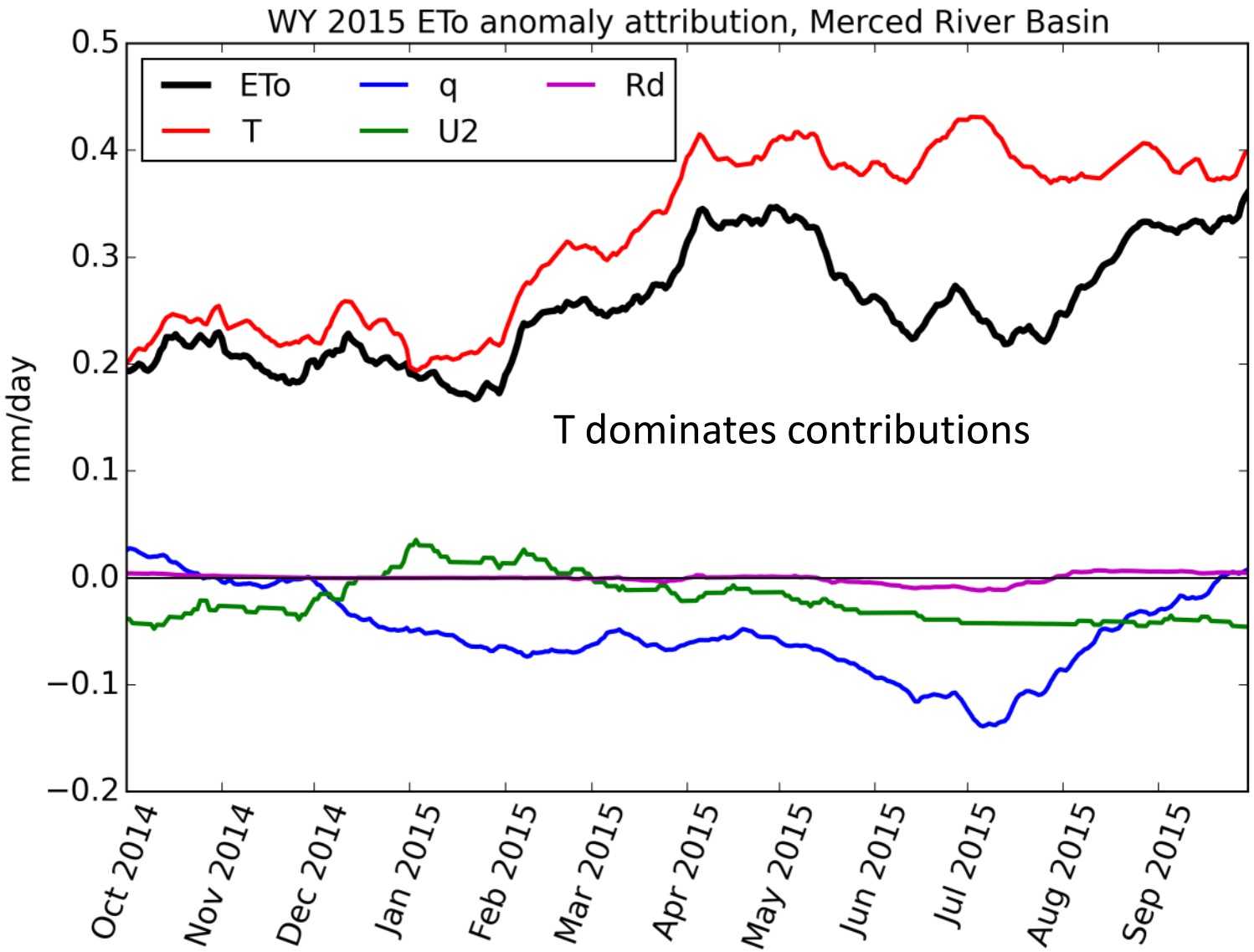

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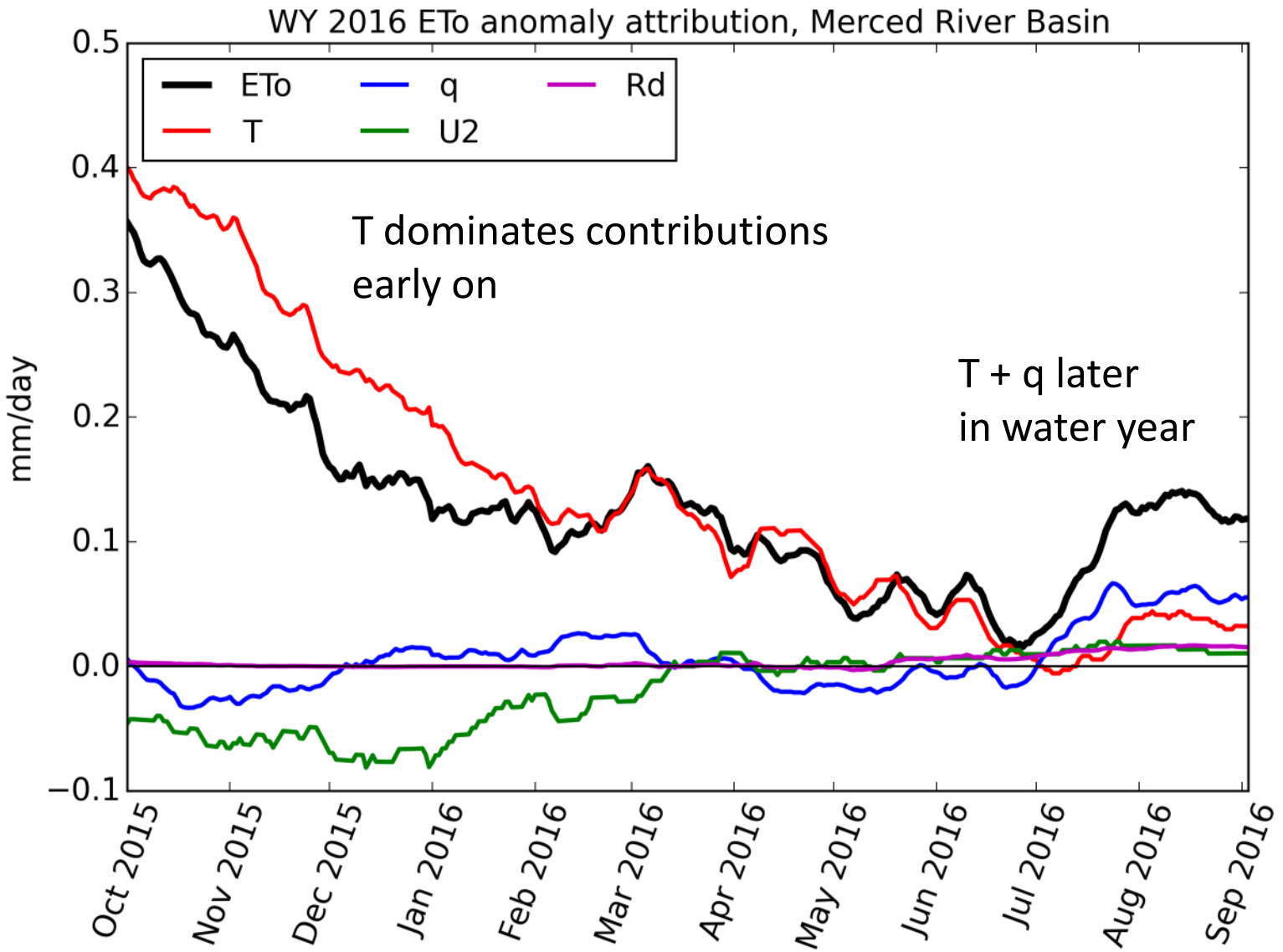

Conclusions

- Precipitation more correlated to streamflow droughts than ET_o
- However, ET_o alone still strongly related to streamflow
- Precipitation and ET_o during cool season most important for water year streamflow
- ET_o anomalies were driven by different contributions of ET_o drivers throughout the 2012-2016 drought
- 2012-2013: greatest contributions from **temperature** *but* large contributions from **humidity** and occasionally **wind speed**
- 2014-2016: large **temperature** anomalies dominated the ET_o signal
- Contributions from **radiation** always minor

Future Work

EDDI work:

- *Operationalizing an Evaporative Demand Drought Index Service for Drought Monitoring and Early Warning*
- NOAA Research Transition Acceleration Program (RTAP), 3-years, ~ $900K
- Experimental daily updated EDDI maps: ftp://ftp.cdc.noaa.gov/pub/Public/mhobbins/EDDI/
- Seasonal forecasts of ET_o anomalies for drought early warning

Thank you!

Questions?

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Lake Tahoe as seen from top of Incline Peak, NV. February, 2014