The Evaporative Demand Drought Index (EDDI): a new drought-monitoring and early warning tool

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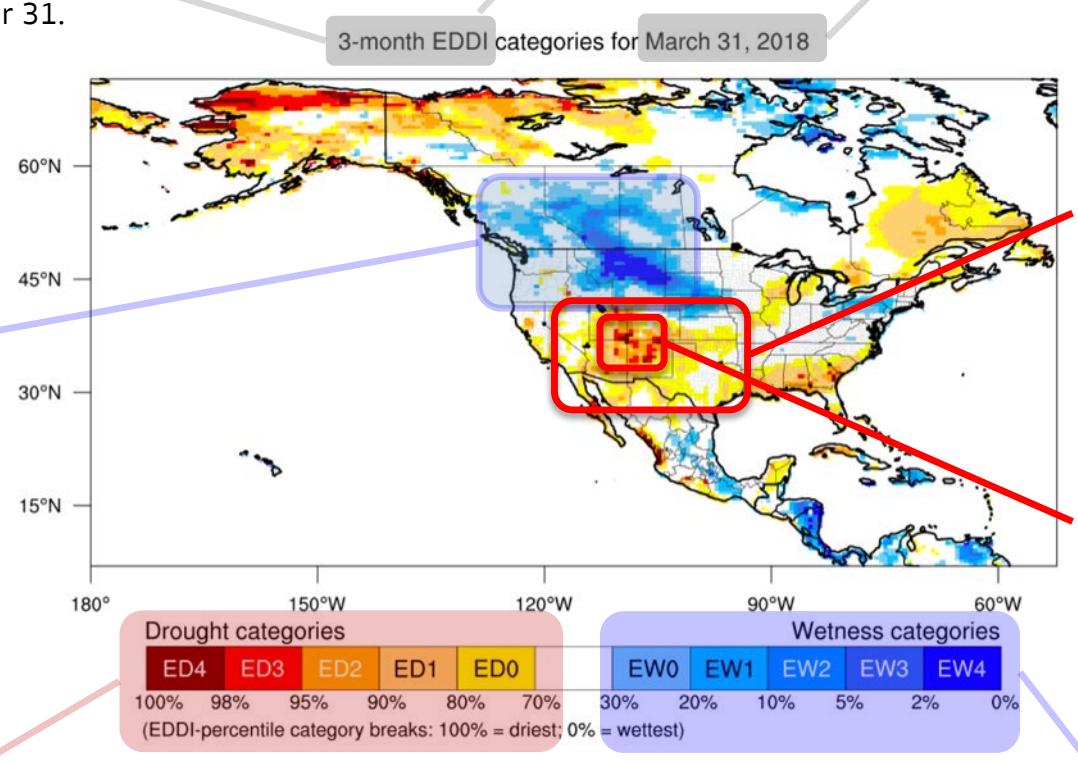
What is EDDI?

Multiple timescales:
1-12 months at each month-end,
1 dekad at each dekad-end.

Latency of ~ 10 days, so this map was released on April 10. 5-day latency of CONUS product.

This 3-month EDDI map is based on E_0 from Jan 1 - Mar 31.



E_0 is unusually low in the US Northern Great Plains, the Canadian Prairies, and the Northern Rockies, indicating wetter-than-normal surface conditions and atmosphere.

E_0 is unusually high across the southwestern US and northern Mexico, indicating drier-than-normal surface conditions and atmosphere.

ED4 in Four Corners region of US means that such dry conditions are expected only 2% of Jan 1 – Mar 31 periods.

Names, colors, and %ile breaks for EDDI drought categories reflect those of the US Drought Monitor.

Wetness and dryness categories mirror each other, so ED2 and EW2 have identical expected frequency.

EDDI: the anomaly in **evaporative demand** at a specified timescale, for a given location, expressed as a percentile.

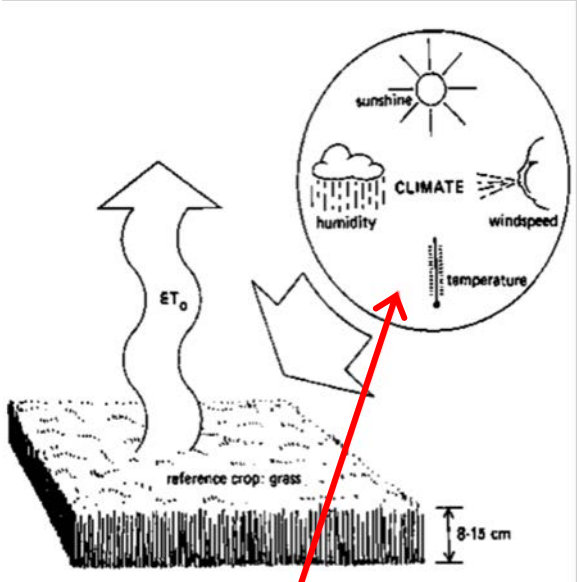
Background

What is evaporative demand (E_0)?

ET = actual evapotranspiration
E_0 = evaporative demand

- ET that would occur given an unlimited moisture supply:
  - **Reference *ET*** (ET_0)
  - Potential ET (PET)
  - Pan evaporation
- E_0 easier to quantify than ET
- Often estimated from temperature…
- …but fully **physically based** methods are much better,
  e.g., *Penman-Monteith*

"Thirst of the atmosphere"

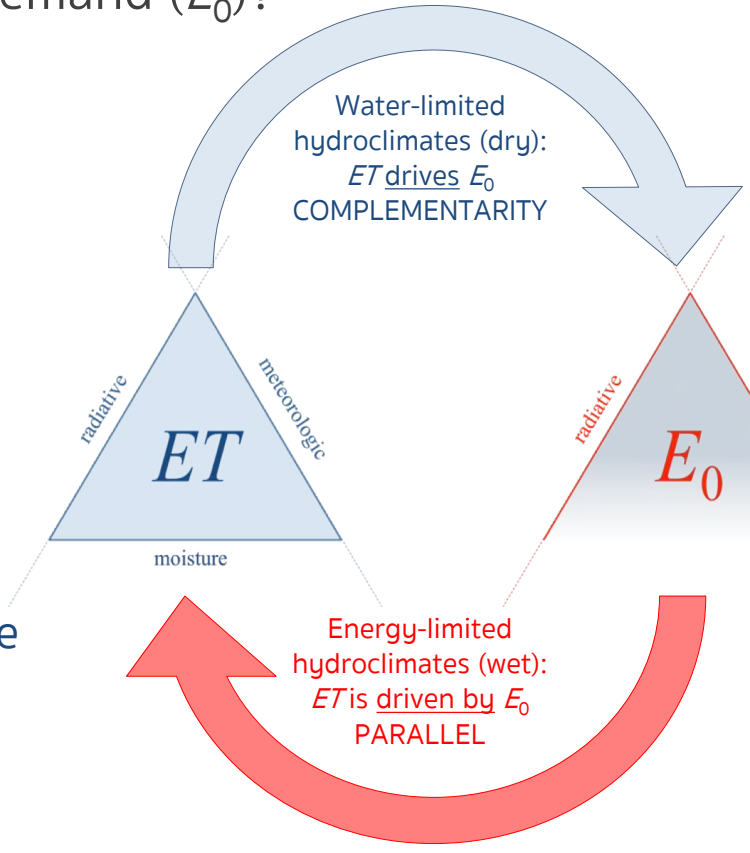


fao.org

physically based E_0 contains valuable information on drought dynamics

Background

What is evaporative demand (E_0)?



