

NOAA's reference *ET* product and Evaporative Demand Drought Index (EDDI)

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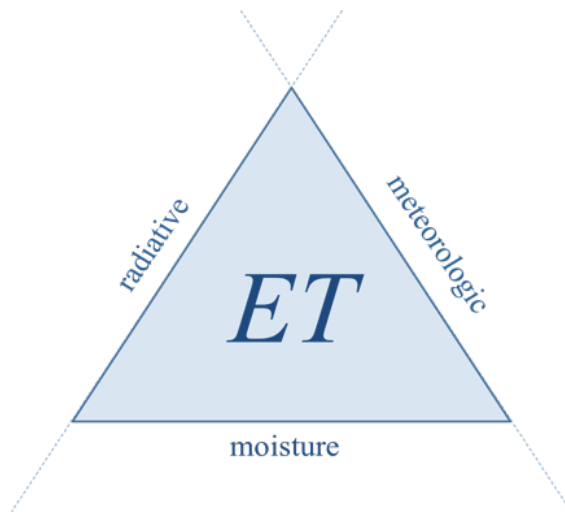


ET / evaporative demand interactions

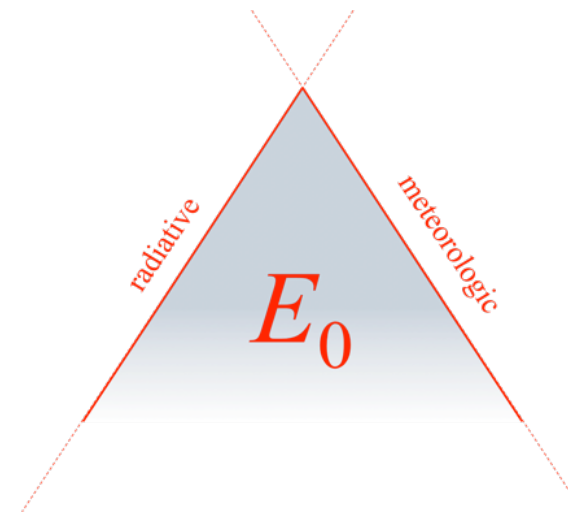
Supply and demand

E_0 = evaporative demand
 ET = actual evapotranspiration
 PET = potential evaporation
 ET_0 = reference evapotranspiration

