# The Evaporative Demand Drought Index (EDDI):

## an emerging drought-monitoring & early warning tool


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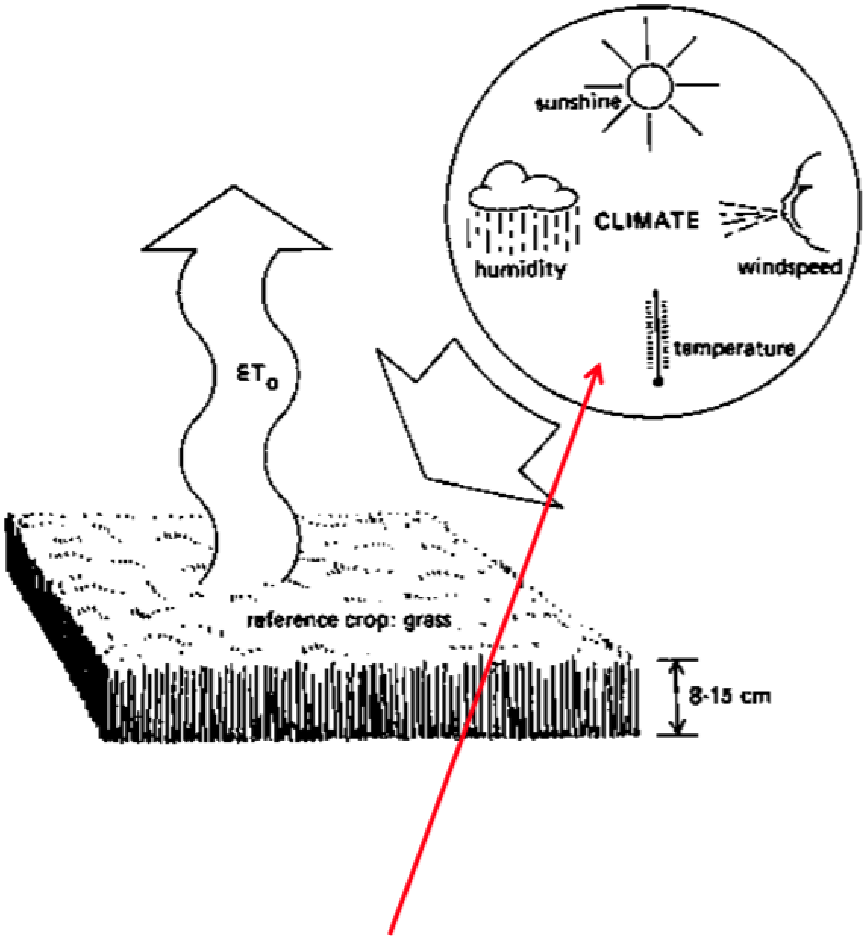
# What is Evaporative Demand ($E_0$)?

*ET* = actual evapotranspiration
$E_0$ = evaporative demand

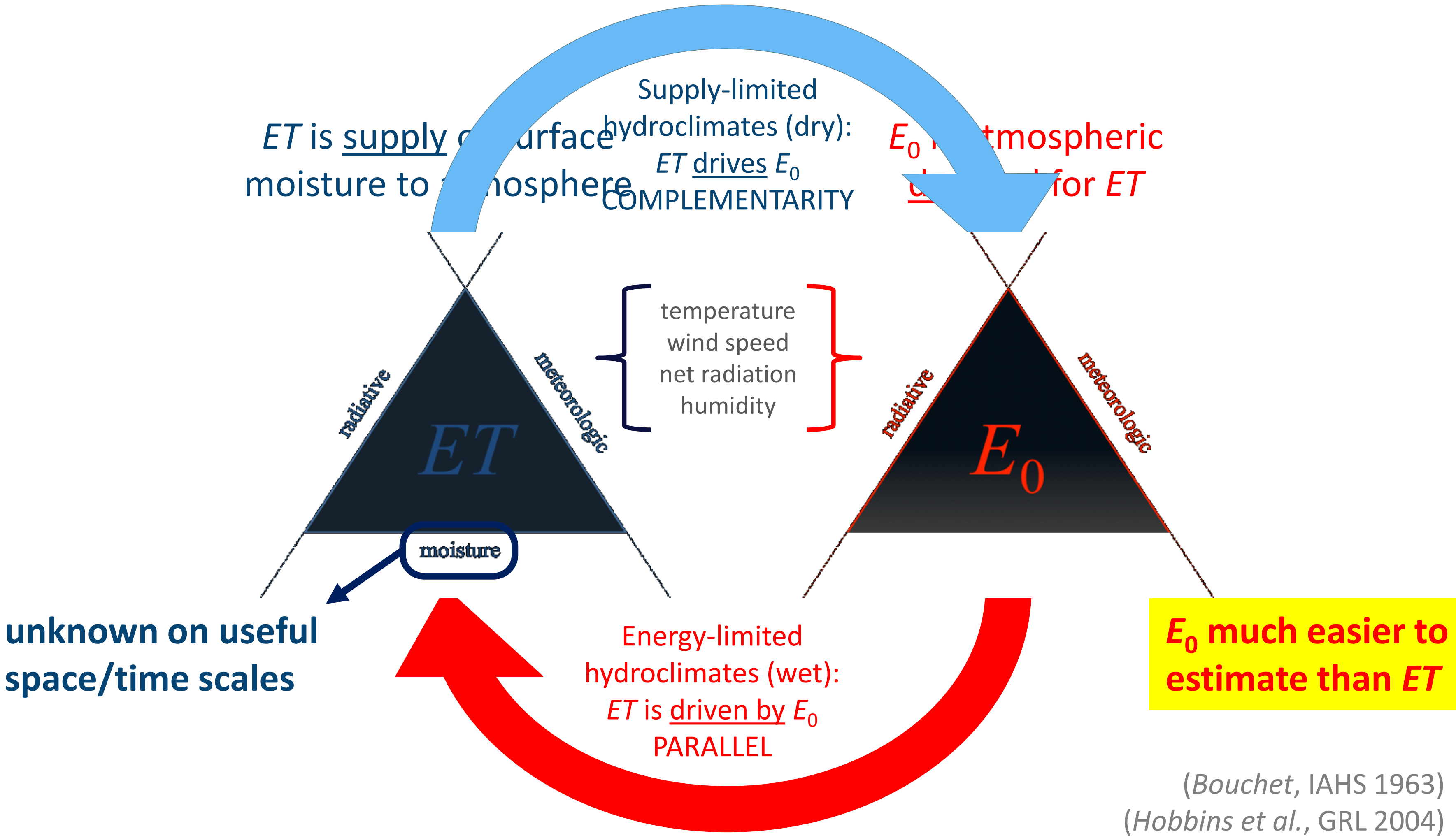
- "Thirst of the atmosphere"
- *ET* occurring given an unlimited moisture supply
  - **Reference *ET***
  - Potential *ET ("PET")*
  - Pan evaporation
- There are good estimates and bad estimates:
  - **physically based**
  - temperature-based




**Physically-based** $ET_o$ **contains valuable information related to drought dynamics**

# $E_0$ / *ET* constraints and interactions

*ET* = actual evapotranspiration
$E_0$ = evaporative demand




(*Bouchet*, IAHS 1963)
(*Hobbins et al.*, GRL 2004)

# Estimating $E_0$ from reference $ET$

$\lambda$ = latent heat of vaporization
$R_n$ = net radiation (SW + LW) at crop surface
$G$ = ground heat flux
$U_2$ = 2-m wind speed
$e_{sat}$ / $e_a$ = saturated / actual vapor pressure
$\Delta = de_{sat}/dT$ at air temperature $T$
$\gamma$ = psychrometric constant
$C_n$, $C_d$ = constants for crop type and time-step

Penman-Monteith Reference *ET* (FAO-56):

$$ET_0 = \underbrace{\frac{0.408\Delta}{\Delta+\gamma(1+C_dU_2)}(R_n-G)\frac{86400}{10^6}}_{\text{Radiative forcing (sunshine, } T\text{)}} + \underbrace{\frac{\gamma\frac{C_n}{T}}{\Delta+\gamma(1+C_dU_2)}U_2\frac{(e_{sat}-e_a)}{10^3}}_{\text{Advective forcing (wind, humidity, } T\text{)}}$$

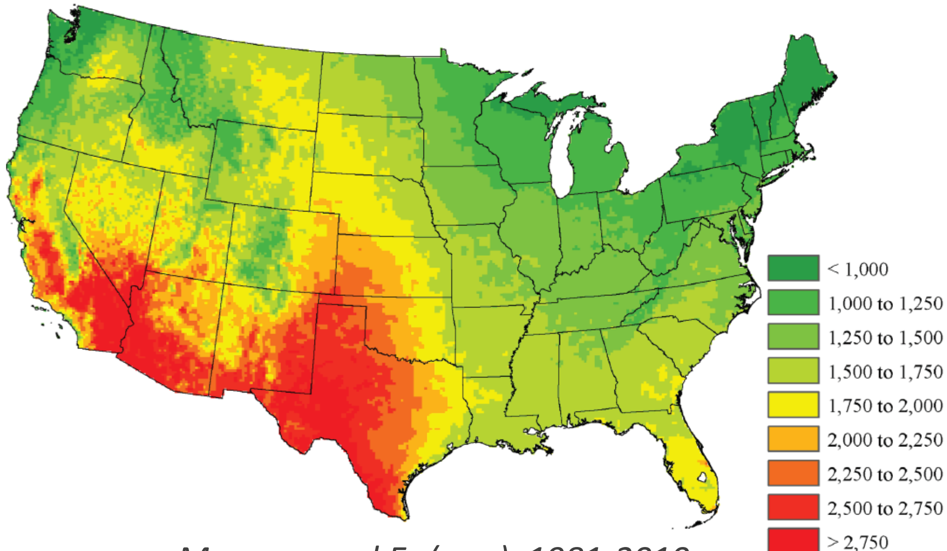
"Reference" crop specified:

- 0.12-m grass or 0.50-m alfalfa
- well-watered , actively growing,
- completely shading the ground,
- albedo of 0.23.

Drivers from NLDAS-2:

- temperature at 2 m
- specific humidity at surface
- downward SW at surface
- wind speed at 10 m

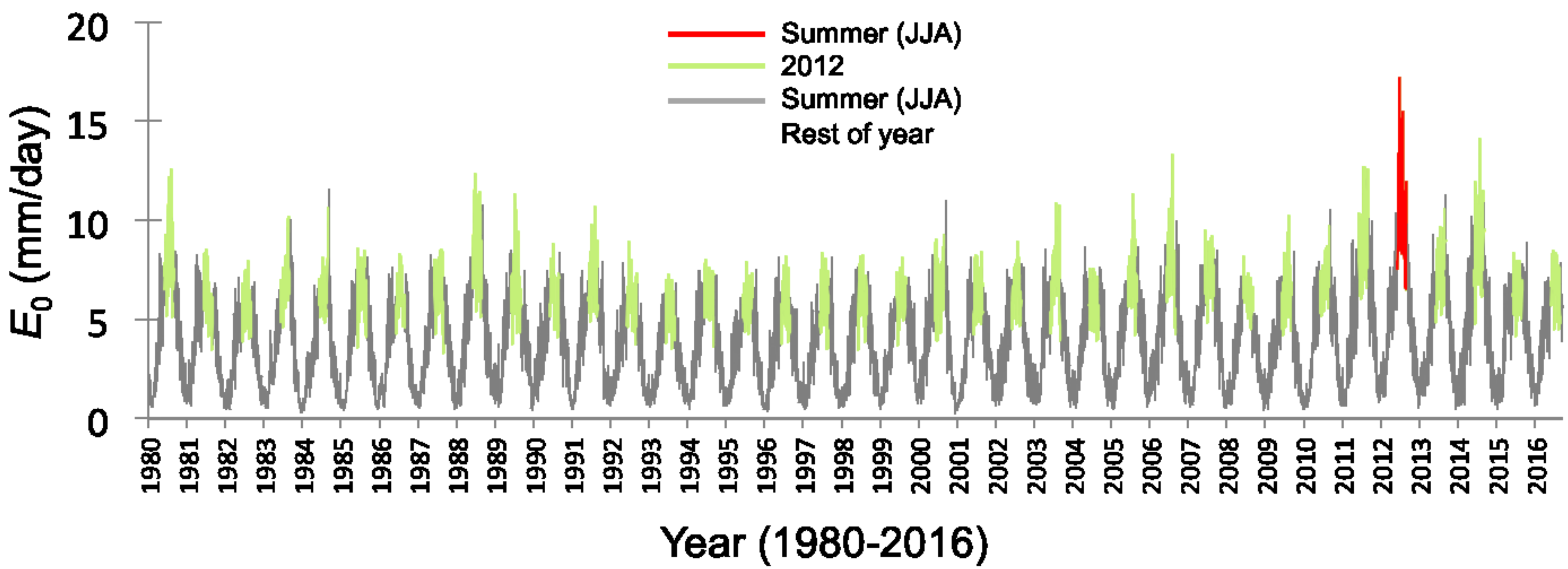
- daily, Jan 1, 1979 – present
- ~12-km, CONUS-wide