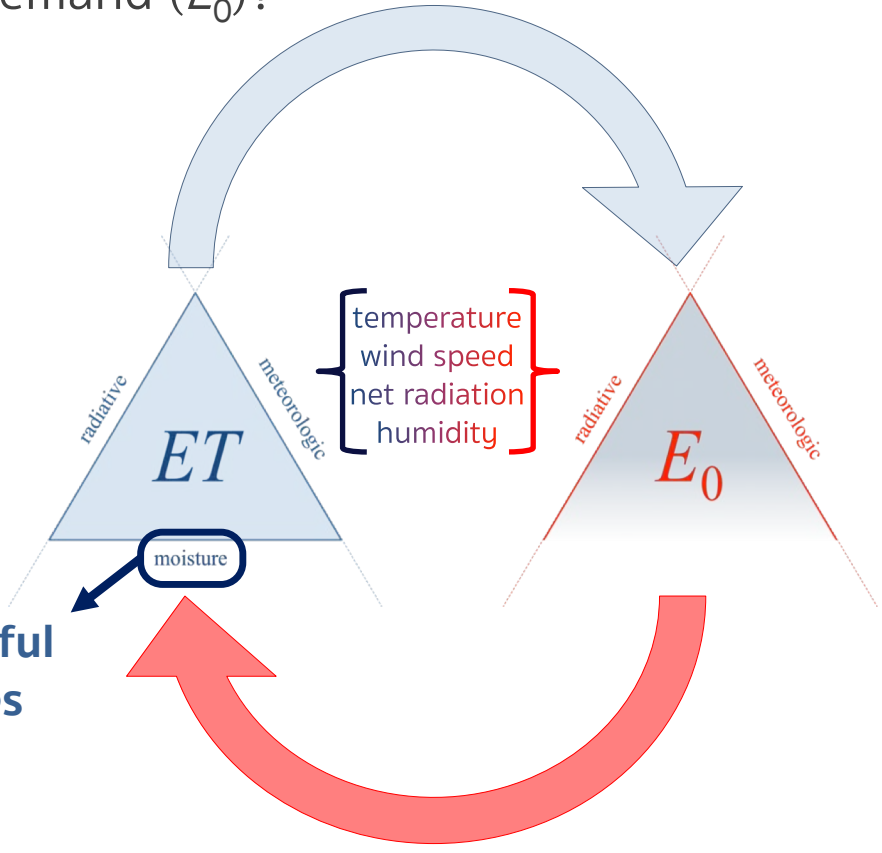
ET is supply of surface moisture to atmosphere

E_0 is atmospheric demand for *ET*

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

Background

What is evaporative demand (E_0)?



unknown on useful space/time scales

E_0 is much easier to estimate than ET

Background

E_0, drought, and supply / demand

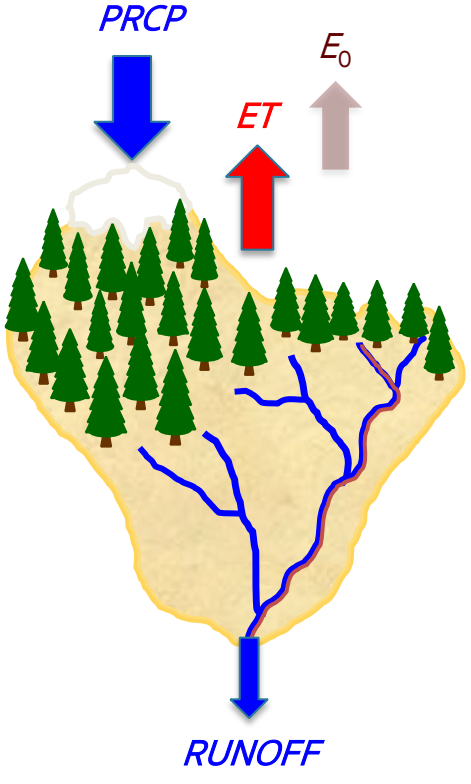
Drought = imbalance of supply to, and demand for, surface moisture

Water balance on a land surface:

~ f(*Prcp*, *ET*)

where *ET* is driven by:

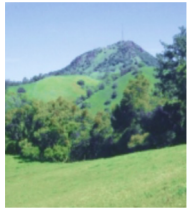
- evaporative demand (E_0),
- surface moisture status.

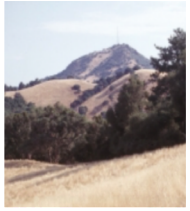


Background

E_0 and drought

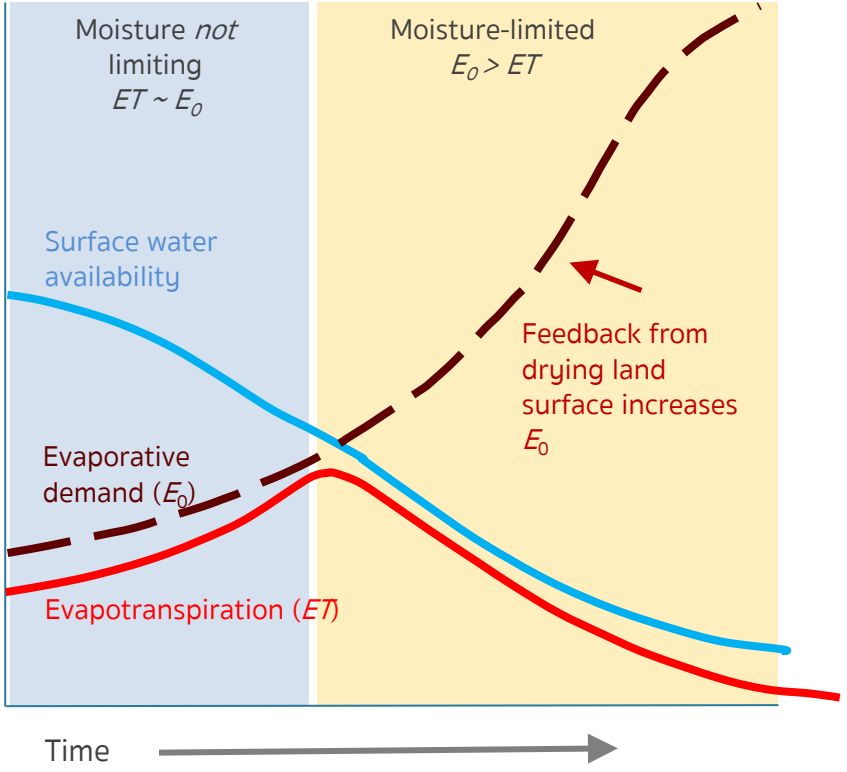
Relationship between E_0 and *ET* changes as land surface dries out





- When surface moisture is sufficient, rising E_0 leads to rising *ET*
- When moisture is limited, *ET* declines, while E_0 rises even more steeply

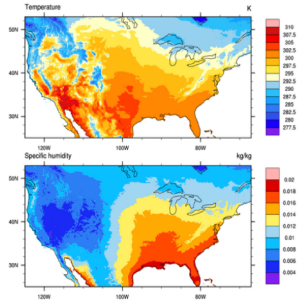
E_0 rises in all forms of, and all points in, drought.



Background

How is EDDI calculated?