ET is supply of surface
moisture to atmosphere



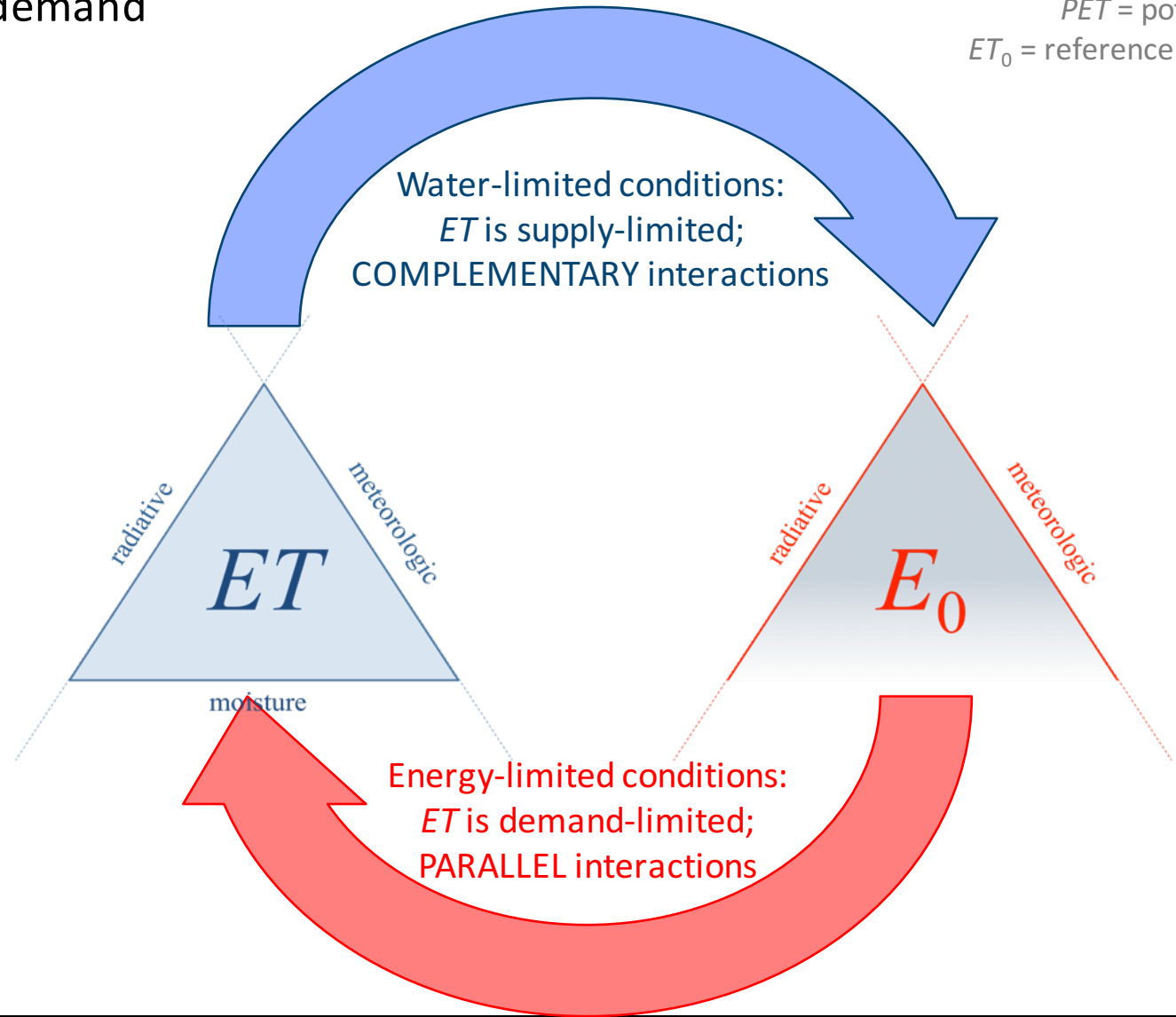
E_0 is atmospheric
demand for ET



ET / evaporative demand interactions

Supply and demand

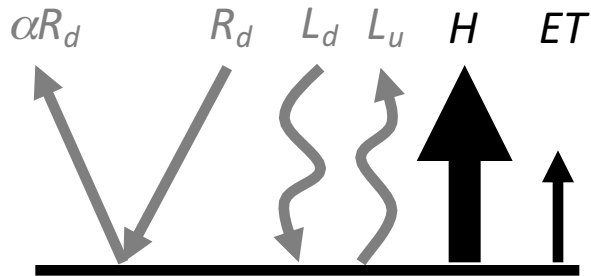
E_0 = evaporative demand
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E_0 / ET interactions in drought

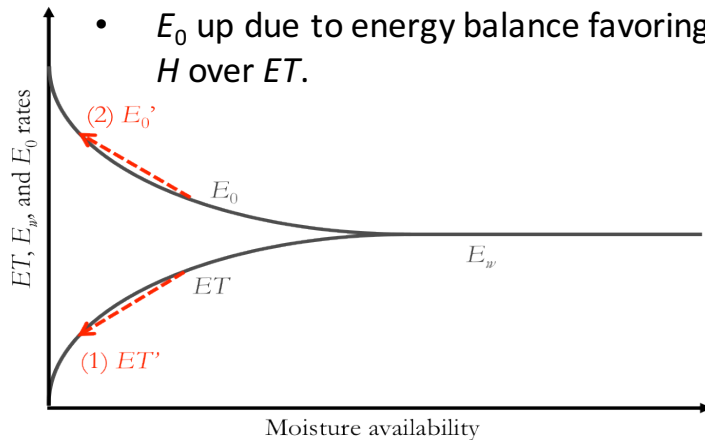
$$(R_d - R_u) + (L_d - L_u) - G = H + ET$$

Sustained drought - water limited



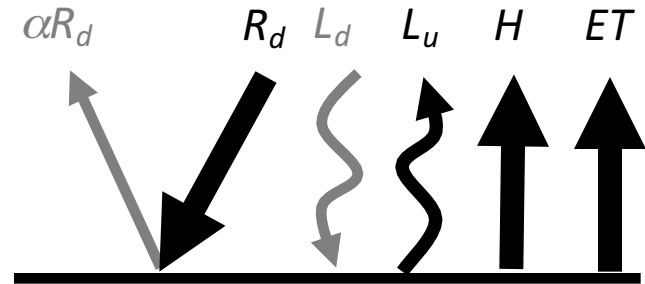
ET and E_0 vary in **complementary directions**:

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



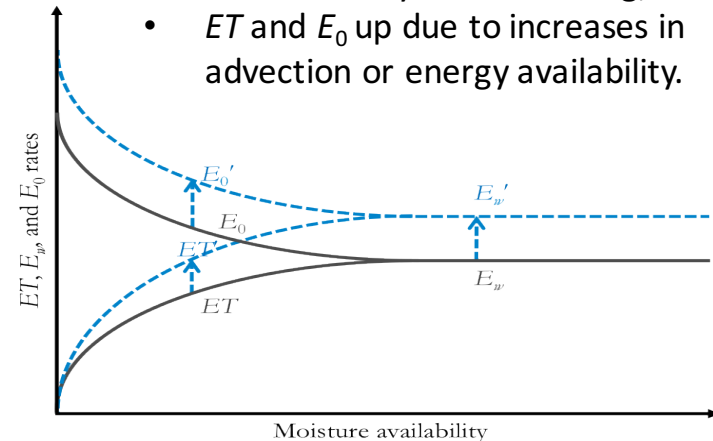
(Hobbins et al., 2004)

Flash drought - energy driven



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

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

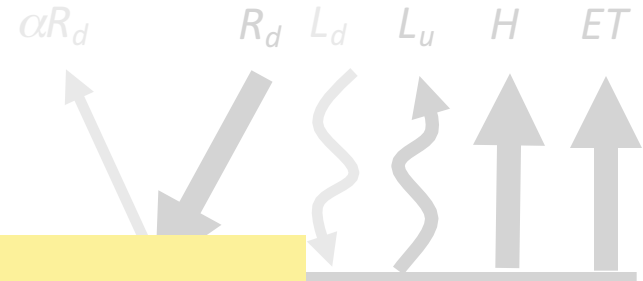


E_0 / ET interactions in drought

$$(R_d - R_u) + (L_d - L_u) - G = H + ET$$

Sustained drought - water limited

Flash drought - energy driven

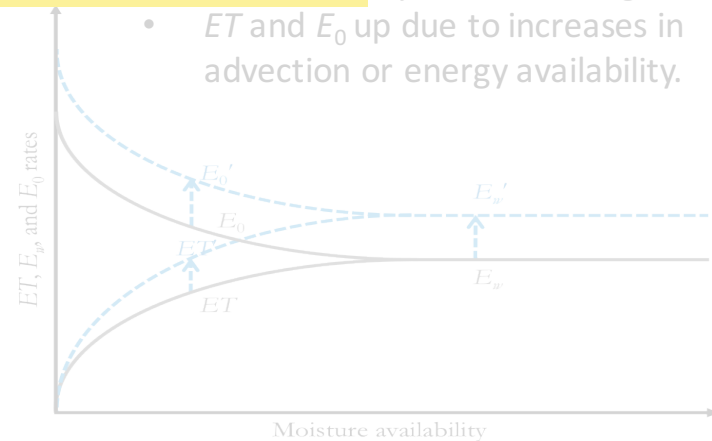
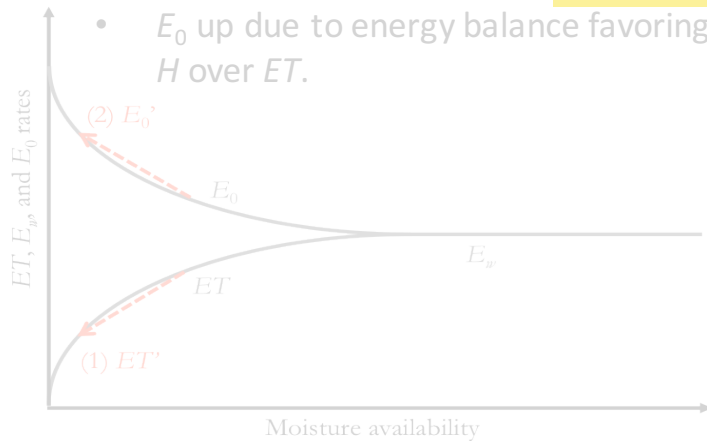


Take home:
 in both drought types, E_0 increases.

ET and E_0 vary in complementary directions in a parallel direction:

- ET down due to moisture limitation
- E_0 up due to energy balance favoring H over ET .

- ET and E_0 up due to increases in advection or energy availability.