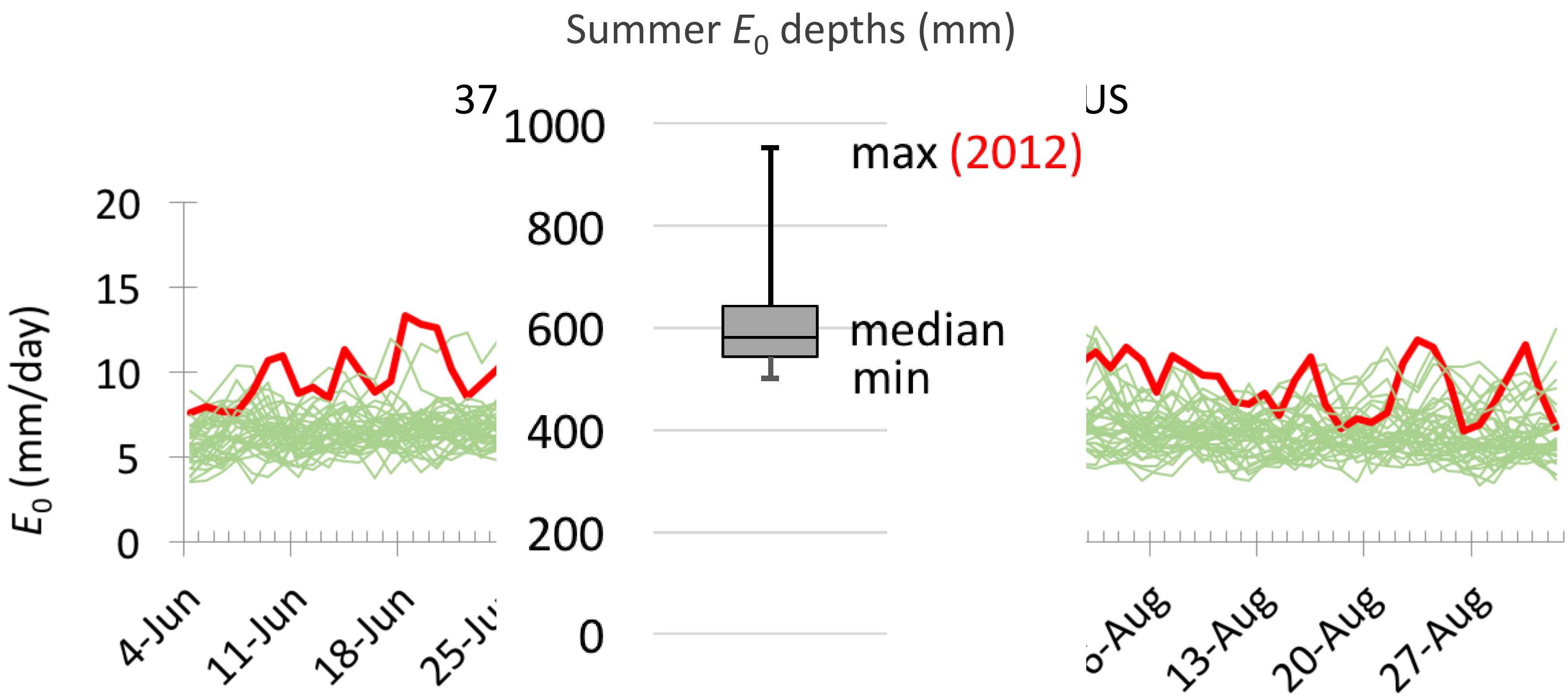

*Mean annual $E_0$ (mm), 1981-2010*

# Calculating EDDI

$E_0$ (reference *ET*) – Midwest US

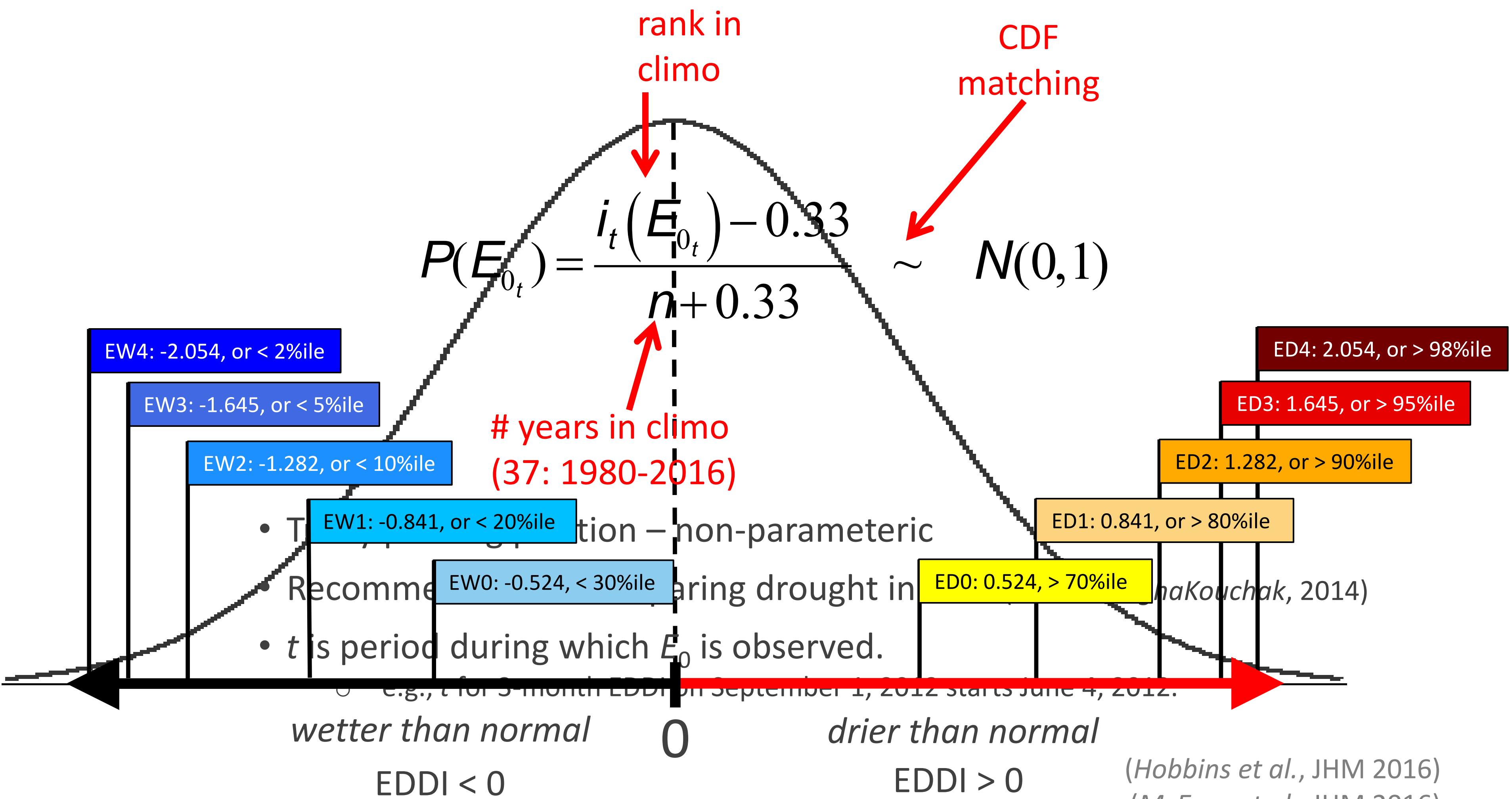


# Calculating EDDI




*2012 has **rank of 1** in*
*37-year $E_0$ climatology*

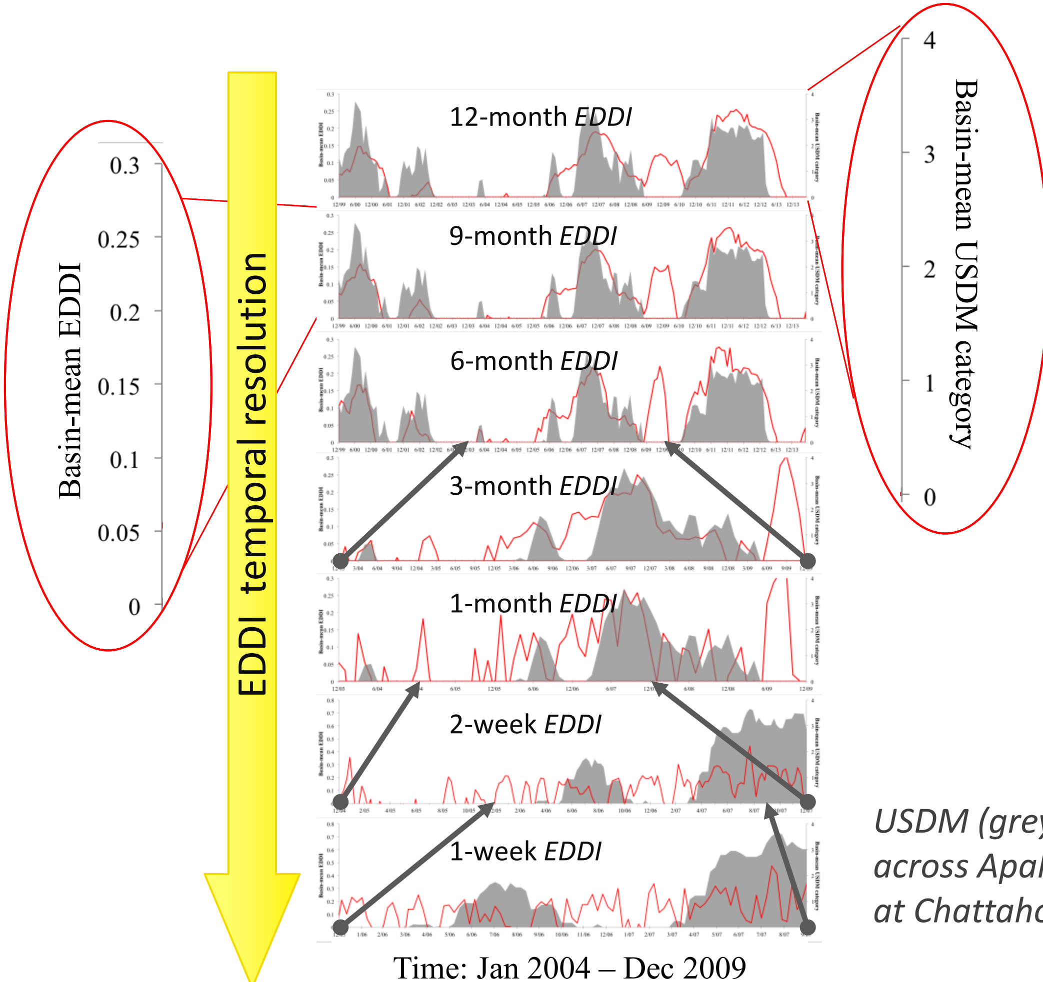
# Calculating EDDI




(*Hobbins et al.*, JHM 2016)
(*McEvoy et al.*, JHM 2016)