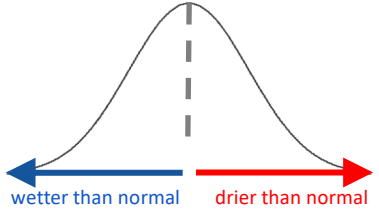
Meteorological, radiative inputs
temperature, humidity, wind speed, solar radiation
NLDAS-2 or MERRA-2, 0.125° gridded, daily



Reference evapotranspiration calculation
Penman-Monteith FAO56

$$E_0 \approx ET_0 = \underbrace{\frac{0.408\Delta}{\Delta+\gamma(1+C_d U_2)}(R_n - G)\frac{86400}{10^6}}_{\text{Radiative forcing (sunshine, } T\text{)}} + \underbrace{\frac{\gamma\frac{C_n}{T}}{\Delta+\gamma(1+C_d U_2)}U_2\frac{(e_{sat}-e_a)}{10^3}}_{\text{Advective forcing (wind, humidity, } T\text{)}}$$

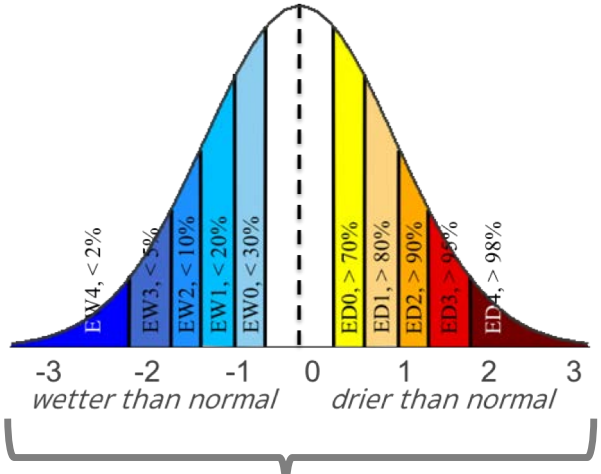
Rank-based non-parametric standardization
based on historic climatology of ET_0



EDDI

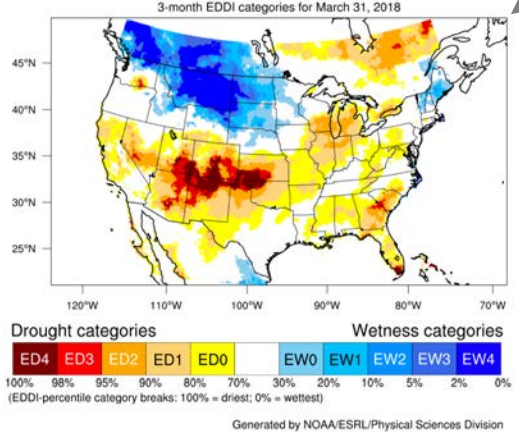
Background

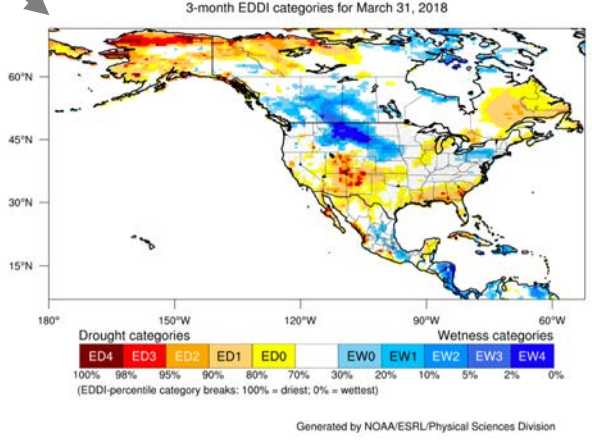
How is EDDI calculated?



- EDDI is simple to calculate
- CONUS
- North America

NLDAS-2 for CONUS



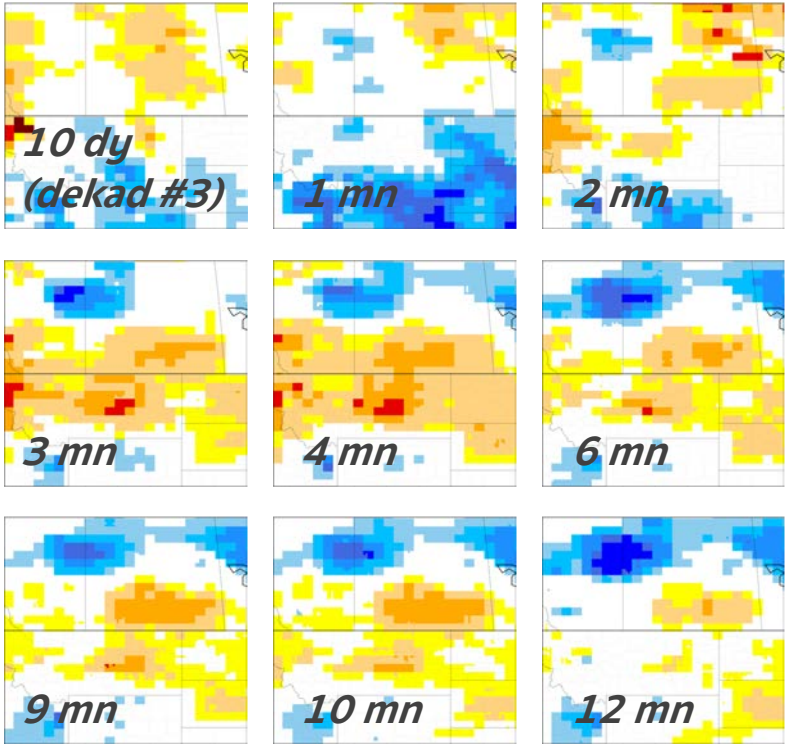


MERRA-2 for North America

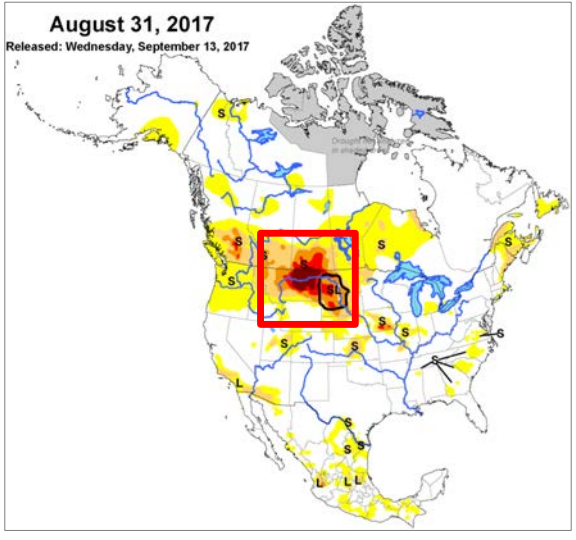
Background

Multi-scalar drought index

EDDI, August 31, 2017



NADM, August 31, 2017



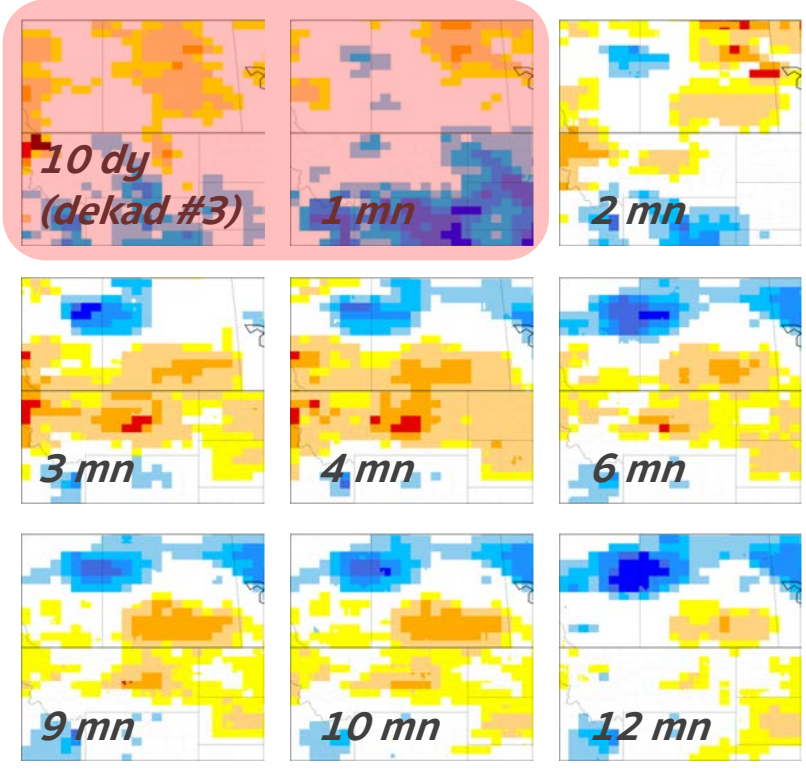
EDDI reflects drying different dynamics, 13 time-scales:

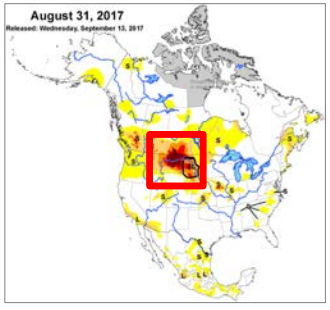
- 1 dekad (3/mon)
- 1 … 12 months

Background

Multi-scalar drought index

EDDI, August 31, 2017



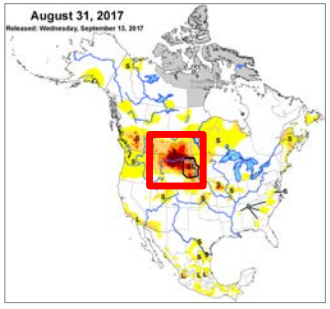


Flash drought potential

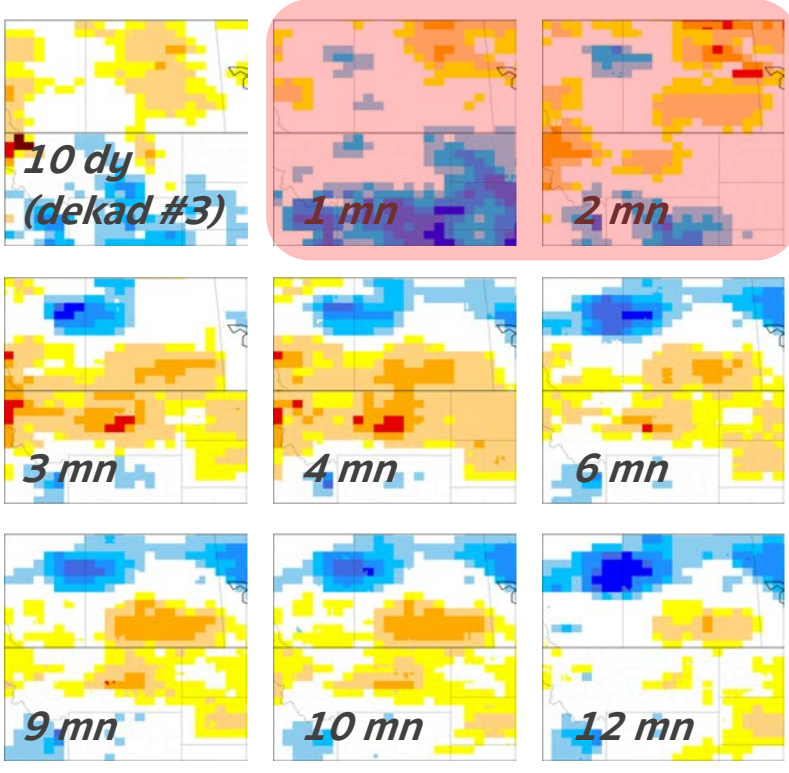
(1-dk to 1-month EDDI)

Background

Multi-scalar drought index



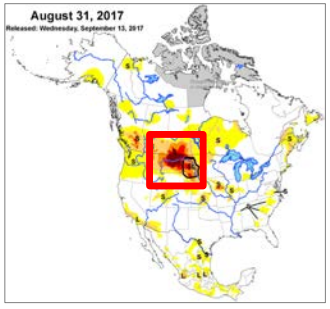
EDDI, August 31, 2017



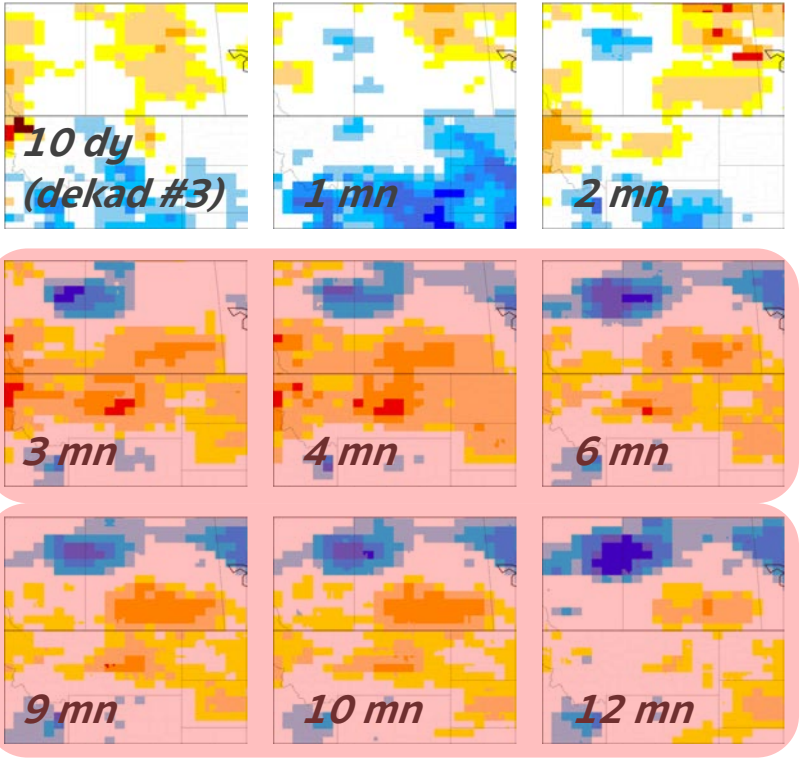
Emerging conditions
(that *could* lead to drought)
(1- to 2-month EDDI)

Background

Multi-scalar drought index



EDDI, August 31, 2017



Persistent drought conditions

(> 3-month EDDI)

Two EDDI products
CONUS and North America

λ = 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
γ = psychrometric constant
C_n, C_d = constants for crop type and time-step

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

$$E_0 \approx ET_0 = \underbrace{\frac{0.408\Delta}{\Delta+\gamma\left(1+C_dU_2\right)}\left(R_n-G\right)\frac{86400}{10^6}}_{\text{Radiative forcing (sunshine, } T\text{)}} + \underbrace{\frac{\gamma\frac{C_n}{T}}{\Delta+\gamma\left(1+C_dU_2\right)}U_2\frac{\left(e_{sat}-e_a\right)}{10^3}}_{\text{Advective forcing (wind, humidity, } T\text{)}}$$

"Reference" crop specified:

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

CONUS – **NLDAS-2:**

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

- daily, Jan 1, 1979 – present
- 0.125°, CONUS-wide

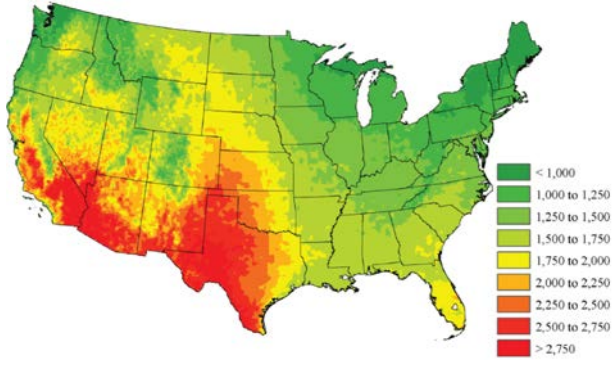
North America – **MERRA-2**:

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

- daily, Jan 1, 1980 – present
- 0.125°, North America (global)

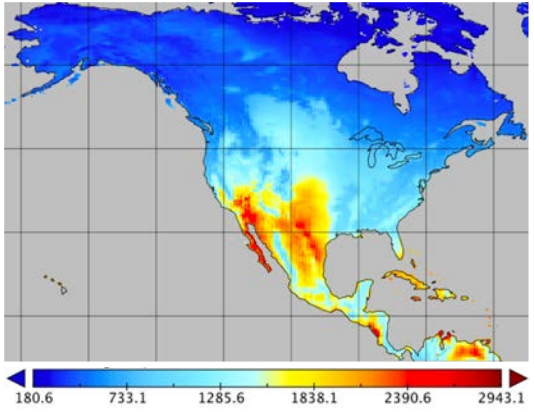
Two EDDI products
CONUS and North America