(Hobbins et al., 2004)

Evaporative demand (E_0) from reference ET (ET_0)

ASCE Standardized Reference ET

$$ET_0 = \underbrace{\frac{0.408\Delta}{\Delta + \gamma(1 + C_d U_2)} (R_n + L_n - G) \frac{86400}{10^6}}_{\text{Radiative forcing}} + \underbrace{\frac{\gamma \frac{C_n}{T}}{\Delta + \gamma(1 + C_d U_2)} U_2 \frac{(e_{sat} - e_a)}{10^3}}_{\text{Advection forcing}}$$

Radiative forcing

Advection forcing

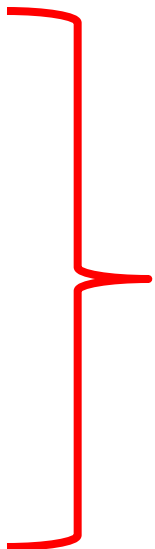
(Allen et al., 1998)

Drivers from NLDAS

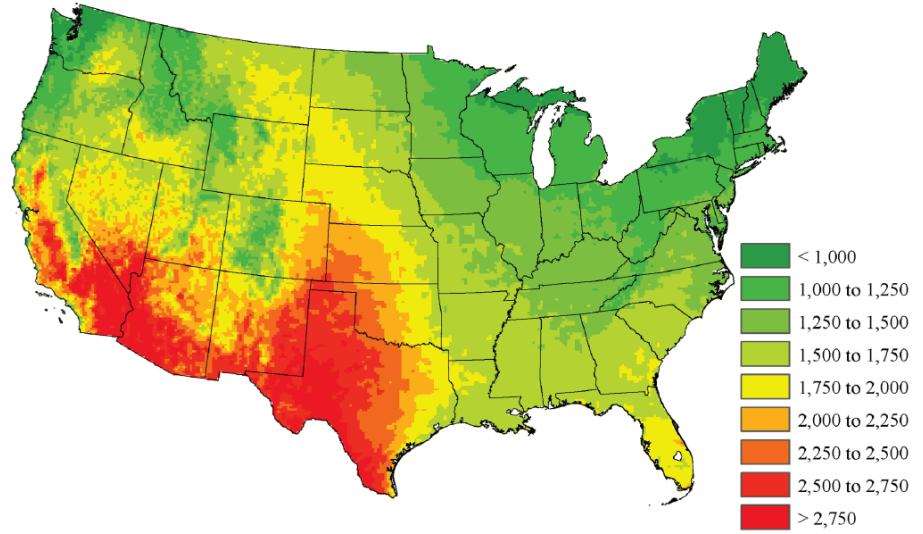
- temperature at surface (2 m)
- specific humidity at surface
- downward SW at surface
- 10-m wind speed at 10 m

Reanalysis of E_0

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



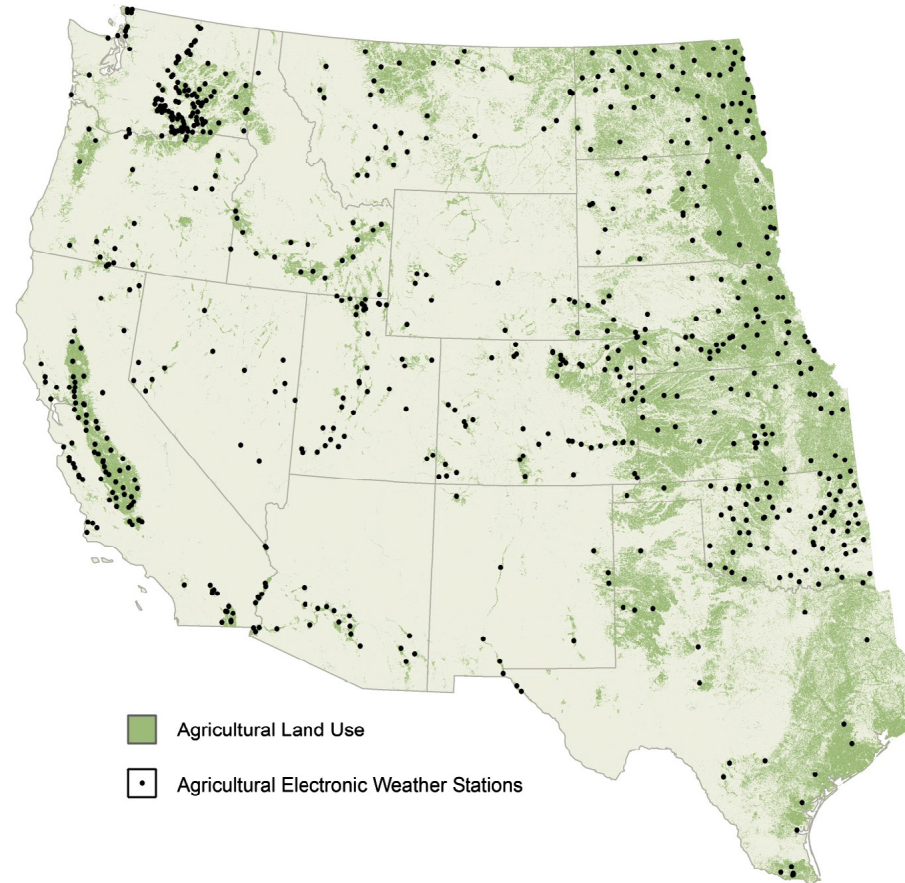
Mean annual ET_0 , 1981-2010 (mm).