# Multi-scalar drought estimator

USDM = United States Drought Monitor



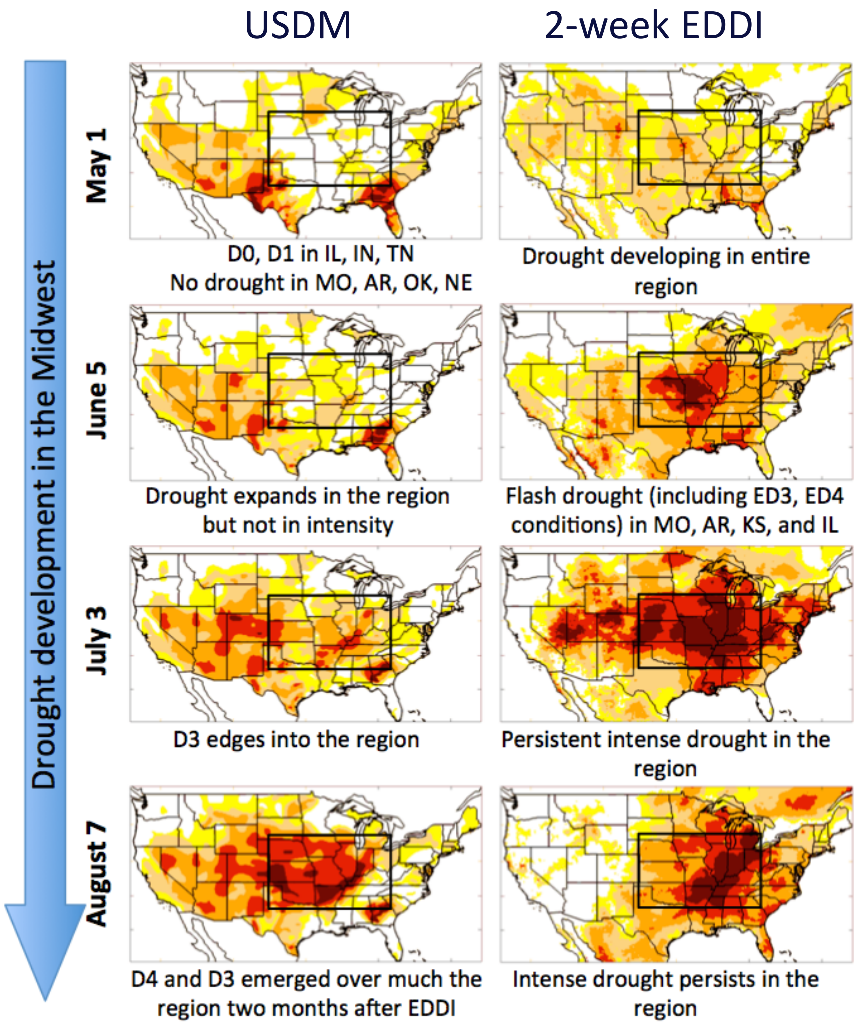

Signals of different drying dynamics are evident at different time-scales

*USDM (grey) and EDDI (red) across Apalachicola River basin at Chattahoochee, FL.*

# Leading indication of drought

2-week EDDI captures
severe drought conditions
~2 months before USDM

*“Flash drought” in the US Midwest, 2012*



# Monitoring across sectors



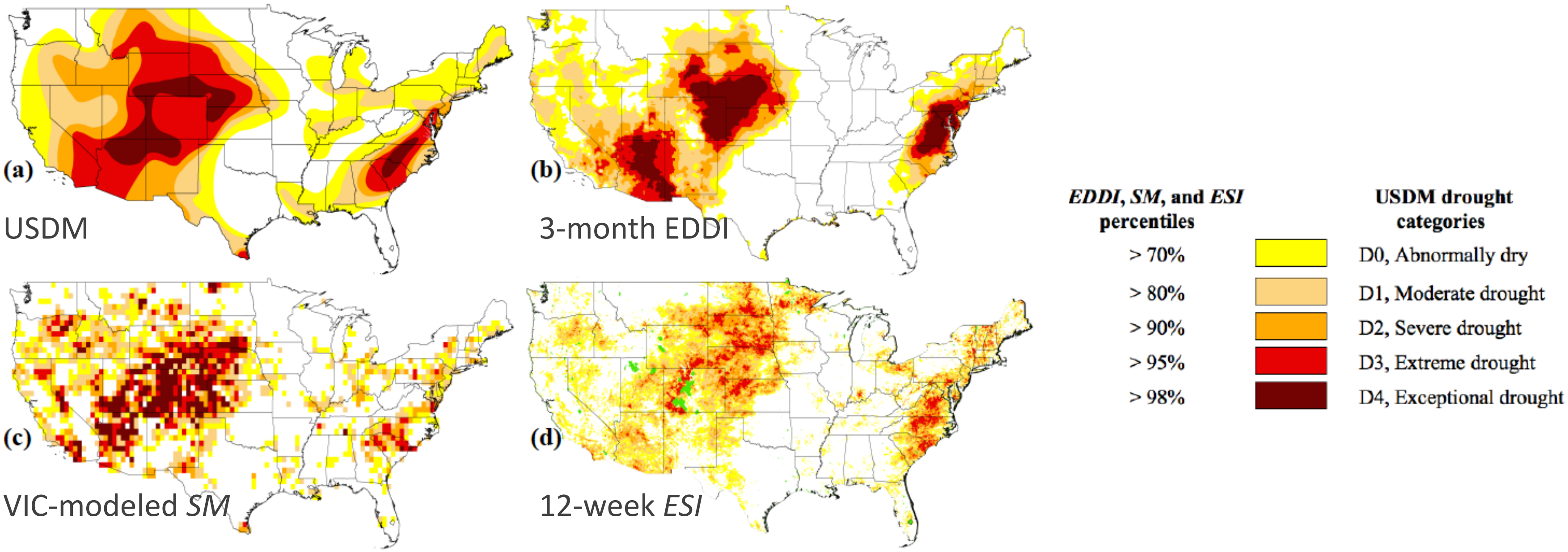
AGRICULTURAL DROUGHT
- soil moisture
- grazing health
- ET

HYDROLOGIC DROUGHT
- streamflow
- snowfall

FIRE-RISK MONITORING
- weather
- fuel loads

# Agricultural drought monitoring

VIC = Variable Infiltration Capacity model
ESI = Evaporative Stress Index



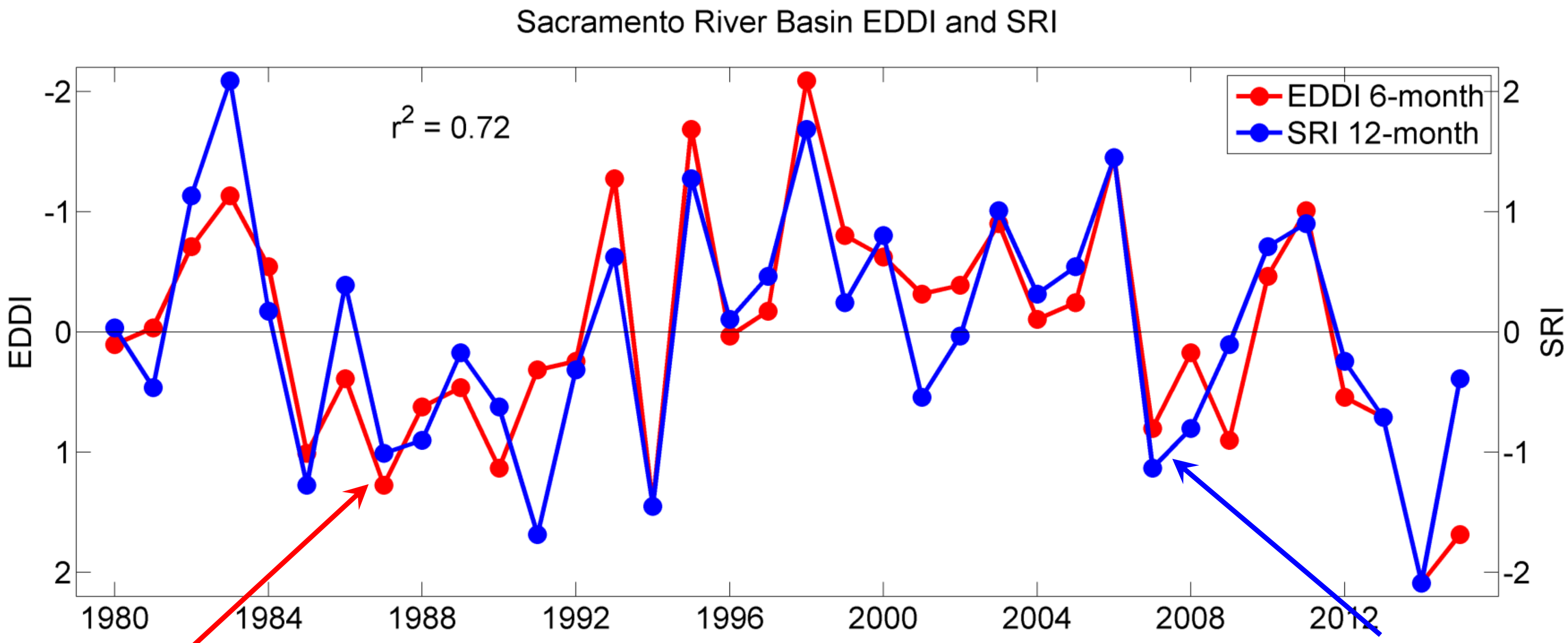

*Agricultural drought across CONUS, July 31, 2002*

(*Hobbins et al.*, JHM 2016)

# Hydrological drought prediction

SRI = Standardized Runoff Index

*Can EDDI help predict late-summer (low-flow) streamflow?*




6-month EDDI
(Nov-Apr)

EDDI contains no *Prcp* information!

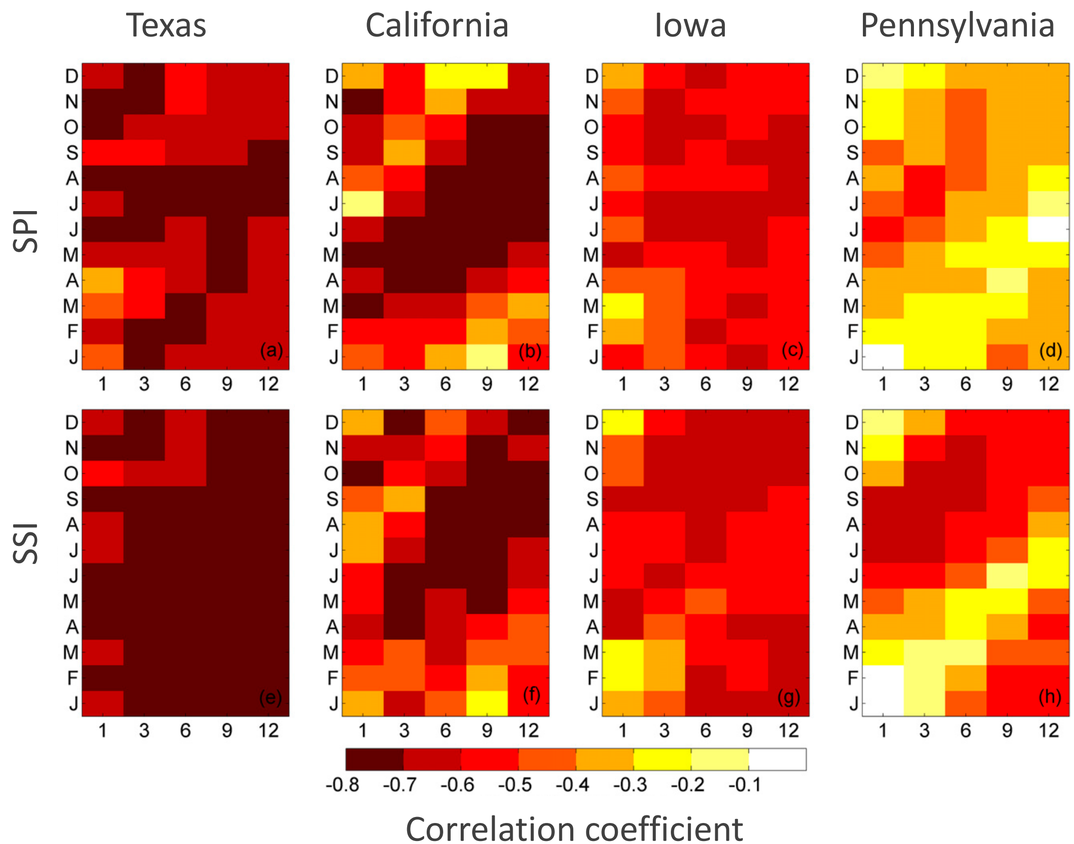
12-month SRI
(Oct-Sep)