CONUS – **NLDAS-2**



Mean annual E_0 (mm), 1981-2010

North America – **MERRA-2**



Mean annual E_0 (mm), 1981-2010

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

- daily, Jan 1, 1979 – present
- 0.125°, CONUS-wide

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

- daily, Jan 1, 1980 – present
- 0.125°, North America (global)

Cross-sectoral monitoring

AGRICULTURAL DROUGHT
- soil moisture
- grazing health
- ET

HYDROLOGIC DROUGHT
- streamflow
- snowfall

FIRE-RISK MONITORING
- weather
- fuel loads

ECOLOGICAL DROUGHT

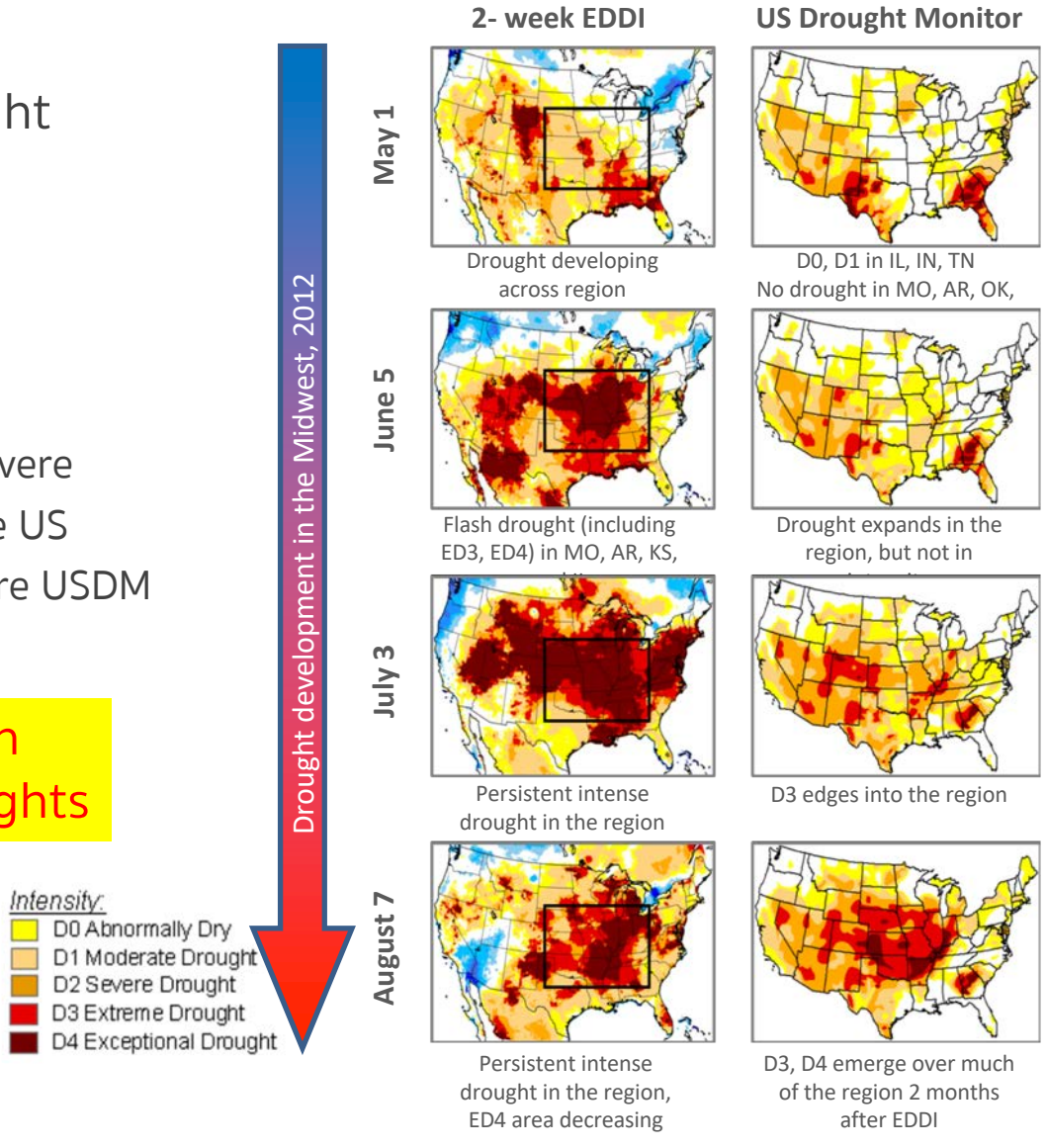
Applications

Early warning – flash drought

May – July, 2012:

2-week EDDI captured severe drought conditions in the US Midwest ~2 months before USDM

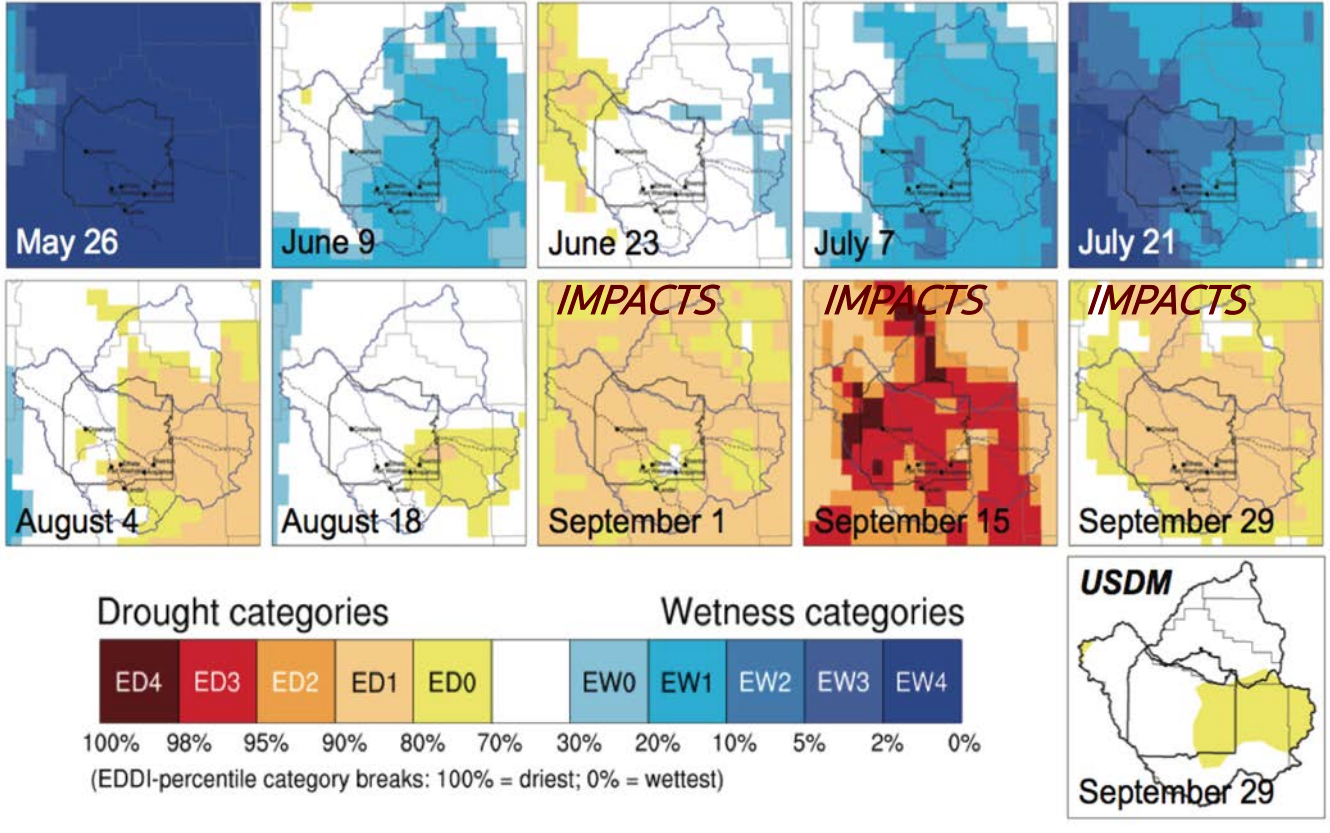
EDDI leads USDM in identifying flash droughts



