The Evaporative Demand Drought Index (EDDI) and the California Drought

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and

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Evaporative demand ($E_0$) concept

$ET$ is supply of surface moisture to atmosphere

$E_0$ is atmospheric demand for $ET$

$ET = \text{actual evapotranspiration}$

$E_0 = \text{evaporative demand}$

$ET_0 = \text{reference evapotranspiration}$

$E_0$ from reanalysis of ASCE Standardized Reference $ET$:

$$ET_0 = \frac{0.408\Lambda}{\Lambda + \gamma(1 + C_d U_2)} \left( R_n + L_a - G \right) + \frac{\gamma C_n}{T} U_2 \frac{(e_{sx} - e_a)}{10^3}$$

Radiative forcing

Adveective forcing

Drivers from NLDAS
- temperature at surface (2 m)
- specific humidity at surface
- downward SW at surface
- 10-m wind speed at 10 m

Reanalysis of $E_0$
- daily
- Jan 1, 1979 – present
- ~12-km
- CONUS-wide

Mean annual $E_0$ (from $ET_0$), 1981-2010 (mm).
$E_0/ET$ interactions in drought
Surface energy budget

\[ R_n + L_n - G = Q_n = H + ET \]
$E_0/ET$ interactions in drought

Sustained drought - water limited

Flash drought - energy driven

Take home:

in both drought types, $E_0$ increases.

$E_0$ up due to energy balance favoring $H$ over $ET$.

$ET$ and $E_0$ vary in a parallel direction:

• $ET$ and $E_0$ up due to increases in advection or energy availability,
• moisture may not be limiting.

$ET$ and $E_0$ vary in complementary directions:

• $ET$ down due to moisture limitations,
• $E_0$ up due to energy balance favoring $H$ over $ET$.

(Hobbins et al., 2004)
$E_0$, $ET$ and the water balance
Russian River, CA

$E_0$ / $ET$ complementarity observed in basin.

$r^2$ of basinwide water balance components

**Monthly (deseasonalized)**

<table>
<thead>
<tr>
<th></th>
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<th>$Prcp$</th>
<th>$Runoff$</th>
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**Annual**

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- $r^2$ for $E_0$-$SM$ higher (83%) than any other annual variable pairs.
- Monthly $E_0$ correlates better to $SM$ than does $ET$ (34% vs. 4%).
- At both time scales, $ET_0$ more strongly linked than $ET$ to hydrologic cycle.
EDDI defined
Standardized anomaly (Z-score)

$$ EDDI_t = \frac{ET_0_t - \bar{ET}_0}{\sigma_{ET_0}} $$

- $t$ is period during which anomaly is observed.
- e.g., $t$ for 2-month EDDI on Jan 31, 2015 starts on Dec 1, 2014.

Daily $E_0$ summed across period $t$

30-year mean $E_0$ across period $t$

30-year stddev of $E_0$ across period $t$

0

wetter than normal
EDDI < 0

drier than normal
EDDI > 0

ED0: 0.524, > 70%ile
ED1: 0.841, > 80%ile
ED2: 1.282, > 90%ile
ED3: 1.645, > 95%ile
ED4: 2.054, > 98%ile
EDDI as multi-scalar drought estimator

- Signals of different drying dynamics evident at different time-scales.
- EDDI signal precedes USDM at many time-scales.

USDM (grey) and EDDI (red) across Apalachicola River basin at Chattahoochee, FL.
Drought onset
June 28, 2011

Texas drought still evident

6-month EDDI

USDM = United States Drought Monitor
Drought intensification attribution
February-July 2014

$E_0$ signal of drought intensification:

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

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

anomalies observed in $E_0$ reanalysis

Drought intensification of $E_0$ and its drivers:

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

Changes in 12-week $E_0$ (mm)

$E_0$ signal in Sacramento River basin

CA-mean USDM and EDDI

12-week anomalies ($\Delta$) of $E_0$ and its drivers

- $E_0$ signal of drought intensification:
- first, below-normal $q$ (while $T$ falling).
- then, increasing $T$ and, to a lesser degree, $R_d$.
- $U_2$ plays little role.
Drought at its most intense (so far)
late July, 2014
In-drought wetting attribution
November-December 2014

1-week series of ΔE₀ and each drivers’ contributions (mm)

E₀ declines during Prcp:
• +ve Δq depresses E₀ and EDDI
• despite +ve ΔT
Drought current conditions
end of WY 2015 (Sept 30)
$ET_0$ and the water balance
Russian River basin

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- $E_0$-Runoff $r^2$ (16%, 49%) exceeds $ET$-Runoff $r^2$ (2%, 3%).
- despite $ET$ being a linear component of the hydrologic cycle!
EDDI and hydrologic drought
EDDI and the Standardized Runoff Index (SRI)

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

Sacramento River Basin EDDI and SRI

- $r^2 = 0.72$

6 month EDDI (Nov-Apr)

12-month SRI (Oct-Sep)

McEvoy et al., 2014 (EDDI)
Shukla and Wood, 2008 (SRI)
EDDI and hydrologic drought
12-month SRI vs. 6-month EDDI

• 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.

EDDI contains no Prcp information!
EDDI as a drought leading indicator
Sacramento River basin

Optimizing EDDI window-length is straightforward.

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

6- to 7-month EDDI predicts USDM 2-3 months ahead with $r = 0.6$. 
• easy to calculate, physically rational:
  o responds rapidly to drying and wetting,
  o responds to both sustained and flash droughts,
  o independent of Prcp and R/S data,
  o low-latency ~5 days.

• permits decomposition of evaporative drought drivers.

• permits near real-time drought monitoring / early warning.

• consistent with USDM and other monitors, but not duplicative.

• multi-scalar:
  o short-term EDDI (e.g., < 12-week) good for agricultural areas,
  o long-term EDDI (e.g., 6-month) better for water-limited hydrologic drought monitoring.

• aggregation window may be calibrated for:
  o early warning relative to other monitors,
  o demands specific to regions, hydroclimates, and sectors.

• $E_0$ (and EDDI, and drought) can be forecast.