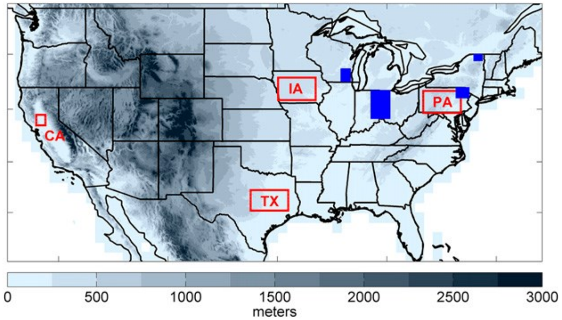
(EDDI - *McEvoy et al.*, JHM 2016)
(SRI - *Shukla and Wood,* GRL 2008)

# Comparison to other drought metrics

## Across timescales and hydroclimates

SPI = Standardized Precipitation Index
SSI = Standardized Soil Moisture Index



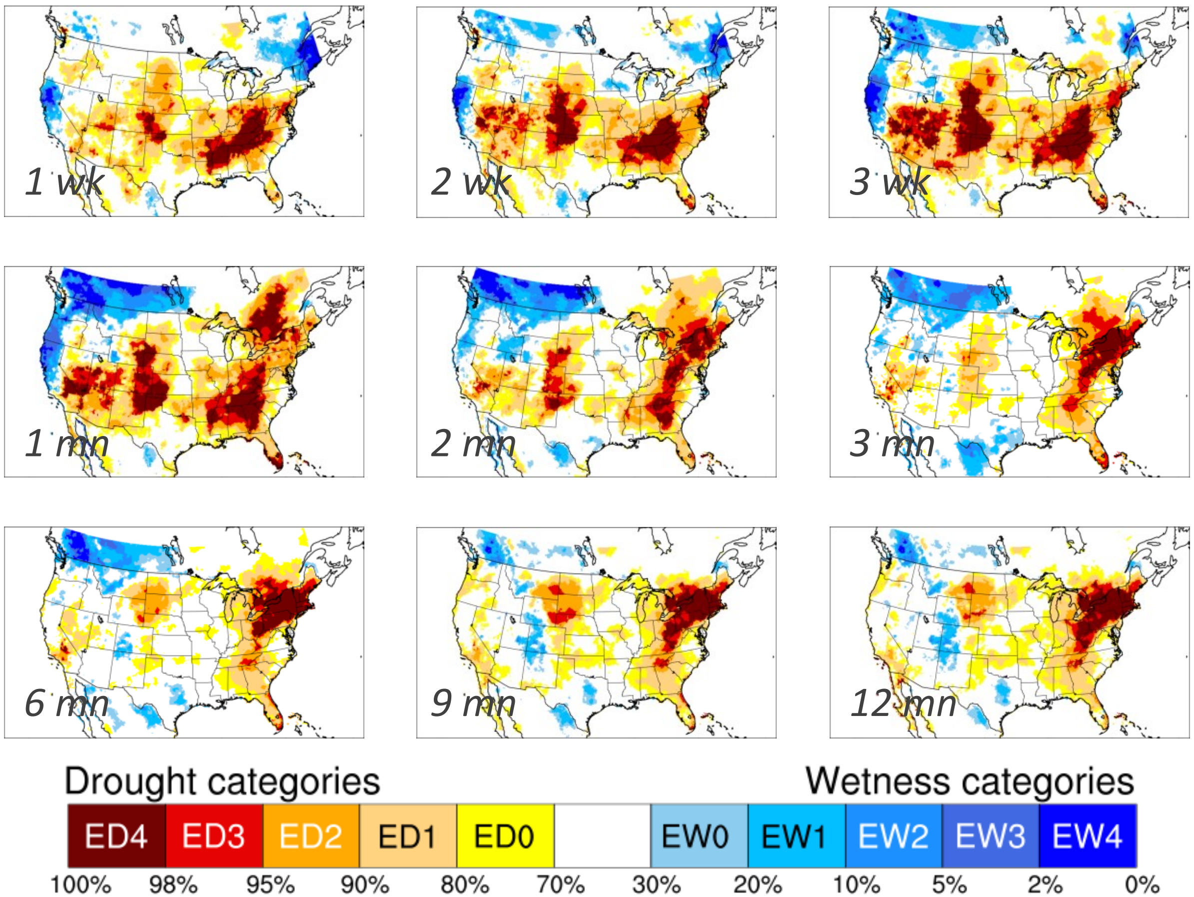




(*McEvoy et al.*, JHM 2016)

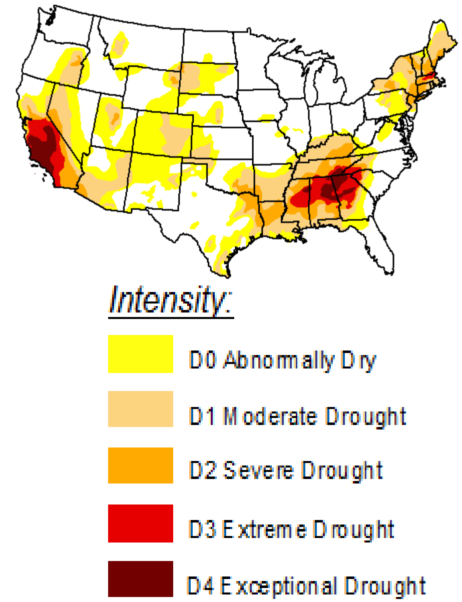
# EDDI at various timescales

*EDDI*
*Nov 4 2016*

*US Drought Monitor*
*Nov 8 2016*



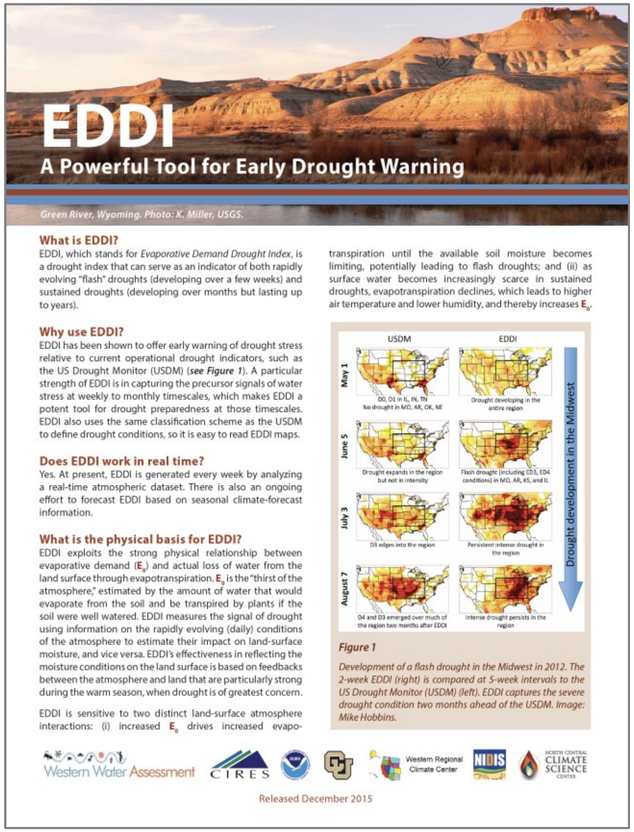

(EDDI-percentile category breaks: 100% = driest; 0% = wettest)



# Next steps

## User outreach, operationalizing, research

### Two-pager:



# EDDI
## A Powerful Tool for Early Drought Warning

*Green River, Wyoming. Photo: K. Miller, USGS.*

**What is EDDI?**
EDDI, which stands for *Evaporative Demand Drought Index*, is a drought index that can serve as an indicator of both rapidly evolving "flash" droughts (developing over a few weeks) and sustained droughts (developing over months but lasting up to years).

**Why use EDDI?**
EDDI has been shown to offer early warning of drought stress relative to current operational drought indicators, such as the US Drought Monitor (USDM) (***see Figure 1***). A particular strength of EDDI is in capturing the precursor signals of water stress at weekly to monthly timescales, which makes EDDI a potent tool for drought preparedness at those timescales. EDDI also uses the same classification scheme as the USDM to define drought conditions, so it is easy to read EDDI maps.

**Does EDDI work in real time?**
Yes. At present, EDDI is generated every week by analyzing a real-time atmospheric dataset. There is also an ongoing effort to forecast EDDI based on seasonal climate-forecast information.

**What is the physical basis for EDDI?**
EDDI exploits the strong physical relationship between evaporative demand ($E_0$) and actual loss of water from the land surface through evapotranspiration. $E_0$ is the "thirst of the atmosphere," estimated by the amount of water that would evaporate from the soil and be transpired by plants if the soil were well watered. EDDI measures the signal of drought using information on the rapidly evolving (daily) conditions of the atmosphere to estimate their impact on land-surface moisture, and vice versa. EDDI's effectiveness in reflecting the moisture conditions on the land surface is based on feedbacks between the atmosphere and land that are particularly strong during the warm season, when drought is of greatest concern.

EDDI is sensitive to two distinct land-surface atmosphere interactions: (i) increased $E_0$ drives increased evapotranspiration until the available soil moisture becomes limiting, potentially leading to flash droughts; and (ii) as surface water becomes increasingly scarce in sustained droughts, evapotranspiration declines, which leads to higher air temperature and lower humidity, and thereby increases $E_0$.



*Figure 1*

*Development of a flash drought in the Midwest in 2012. The 2-week EDDI (right) is compared at 5-week intervals to the US Drought Monitor (USDM) (left). EDDI captures the severe drought condition two months ahead of the USDM. Image: Mike Hobbins.*

Western Water Assessment · CIRES · Western Regional Climate Center · NIDIS · North Central Climate Science Center

Released December 2015

### Next steps:

- Operationalizing EDDI at NOAA National Water Center
- Enlarge and engage user-base
- EDDI User's Manual
- Continued research and development collaboration with research partners (DRI):
  - attribution component
  - forecast component
  - wildfire prediction

(2-pager: *Rangwala et al.*, NOAA 2015)

# Drivers of drought

$E_0 = f(T, R_d, q, U_2)$, so

$$\Delta E_0 = \frac{\partial E_0}{\partial T}\Delta T + \frac{\partial E_0}{\partial R_d}\Delta R_d + \frac{\partial E_0}{\partial q}\Delta q + \frac{\partial E_0}{\partial U_2}\Delta U_2$$

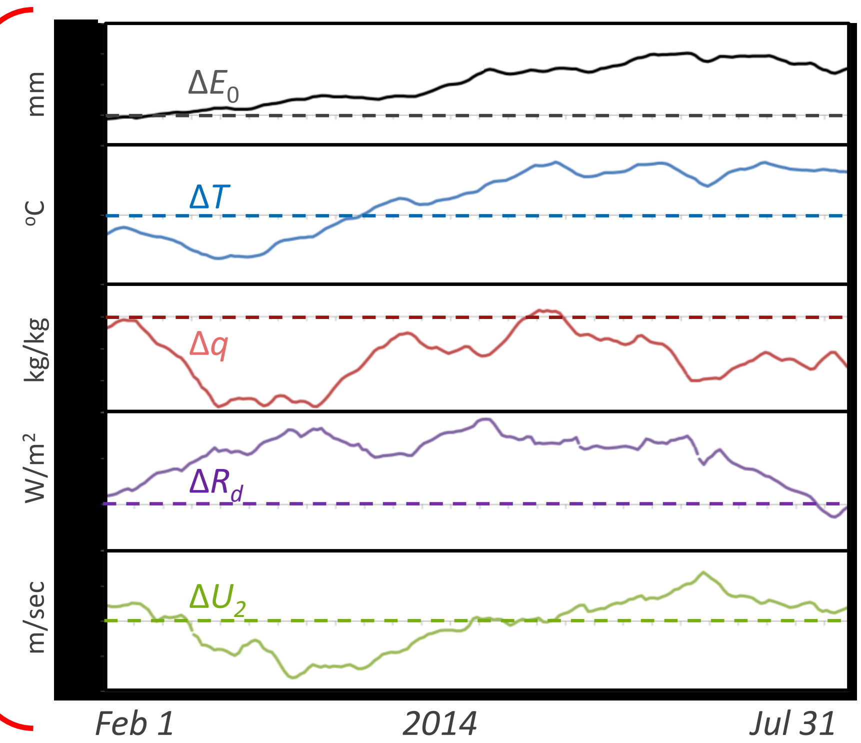
anomalies observed in reanalyses

derived analytically (*Hobbins*, 2016)