Future work on NOAA's ET_0

Multi-generational ET_0 product

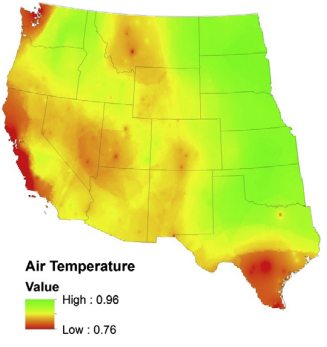
- Generation 0 - **current status**:
 - underpins EDDI.
- Generation 1:
 - assimilating ET_0 ag/met observations,
 - FRET bias correction.
- Generation 2 - improved drivers (NLDAS-2.5 or NLDAS-3):
 - increased spatial resolution,
 - decreased latency.
- Generation 3 - ambient conditioned drivers.



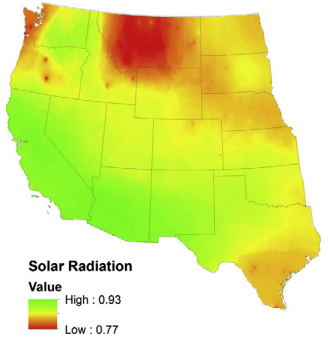
NLDAS ET₀ forcings validation

R-squared

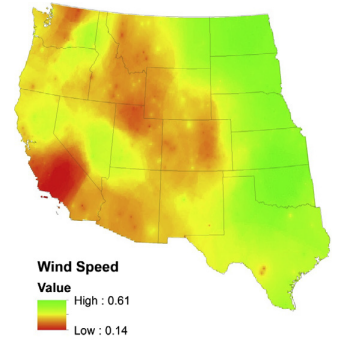
2-m air temperature



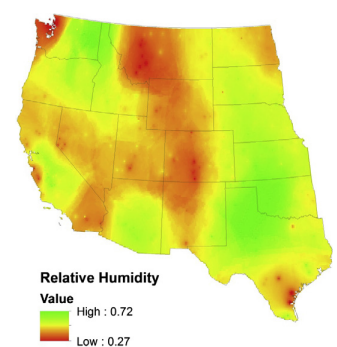
downwelling SW



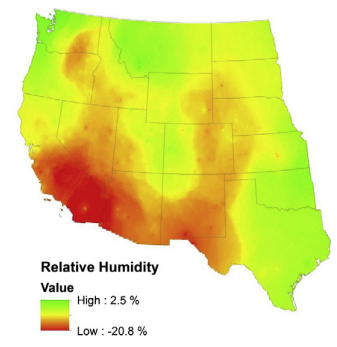
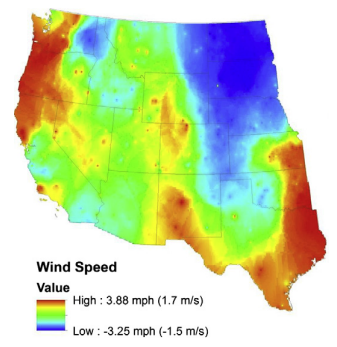
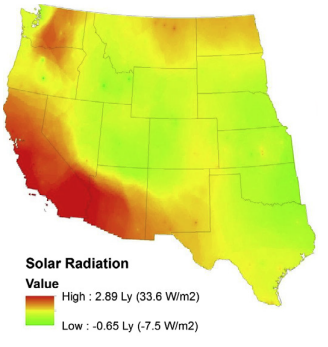
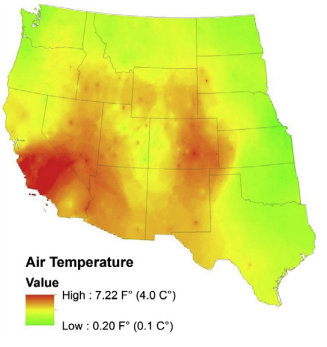
2-m wind speed (from 10-m U, V vectors)



