The Evaporative Demand Drought Index (EDDI): an emerging drought-monitoring & early warning tool

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What is 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
Why Evaporative Demand?

**ET** is supply of surface moisture to atmosphere

In supply-limited or **dry** hydroclimates **ET** drives **$E_0$**

**$E_0$** is atmospheric demand for **ET**

- Temperature
- Wind speed
- Net radiation
- Humidity

In energy-limited or **wet** hydroclimates **ET** is driven by **$E_0$**

**$E_0$** much easier to estimate than **ET**

*Bouchet, IAHS 1963*

(Hobbins et al., GRL 2004)
How do we calculate EDDI?

$E_0$ (reference ET) – Midwest US

- **Summer (JJA)**
- **Rest of year**

$E_0$ (mm/day)

Year (1980-2016)
How do we calculate EDDI?

Summer $E_0$ depths (mm)

$\text{max (2012)}$

$\text{median min}$

2012 has rank of 1 in 37-year $E_0$ climatology
How do we calculate EDDI?

$P(E_{0,t}) = \frac{i_t(E_{0,t}) - 0.33}{n + 0.33} \sim N(0,1)$

- The approach is non-parametric.
- Recommended for comparing drought indices (Hao and AghaKouchak, 2014).
- $t$ is period during which $E_0$ is observed.
  - e.g., $t$ for 3-month EDDI on September 1, 2012 starts June 4, 2012.

EDDI < 0: wetter than normal
EDDI > 0: drier than normal

CDF matching

- 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

EW0: -0.524, < 30%ile
- EW1: -0.841, < 20%ile
- EW2: -1.282, < 10%ile
- EW3: -1.645, < 5%ile
- EW4: -2.054, < 2%ile

- CDF matching
- # years in climo (37: 1980-2016)
What does EDDI offer?
A multi-scalar drought estimator

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

USDM (grey) and EDDI (red) across Apalachicola River basin at Chattahoochee, FL.
What does EDDI offer?
Leading indication of drought

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

“Flash drought” in the US Midwest, 2012
What does EDDI offer?
Monitoring across sectors

**HYDROLOGIC DROUGHT**
- streamflow
- snowfall

**AGRICULTURAL DROUGHT**
- soil moisture
- grazing health
- ET

**FIRE-RISK MONITORING**
- weather
- fuel loads

Farming

Ranching
What does EDDI offer?

Agricultural drought monitoring

(a) USDA Drought Monitor
(b) 3-month EDDI
(c) VIC-modeled SM
(d) 12-week ESI

Agricultural drought across CONUS, July 31, 2002

(Hobbins et al., JHM 2016)
What does EDDI offer?

Current conditions (November 1):

2-week EDDI

9-month EDDI

US Drought Monitor

Live EDDI maps for PNW DEWS available:
ftp://ftp.cdc.noaa.gov/Public/mhobbins/EDDI/PNW_DEWS/
What does EDDI offer?

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

3-month EDDI development, since WY 2016

Drought categories

ED4  ED3  ED2  ED1  ED0
100%  98%  95%  90%  80%

Wetness categories

EW0  EW1  EW2  EW3  EW4
30%  20%  10%  5%  2%  0%

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

Generated by NOAA/ESRL/Physical Sciences Division
What’s next for EDDI?
User outreach, operationalizing, research

Two-pager:

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 indices, such as the US Drought Monitor (USDM) (see Figure 1). A particular strength of EDDI is in capturing the precursory signals of water stress at weekly to monthly timescales, which makes EDDI a useful drought predictive tool. 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-forced information.

What is the physical basis for EDDI?
EDDI exploits the strong physical relationship between evapotranspiration demand, $E_d$, and actual loss of water from the land surface through evapotranspiration, $E_L$, in the "wettest" of the atmosphere’s evapotranspiration index 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 in turn, 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: (1) increased $E_d$ drives increased evapotranspiration until the available soil moisture becomes limiting, potentially leading to "flash" droughts, and (2) as surface water becomes increasingly scarce in sustained droughts, evapotranspiration declines, which leads to higher air temperature and lower humidity, and thereby increases $E_d$.

Next steps:

• 3-year NOAA-RTAP grant to operationalize EDDI at NOAA National Water Center

• Enlarge and engage user-base

• 2-year NOAA-SARP grant for wildfire prediction

• Continued collaboration with DRI
  o research & development
  o add forecast component

• EDDI User’s Manual

(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)  

Daily, weekly - FRET

Seasonally (with greater skill than $Prcp$)

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

FRET = Forecast Reference Evapotranspiration

$Prcp$ = precipitation
Predicting wildfire risk

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

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

![Graph showing the relationship between 12-month $E_0$ in June (mm) and 1000-hour fuel moisture, May-Oct (%), with $r^2 = 0.74$.](image-url)
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
\(E_0\) is forecastable (McEvoy et al., GRL 2016)

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