$E_0$ changes due to changes in:

- $T$, temperature
- $R_d$, solar radiation
- $q$, humidity
- $U_2$, wind speed

*Sacramento River basin, CA*




(*Hobbins et al.*, JHM 2016)

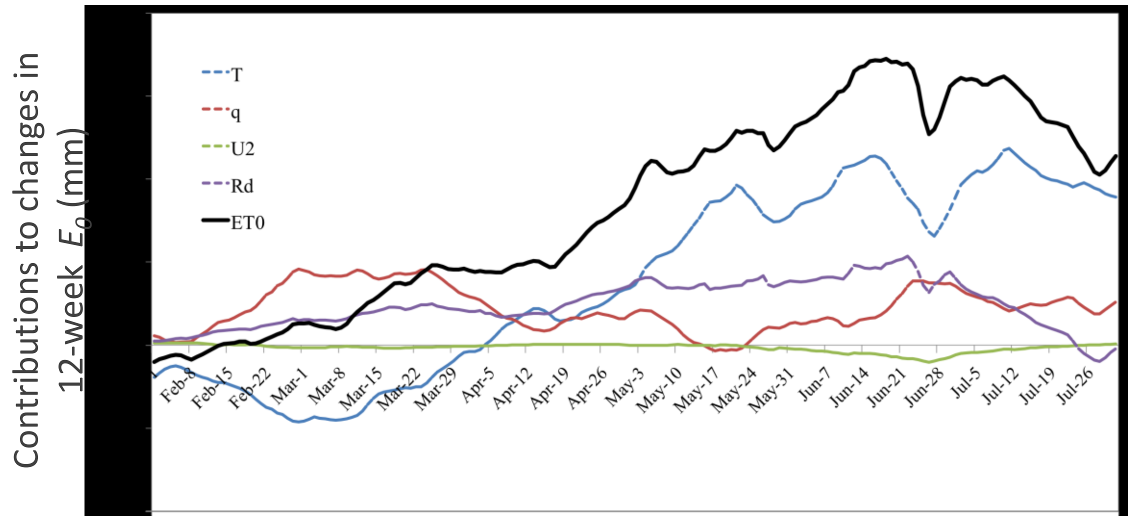
# Drivers of drought

Drought intensification (increasing $E_0$) forced by:

- first, below-normal $q$ (while $T$ falling)
- then, increasing $T$ and, to a lesser degree, $R_d$
- $U_2$ plays little role

$T$ = air temperature
$R_d$ = downwelling SW
$q$ = specific humidity
$U_2$ = wind speed

*Sacramento River basin, CA*

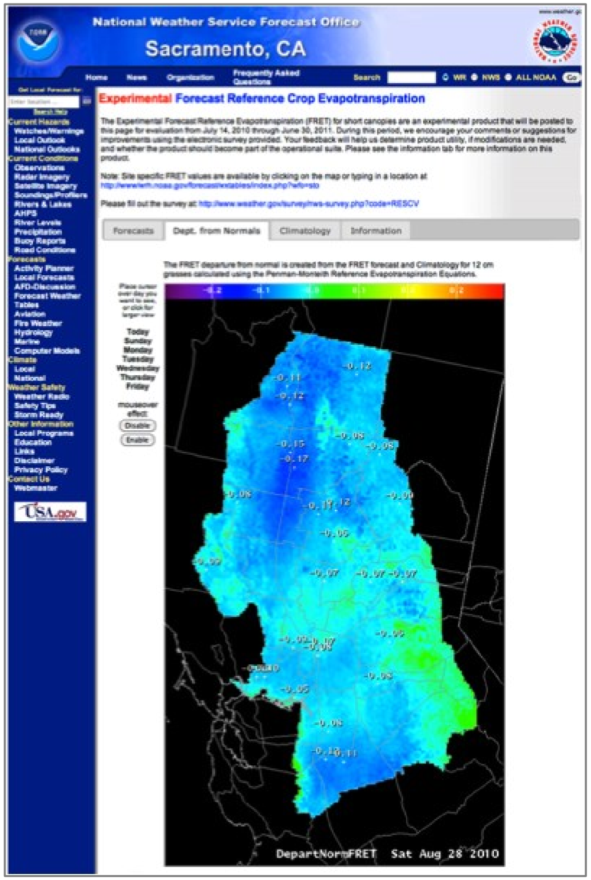



(*Hobbins et al.*, JHM 2016)

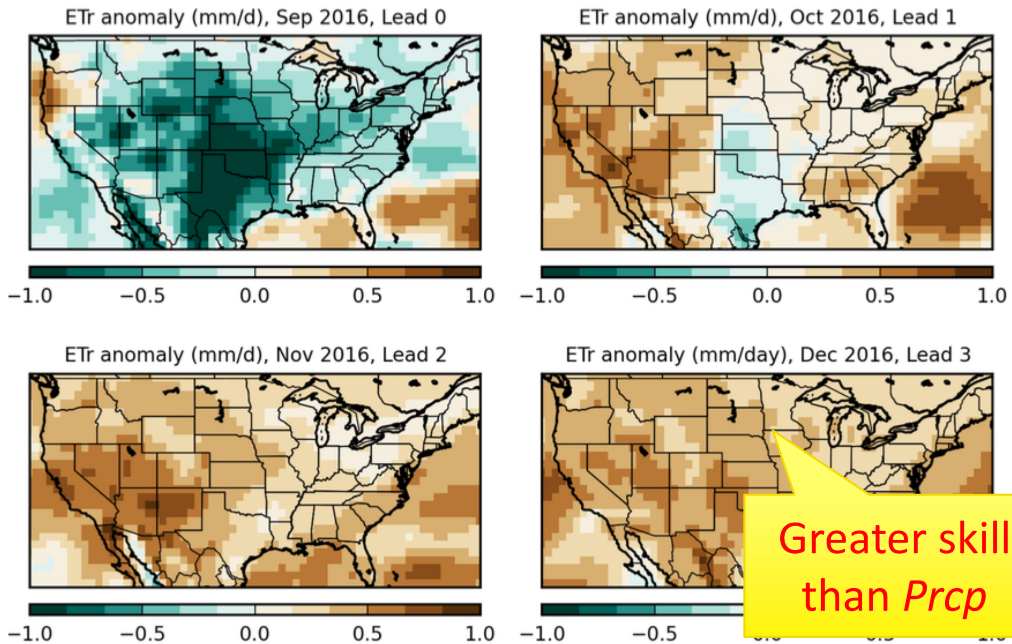
# Forecasting of $E_0$ (and drought)

FRET = Forecast Reference Evapotranspiration
*Prcp* = precipitation

## Daily, weekly - FRET




## Seasonally



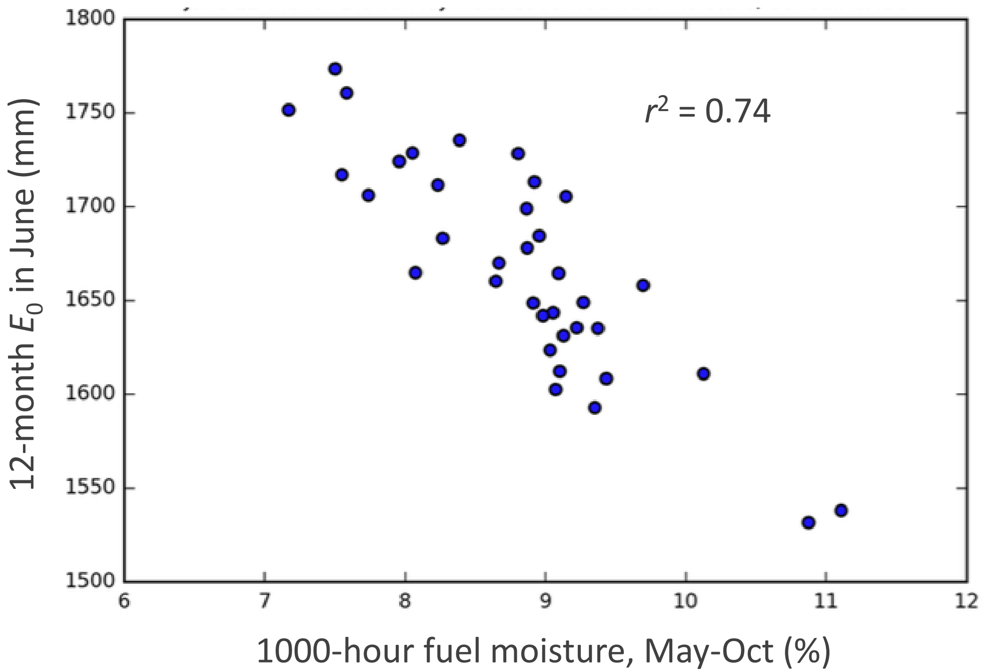

Greater skill than *Prcp*

*CFSv2 4-member ensemble mean initialized Sept 8 (00Z, 06Z, 12Z, and 18Z) – Dan McEvoy, DRI*

(*McEvoy et al.*, GRL 2016)

# Predicting wildfire risk

*$E_0$-fuel load relationship across S. California GACC*




2-year NOAA grant: *Developing a wildfire component for the NIDIS CA DEWS*

# Summary

## $E_0$ and drought:

Physically rational relationship to drought

More readily available than *ET* (than *Prcp*, often)

- latency can be significant

Permits decomposition of evaporative drought drivers

$E_0$ (and EDDI, drought) is forecastable (*McEvoy et al.*, GRL 2016)

## Evaporative Demand Drought Index (EDDI):

Examines drought from <u>demand</u> side

- $E_0$, not *Prcp*

Near-real-time drought monitoring and early warning

- agricultural drought
- hydrologic drought
- fire-weather prediction

Multi-scalar in time and space

Aggregation window may be calibrated for:

- early warning relative to other monitors,
- demands specific to hydroclimates, and sectors.

# $E_0$ / $ET$ interactions in drought

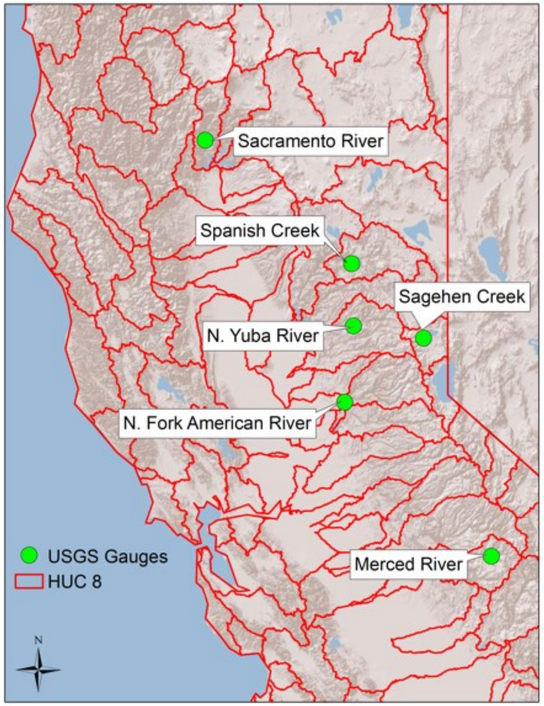
In both drought types,

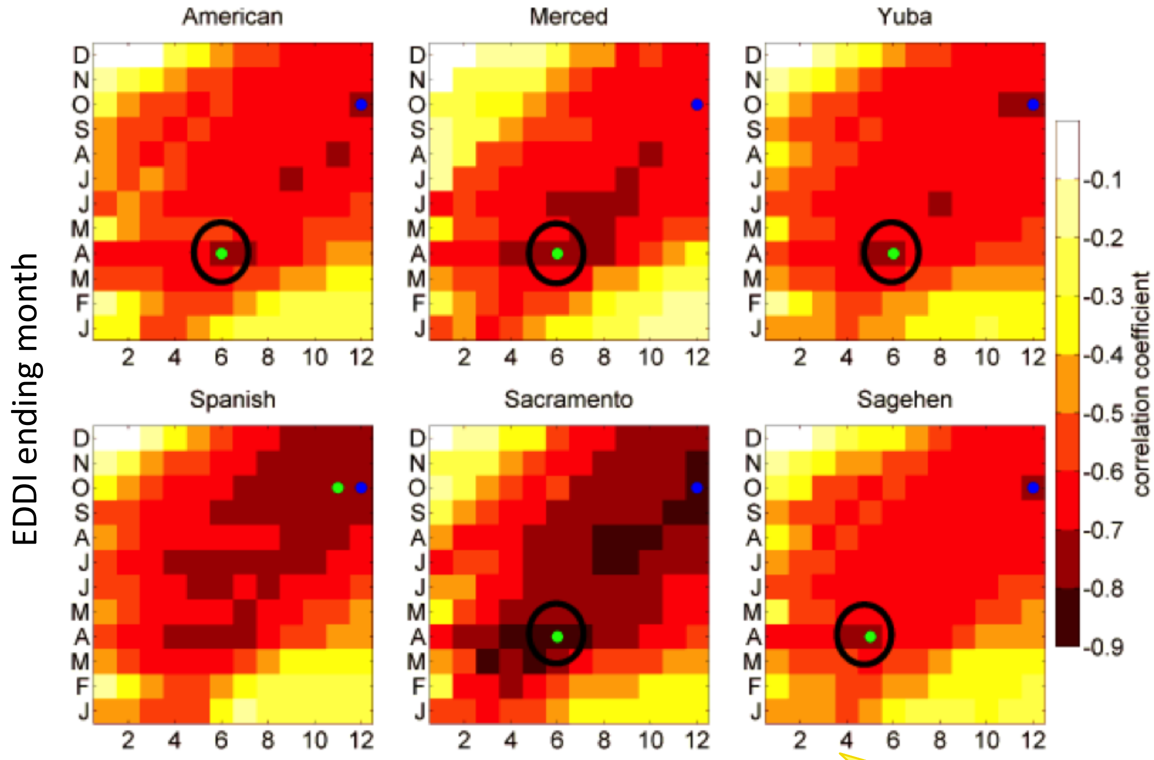
$E_0$ increases.