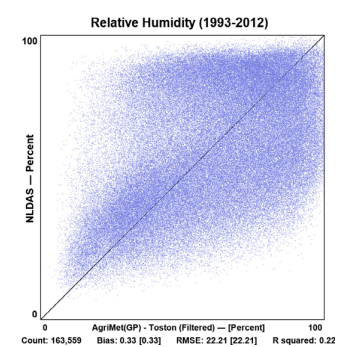
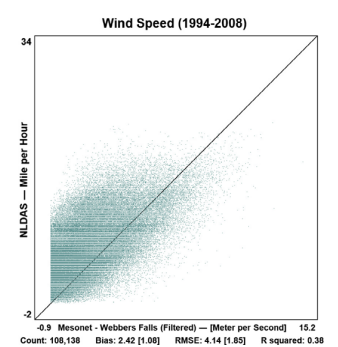
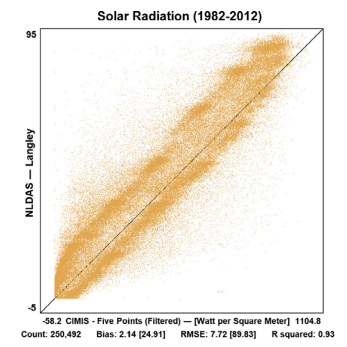
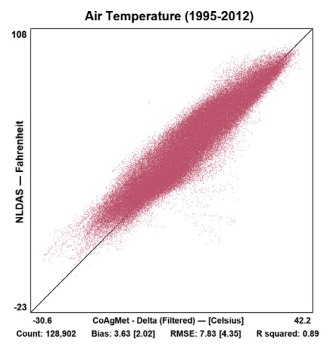
relative humidity (not specific humidity)



Bias (NLDAS - obs)