Applications

Early warning – flash drought

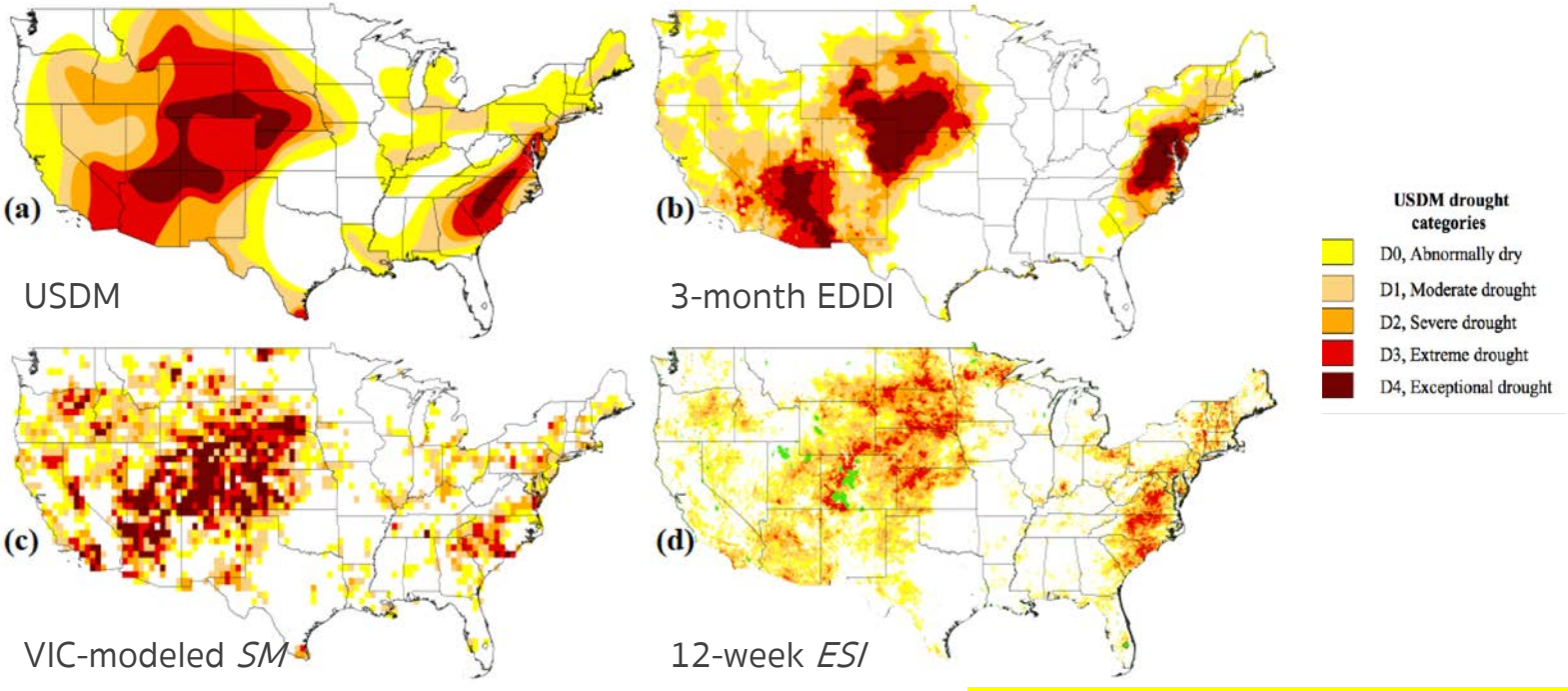
2-week EDDI, 2015 growing season in Wind River IR, WY



Applications

Agricultural drought – July 31, 2002

VIC = Variable Infiltration Capacity model
ESI = Evaporative Stress Index



EDDI shows similar spatial patterns to USDM & other ag-related monitors

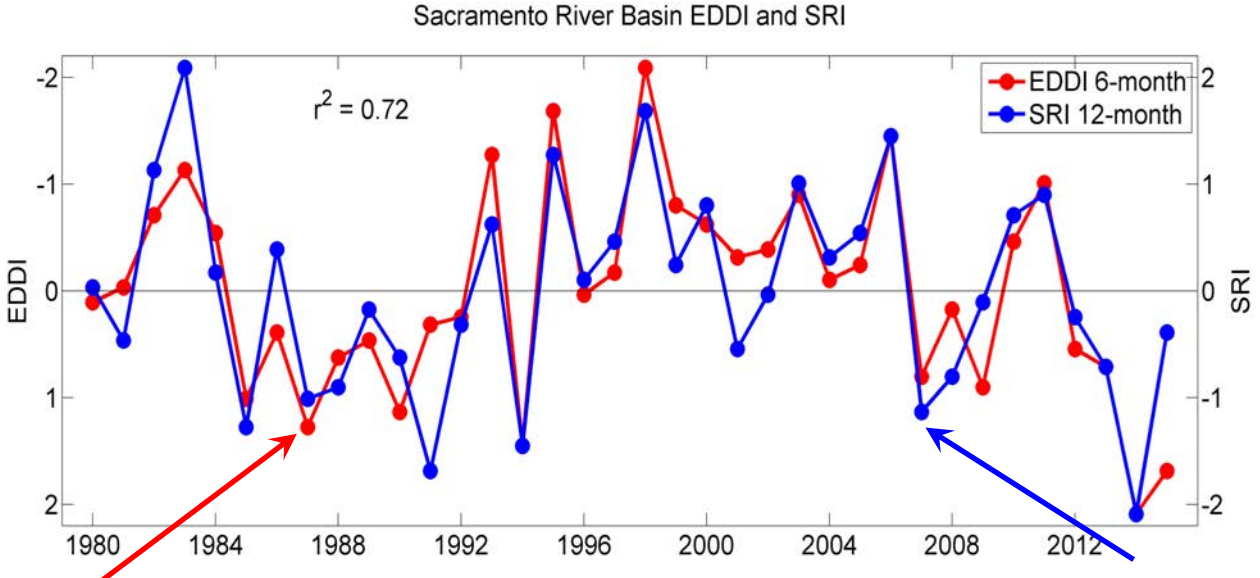
Applications

Early warning – hydrologic drought

SRI = Standardized Runoff Index
(EDDI – *Hobbins et al.*, JHM 2016
McEvoy et al., JHM 2016)
(SRI - *Shukla and Wood*, GRL 2008)

Desert Research Institute

Can EDDI help predict late-summer (low-flow) streamflow?
E.g., 6-month EDDI in Sacramento River Basin, CA



EDDI contains no
Prcp information!