*(Hobbins et al., 2004)*

# EDDI and hydrologic drought

## 12-month SRI vs. 6-month EDDI



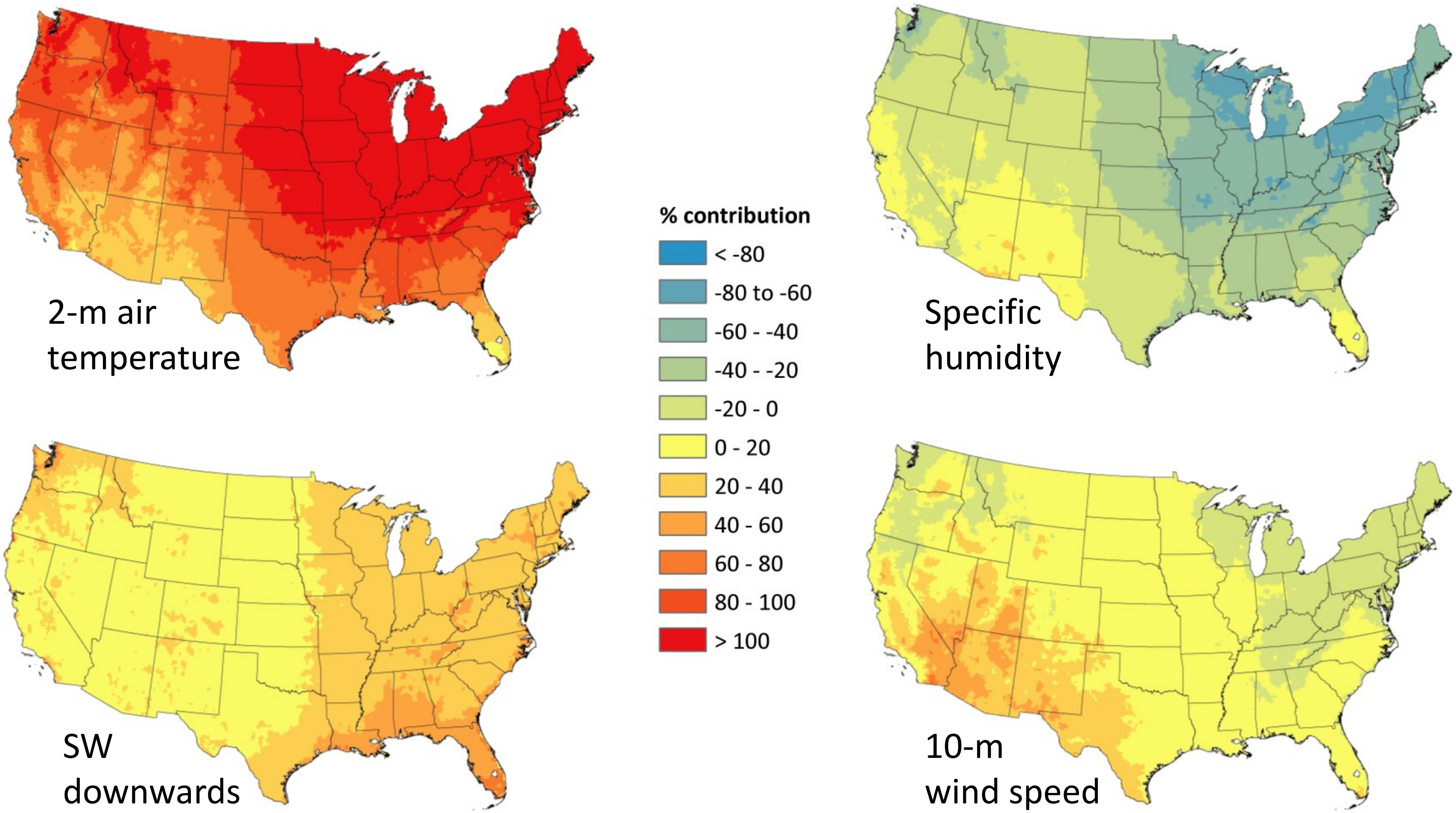




EDDI contains no Prcp information!

- At 5 sites, 6-month EDDI (Nov-Apr) shows strongest relationship to SRI.
- October-April $E_0$ explains greatest variance in WY streamflow (i.e., Oct 1-Sep 30).
- Highlights EDDI's predictive capability.

# Rigorous $E_0$ variability analysis

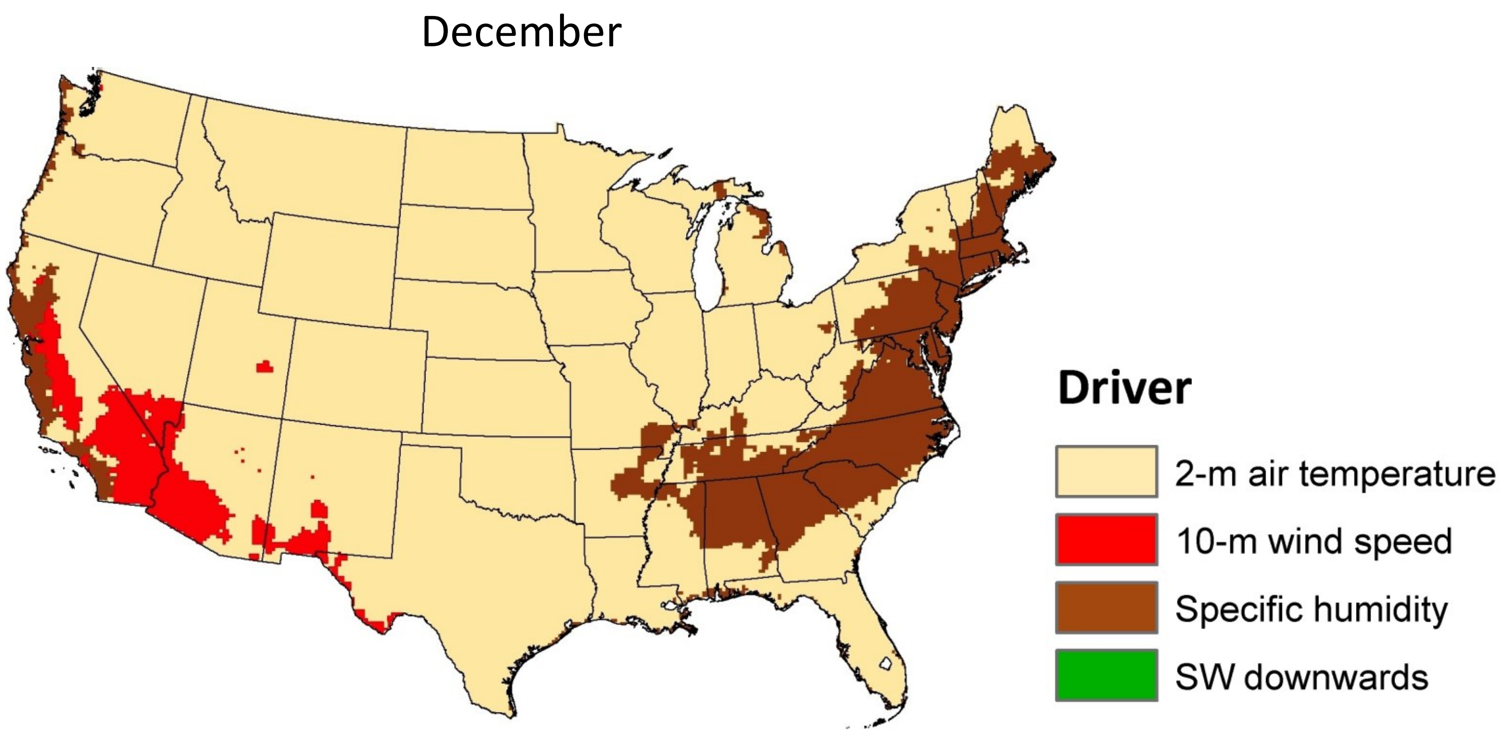
## MJJASO variability contributions, daily $ET_0$, by driver




*Hobbins et al., Trans. ASABE, 2016*

# Rigorous $E_0$ variability analysis

Top driver of daily variability, by month

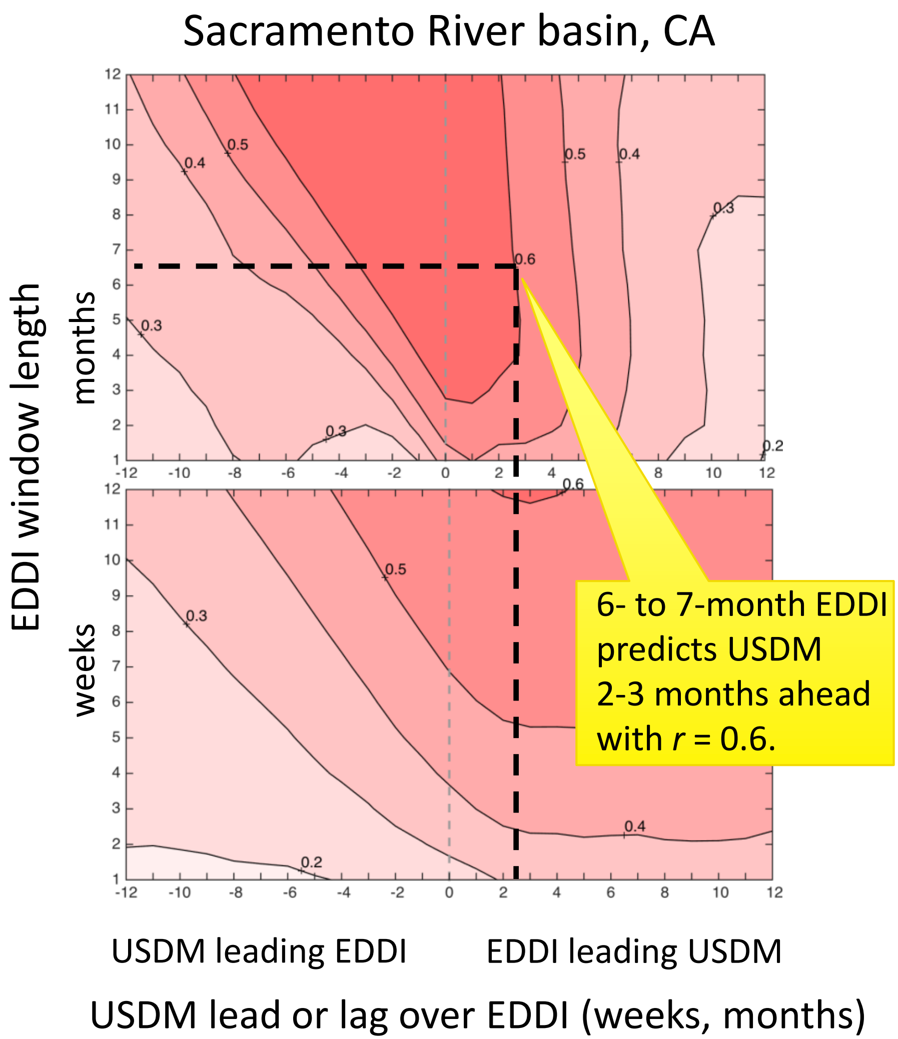



*Hobbins et al., Trans. ASABE, 2016*

# EDDI as a leading indicator of drought

Optimizing EDDI window-length is straightforward.