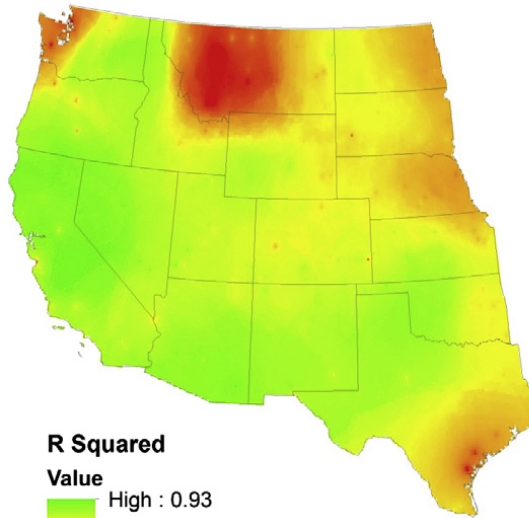
Example station



NLDAS-forced ET_0 validation

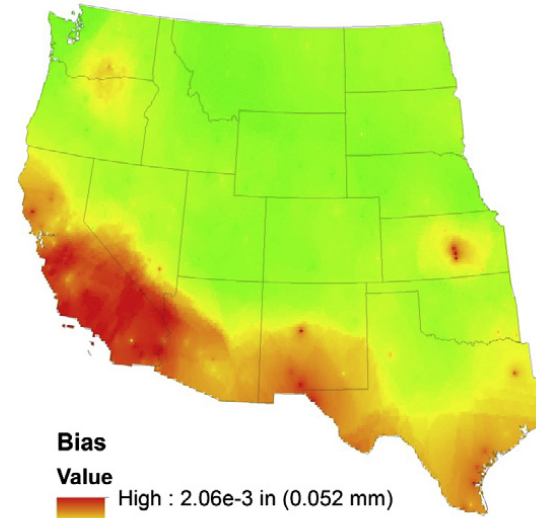
Generation-0 ET_0

R-squared



R Squared
Value
High : 0.93
Low : 0.81

Bias

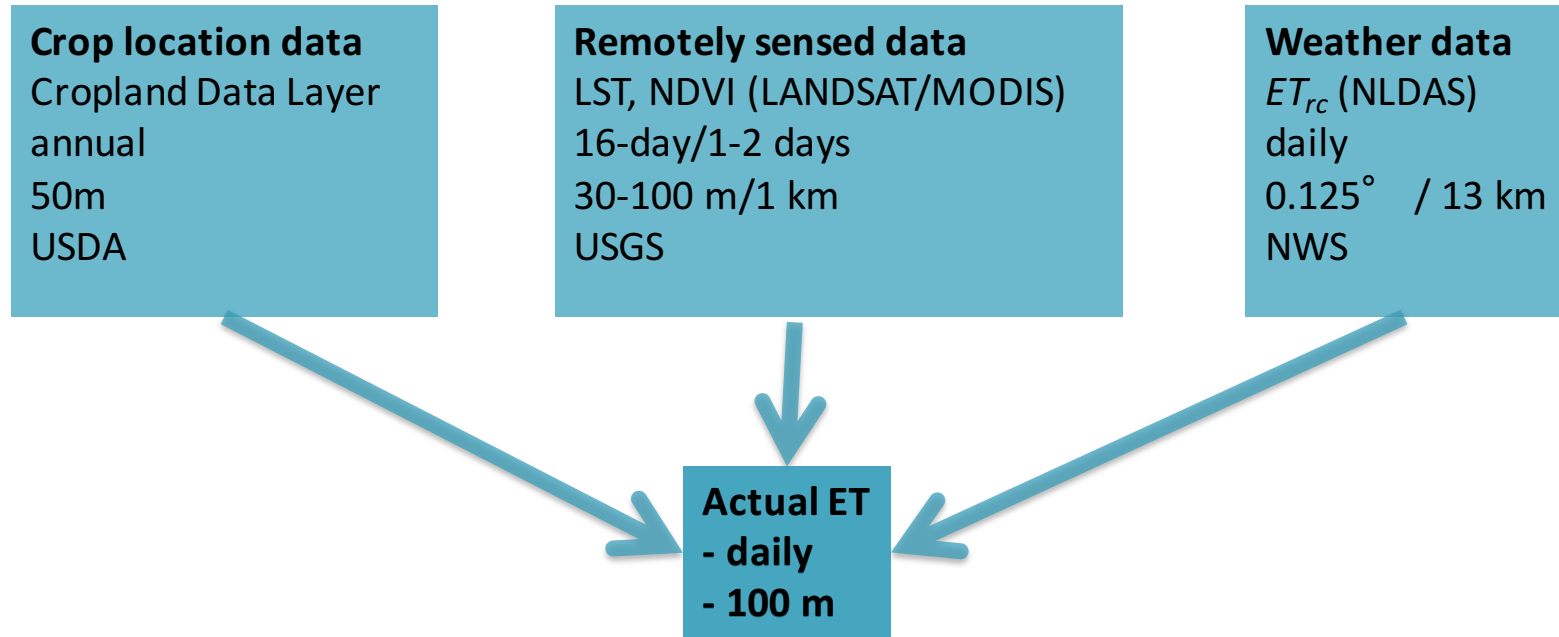


Bias
Value
High : 2.06e-3 in (0.052 mm)
Low : -0.28e-3 in (-0.007 mm)

(Lewis et al., 2013)