Applications

Attribution – diagnosing drought's demand side

How much are changes in E_0 driven by changing:

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

$$E_0 = f(T, R_d, q, U_2), \text{ so}$$

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

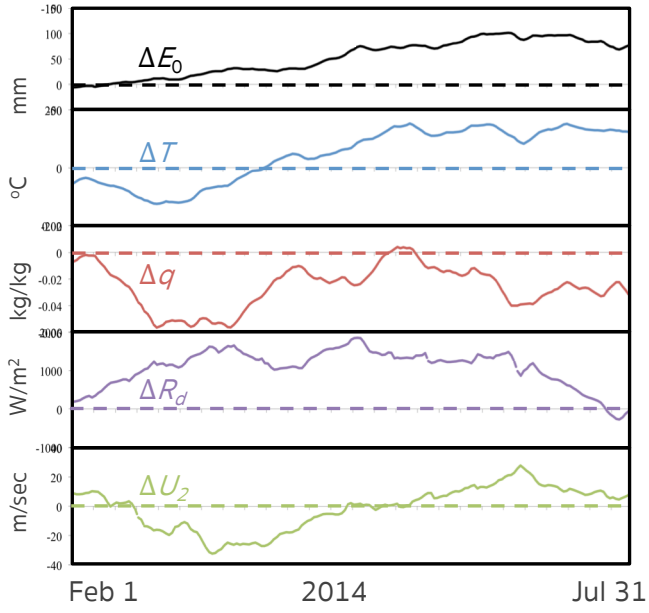
derived analytically

anomalies observed in reanalyses

$$\frac{\partial \mathrm{ET}_r}{\partial T} = \frac{\left\{ \begin{array}{l} 0.408\overline{\Delta}\left[\overline{R}_n \dfrac{4169.871 - 2\overline{T}}{(\overline{T} - 35.85)^2} - 4\sigma f_{cd}\left(0.34 - 0.14\sqrt{\overline{e}_a}\right)\overline{T}^3\right] \\ + \gamma C_n \dfrac{\overline{U}}{\overline{T}}\left[\overline{e}_{sat}\dfrac{4098.171}{(\overline{T} - 35.85)^2} - \dfrac{1}{\overline{T}}(\overline{e}_{sat} - \overline{e}_a)\right] \end{array} \right\}}{\overline{\Delta} + \gamma(1 + C_d\overline{U})} + \frac{\dfrac{4169.871 - 2\overline{T}}{(\overline{T} - 35.85)^2}\overline{\Delta}\left[0.408\overline{\Delta}\,\overline{R}_n + \gamma\dfrac{C_n}{\overline{T}}\overline{U}(\overline{e}_{sat} - \overline{e}_a)\right]}{\left[\overline{\Delta} + \gamma(1 + C_d\overline{U})\right]^2}$$

(*Hobbins*, TransASABE 2016)

E_0 anomalies in Sacramento River basin, CA, 2014



(*Hobbins et al.*, JHM 2016)

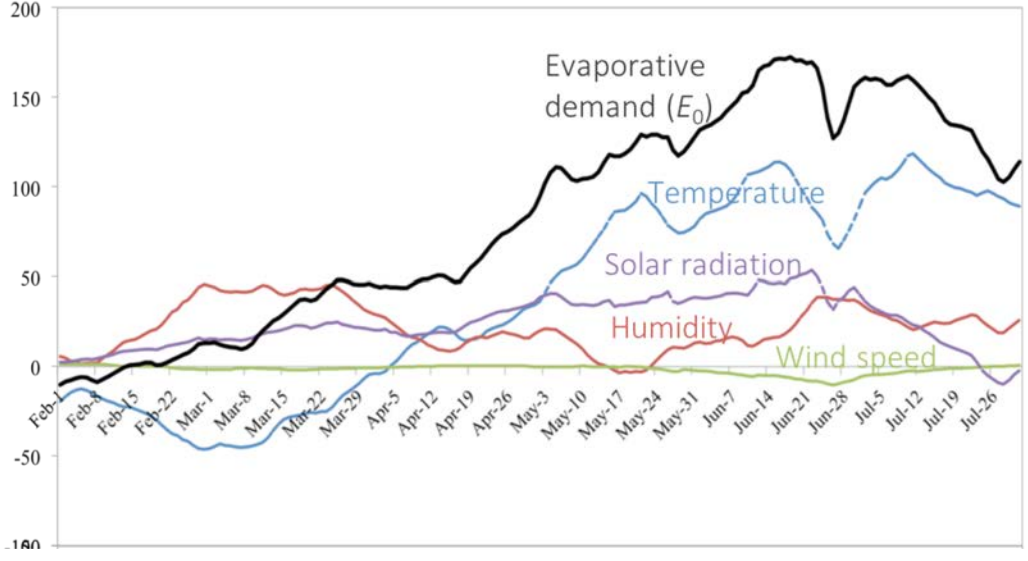
Applications

Attribution – diagnosing drought's demand side

This drought intensification (rising E_0) was forced by:

- First, below-normal *Humidity*
- Then, increasing *Temperature* and, to a lesser degree, *Radiation*
- *Wind speed* played little role

Diagnosing a drought intensification in the Sacramento River basin, CA, Feb 1 – Jul 31, 2014

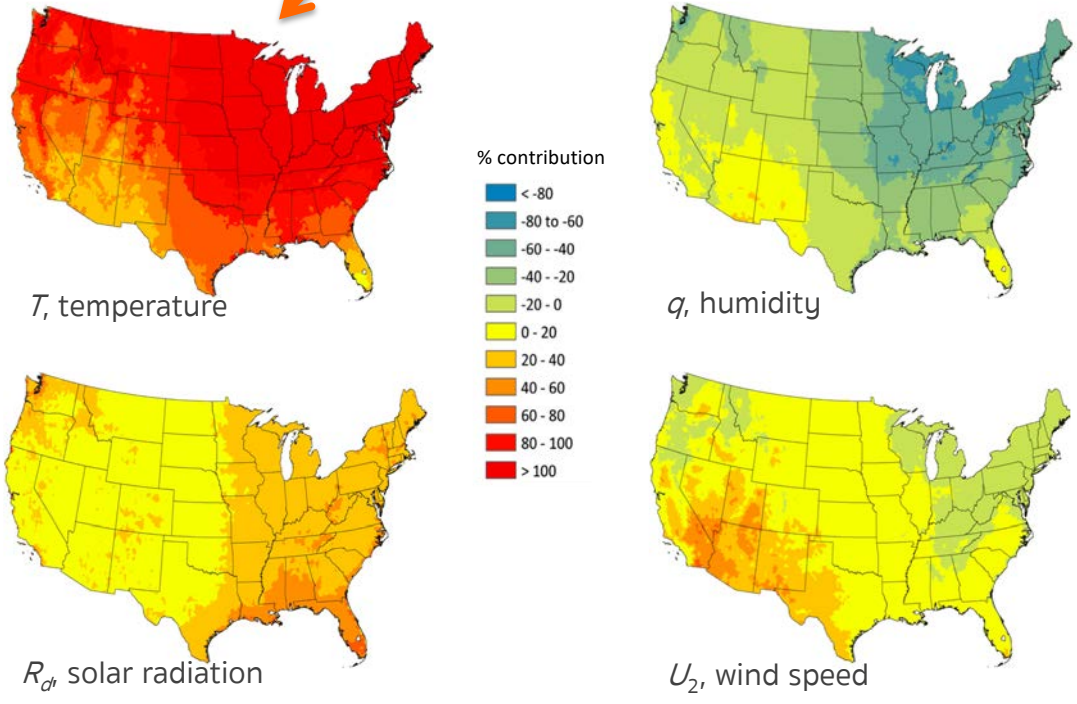


(*Hobbins et al.*, JHM 2016)