Here, EDDI is optimized against USDM for the Sacramento River basin.



# FRET – in a nutshell

Forecast estimate of $ET_0$ for 24-hour period:

Deterministic forecast:

– no ensemble forecasts

Time-and space specs:

– 1- to 7-day lead time

– 24-hour periods run 6z to 6z

– HRAP grid (~2.5 kms)

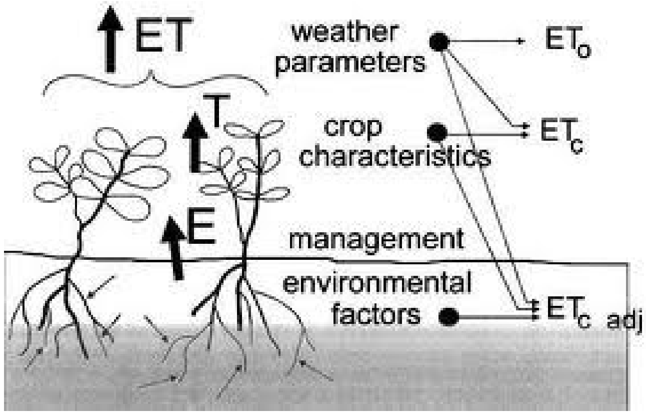
Penman-Monteith (ASCE):

– 12-cm grass reference crop

Drivers:

– sensible weather elements from coupled NWPs

- $T_{max}$, $T_{min}$
- $RH_{max}$, $RH_{min}$
- *10-m wind speed*
- *Sky* (cloud cover %)

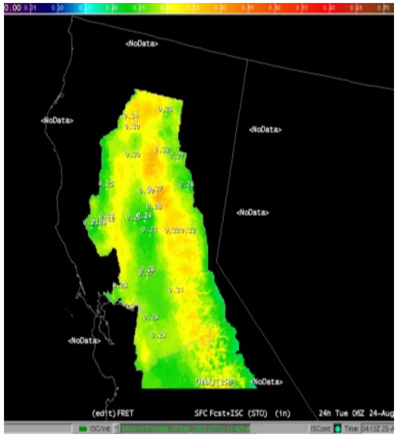
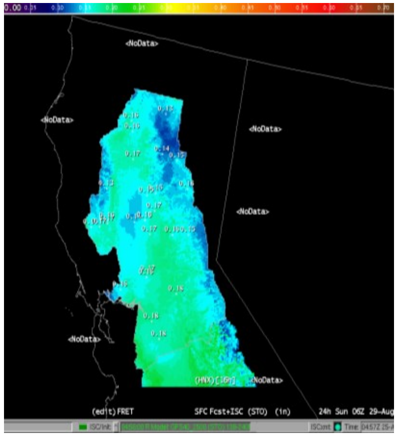
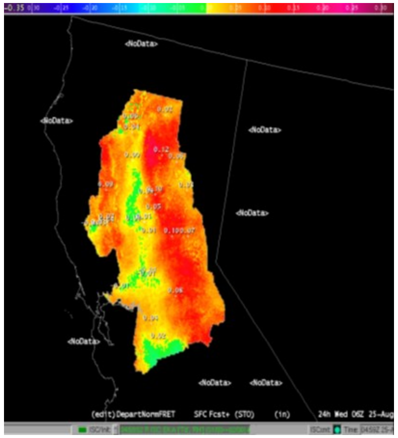
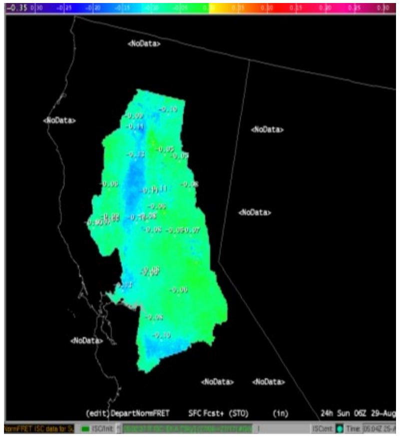



drivers forecasted by loading data from a model (or blend of models), expertly tweaked for consistency with neighboring WFOs / specific local conditions,

- e.g., for wind: may load local WRF data and then increase areas in the Delta for Delta breeze.

# Short-term forecasting of $ET_0$

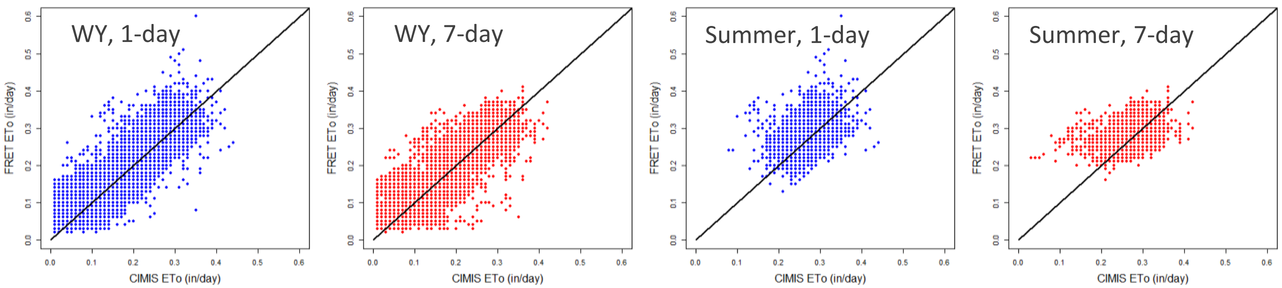
## Example forecasts, 1-day FRET

| | Aug 24, 2013 - hot | Aug 29, 2013 - cool |
|---|---|---|
| Forecast: 1-day FRET |  |  |
| Anom<u>aly</u>: $FRET_{1d} - ET_0$ |  |  |

# Short-term forecasting of $ET_0$

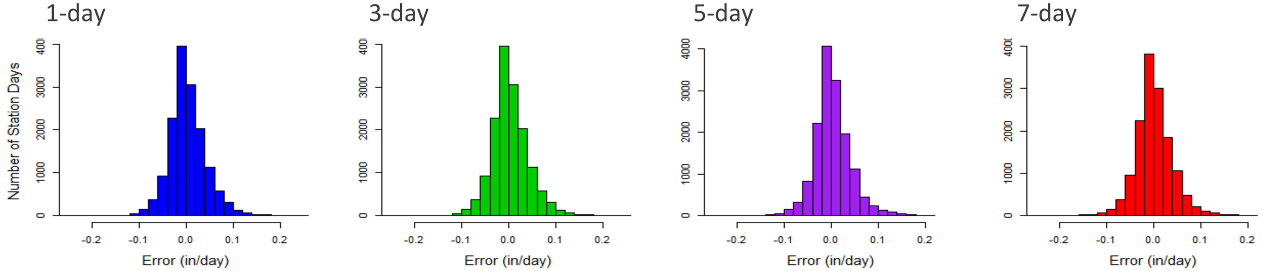
## FRET verification

Water year (WY) and summer FRET $ET_0$ vs. CIMIS observations



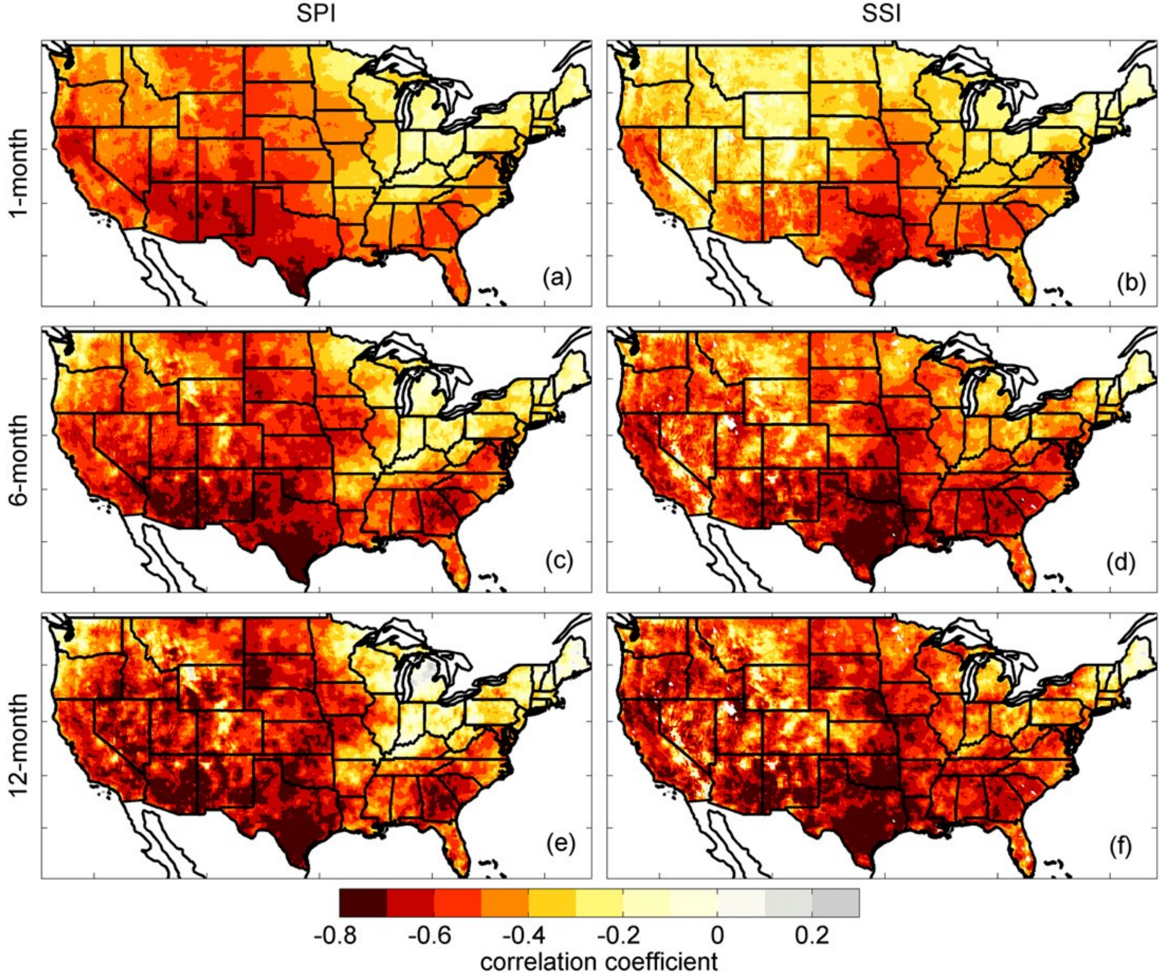

> 80% of FRET values within 0.05 in/day of observed $ET_0$ for all forecast periods.

FRET – CIMIS observation for 48 stations

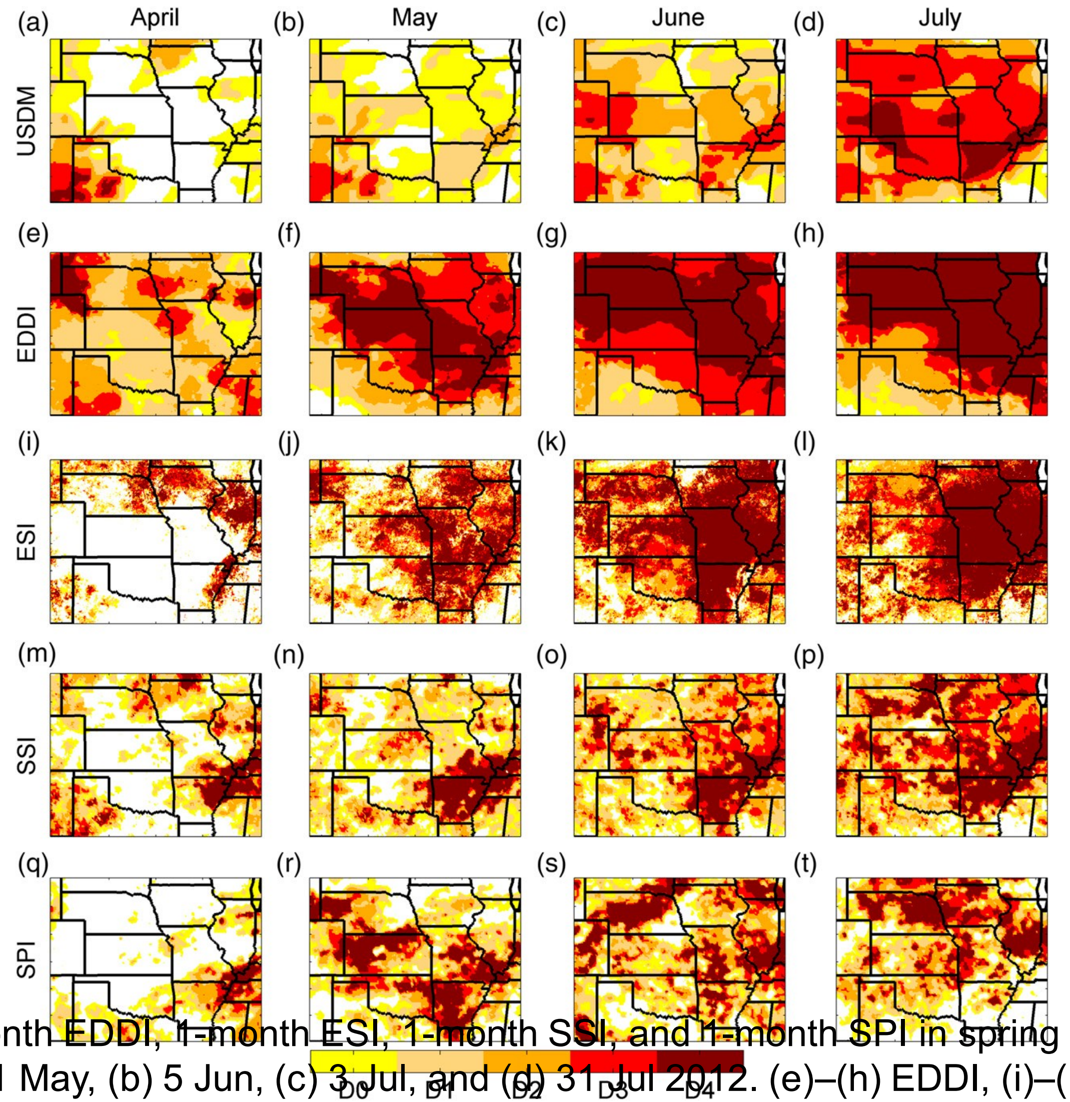



FRET has slight +ve bias wrt observed $ET_0$, increased bias in summer.

| | 2012 Water Year | | | 2012 Summer | | |
|---|---|---|---|---|---|---|
| FRET forecast period | BIAS (in/day) | MBE (-) | MAE (in/day) | BIAS (in/day) | MBE (-) | MAE (in/day) |
| 1-day | 0.006 | 0.18 | 0.029 | 0.015 | 0.07 | 0.036 |
| 3-day | 0.006 | 0.18 | 0.028 | 0.015 | 0.08 | 0.034 |
| 5-day | 0.006 | 0.18 | 0.028 | 0.013 | 0.08 | 0.032 |
| 7-day | 0.004 | 0.17 | 0.028 | 0.012 | 0.07 | 0.032 |




Correlation coefficients between EDDI and SPI at (a) 1-month, (c) 6-month, and (e) 12-month time scales and between EDDI and SSI at (b) 1-month, (d) 6-month, and (f) 12-month time scales. Correlations were computed at each grid point for 1979–2013 over each month (n 5 35) and then averaged over all months in each time scale.




Evolution of USDM, 1-month EDDI, 1-month ESI, 1-month SSI, and 1-month SPI in spring to summer of 2012. USDM data are from (a) 1 May, (b) 5 Jun, (c) 3 Jul, and (d) 31 Jul 2012. (e)–(h) EDDI, (i)–(l) ESI, (m)–(p) SSI, and (q)–(t) SPI are at 1-month time scales at the end of each month. All drought metrics have been converted to USDM categories.

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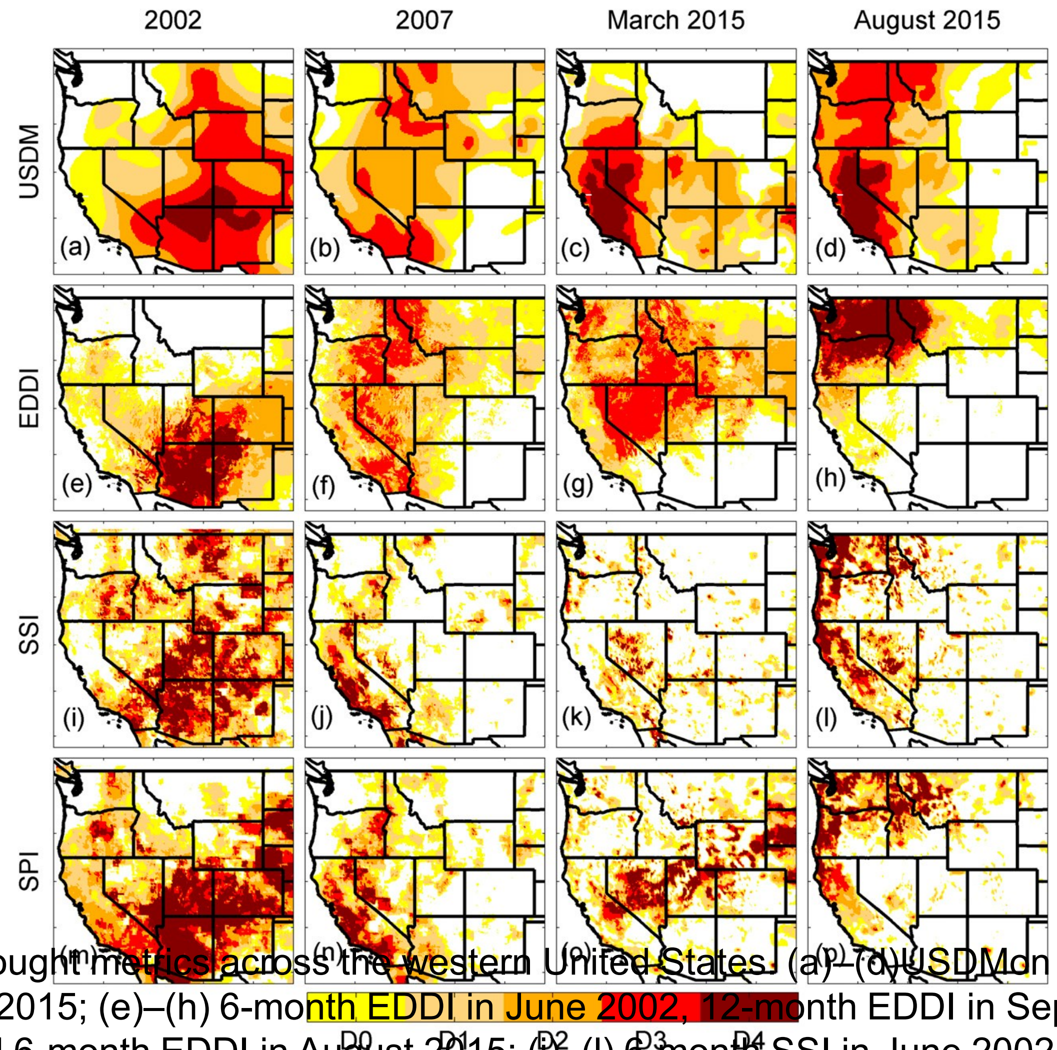
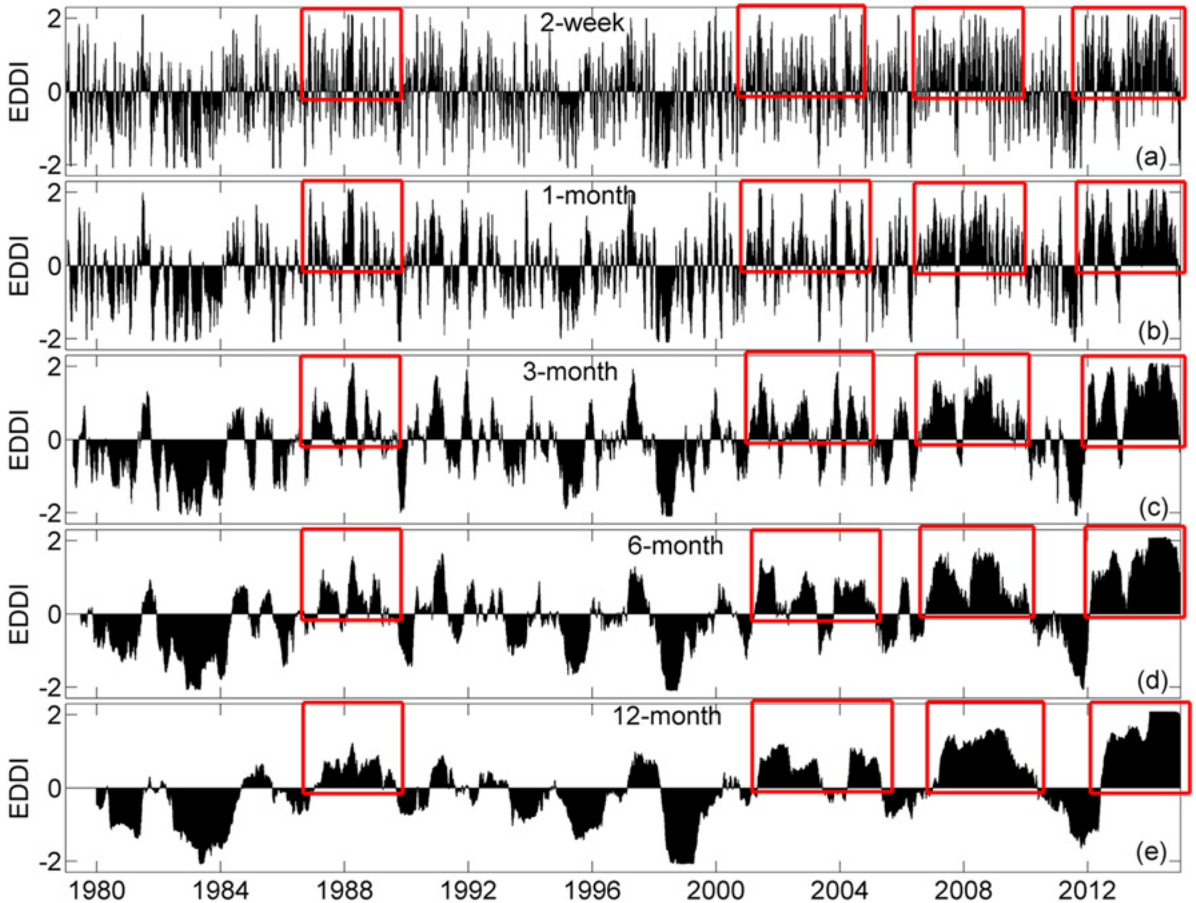



Spatial comparison of drought metrics across the western United States. (a)–(d) USDM on 25 Jun 2002, 2 Oct 2007, 31 Mar 2015, and 1 Sep 2015; (e)–(h) 6-month EDDI in June 2002, 12-month EDDI in September 2007, 6-month EDDI in March 2015, and 6-month EDDI in August 2015; (i)–(l) 6-month SSI in June 2002, 12-month SSI in September 2007, 6-month SSI in March 2015, and 6-month SSI in August 2015; and (m)–(p) 6-month SPI in June 2002, 12-month SPI in September 2007, 6-month SPI in March 2015, and 6-month SPI in August 2015.




Area-averaged time series of EDDI over the northern Sierra Nevada from 1979 to 2014 aggregated at (a) 2-week, (b) 1-month, (c) 3-month, (d) 6-month, and (e) 12-month time scales. Red boxes highlight the four most prominent hydrologic droughts during the time period.