Applications

Attribution – diagnosing drought's demand side

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

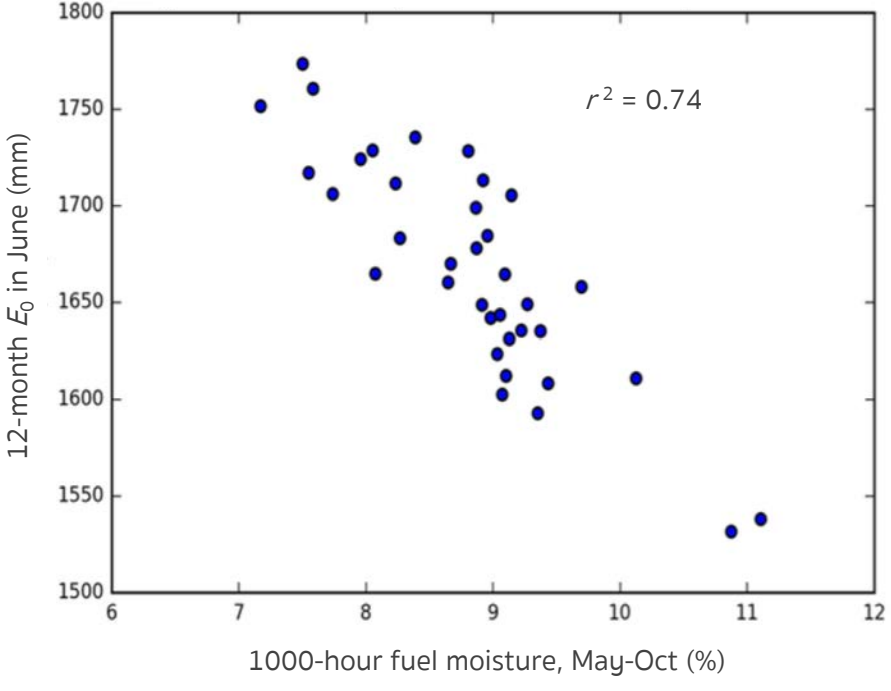


(conceptual maps only)

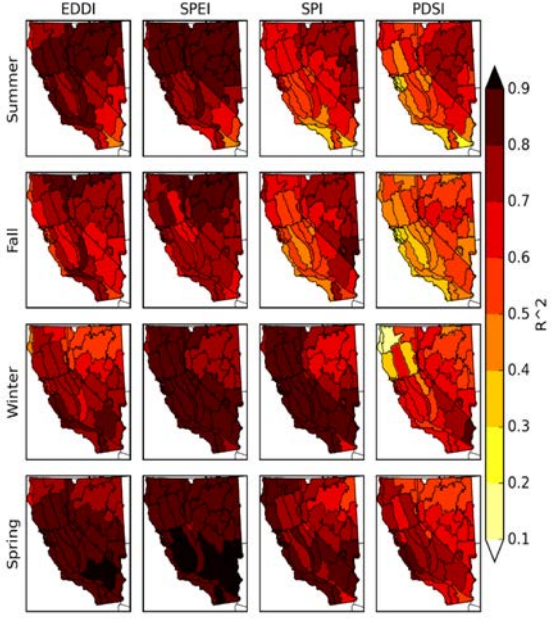
Applications

Wildfire-risk monitoring – fuel loads

E_0 - fuel moisture relationship across S. California GACC



Relating drought indices to fire danger indices



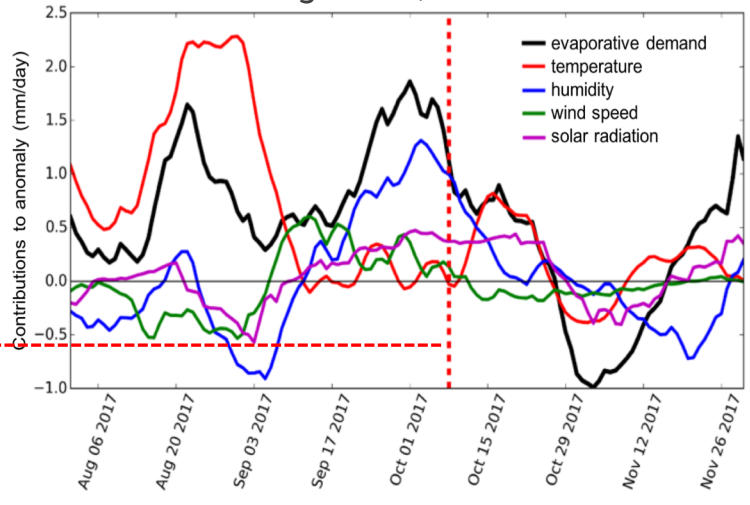
Correlations to 1000-hour fuel moisture across CA and NV

Applications

Wildfire-risk monitoring – fire weather

Can EDDI provide early warning of wildfire risk?

Diagnosis of ΔE_0 for Sonoma County, CA, Aug – Nov, 2017



Predicting fire-weather conditions:

- Tubbs Fire started October 8, 2017: 22 people killed, $1.2 bn losses.
- Decomposing EDDI into its drivers indicates a shift to a humidity-driven spike in E_0 about 4 weeks before the fire.

Challenges | Solutions

- Data latency:
  - 5 days for CONUS - NLDAS
  - 10 days for North America - MERRA
- Spatial resolution:
  - 0.125° lat/long

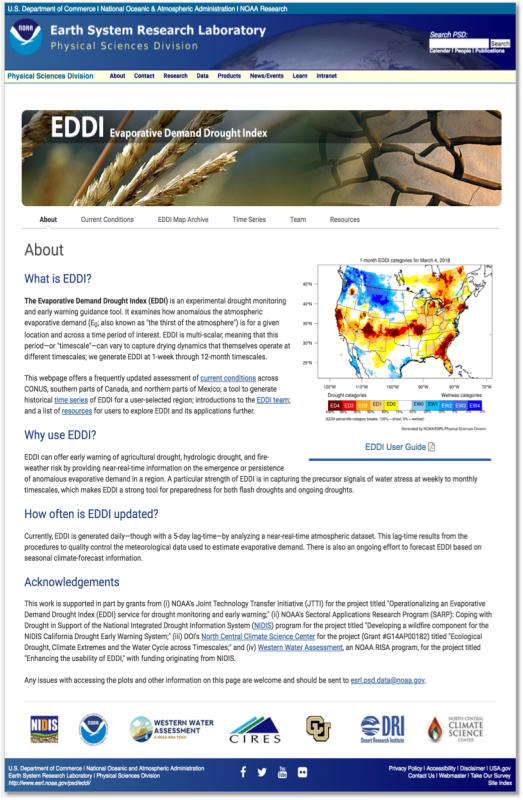
3.5 days when NLDAS-2.5 released…
…later this year

1 day with further NLDAS releases

continental coverage by NLDAS …
…eventually

CONUS-wide at 1 km by National Water Model…
…eventually

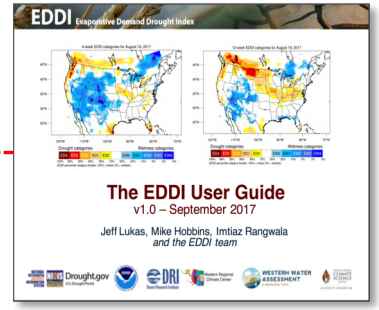
Access to EDDI products

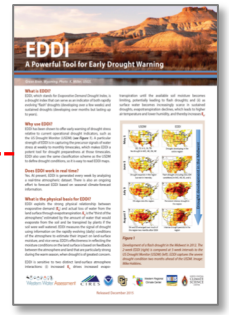


https://www.esrl.noaa.gov/psd/eddi/
or search for “EDDI NOAA”

EDDI website

- Primarily CONUS-oriented:
  - current CONUS maps / synopsis
  - archive of CONUS maps
  - historical EDDI tool
- Team biographies
- Resources
  - user guide
  - 2-pager
  - papers
  - related links





EDDI and ET_0 data access

- EDDI – global / North America
  - complete (> 38-yr) history available via ftp
  - ftp://ftp.cdc.noaa.gov/Projects/EDDI/global_archive/data/ (ascii files)
  - maps delivery is customizable
- ET_0 availability
  - coarse (0.5° lat x 0.6° long) and fine resolution (downscaled to ~0.14°)
  - ftp://ftp.cdc.noaa.gov/Projects/RefET/global/Gen-0/ (NetCDFs)

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