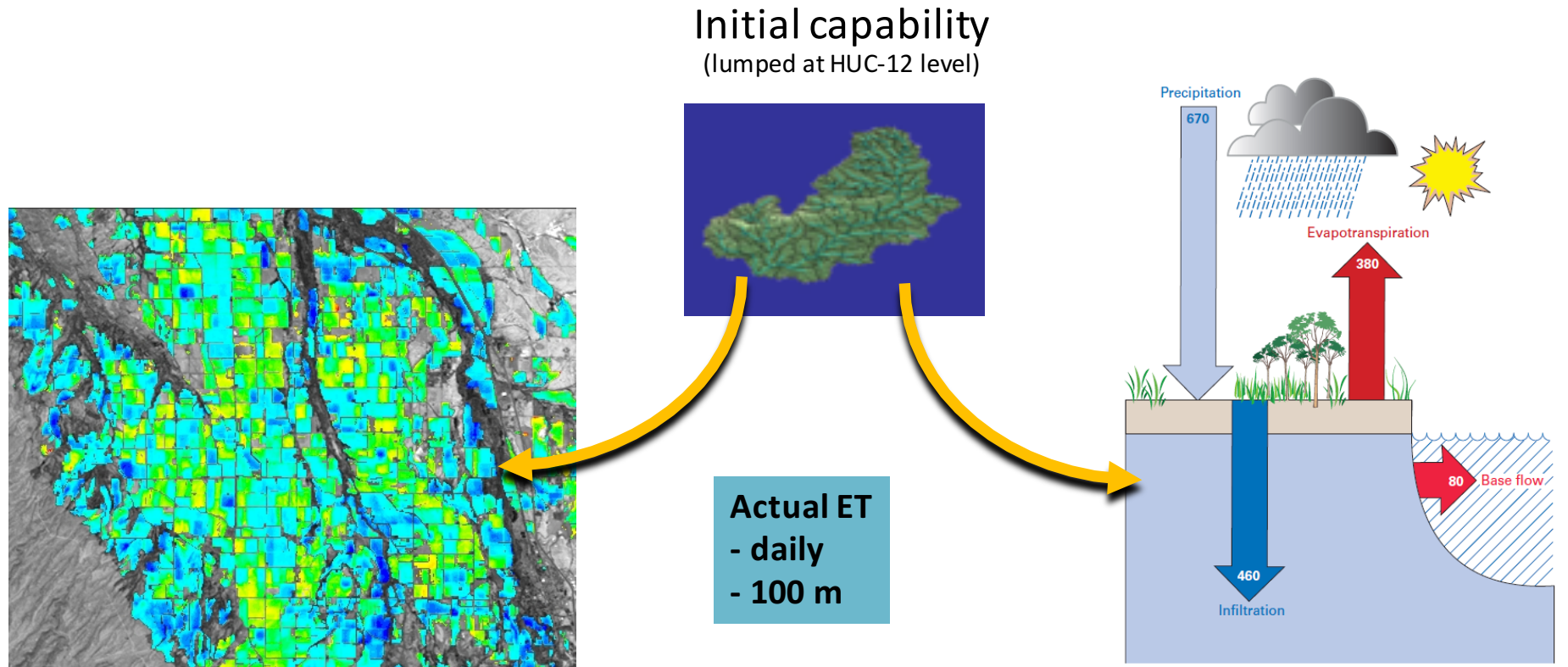
Uses of Generation-0 ET_0

ET component of National Water Census



Uses of Generation-0 ET_0

ET component of National Water Census



Water Use Evaluations:

- LANDSAT
- Consumptive use by irrigated crops
- Crop water productivity

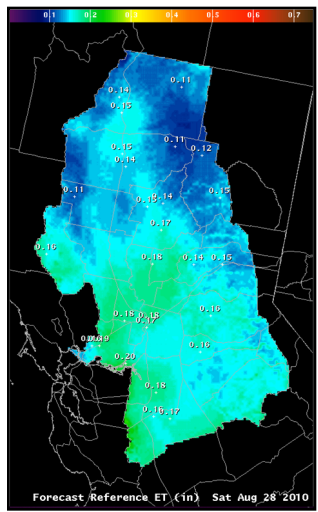
Water Availability:

- MODIS
- Landscape ET as a component of the overall water budget

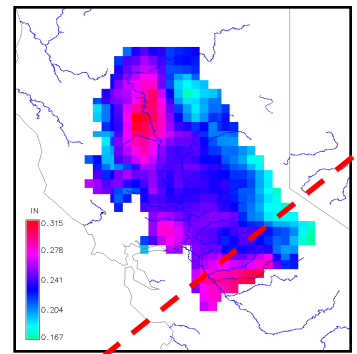
Uses of Generation-0 ET_0

Forecasting ET_0 at daily to weekly time-scales

NDFD forecast surface,
generated at NWC



NLDAS climatology
surface, specific to date



National Weather Service Forecast Office
Sacramento, CA

Experimental Forecast Reference Crop Evapotranspiration

The Experimental Forecast Reference Evapotranspiration (FRET) for short canopies are an experimental product that will be posted to this page for evaluation from July 14, 2010 through June 30, 2011. During this period, we encourage your comments or suggestions for improvements using the electronic survey provided. Your feedback will help us determine product utility, if modifications are needed, and whether the product should become part of the operational suite. Please see the information tab for more information on this product.

Note: Site specific FRET values are available by clicking on the map or typing a location at <http://www.wrh.noaa.gov/forecast/wxtables/index.php?wfo=sto>

Please fill out the survey at: <http://www.weather.gov/survey/nws-survey.php?code=RESCV>

Forecasts | Dept. from Normals | Climatology | Information

The FRET departure from normal is created from the FRET forecast and Climatology for 12 cm grasses calculated using the Penman-Monteith Reference Evapotranspiration Equations.

Place cursor over day you wish to see, or click on larger view

Today
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday

mouseover effect: Disable Enable

Note: Site specific FRET values are available by clicking on the map.

Please fill out the survey at: <http://www.weather.gov/survey/nws-survey.php?code=RESCV>

FRET Neighbors

FRET Departure from Normal Climatology Information

0.5 1.0 1.5 2.0 2.5 3.0 3.5

DepartNormFRET Sat Aug 28 2010



Uses of Generation-0 ET_0

Evaporative Demand Drought Index (EDDI)

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

rank in climo

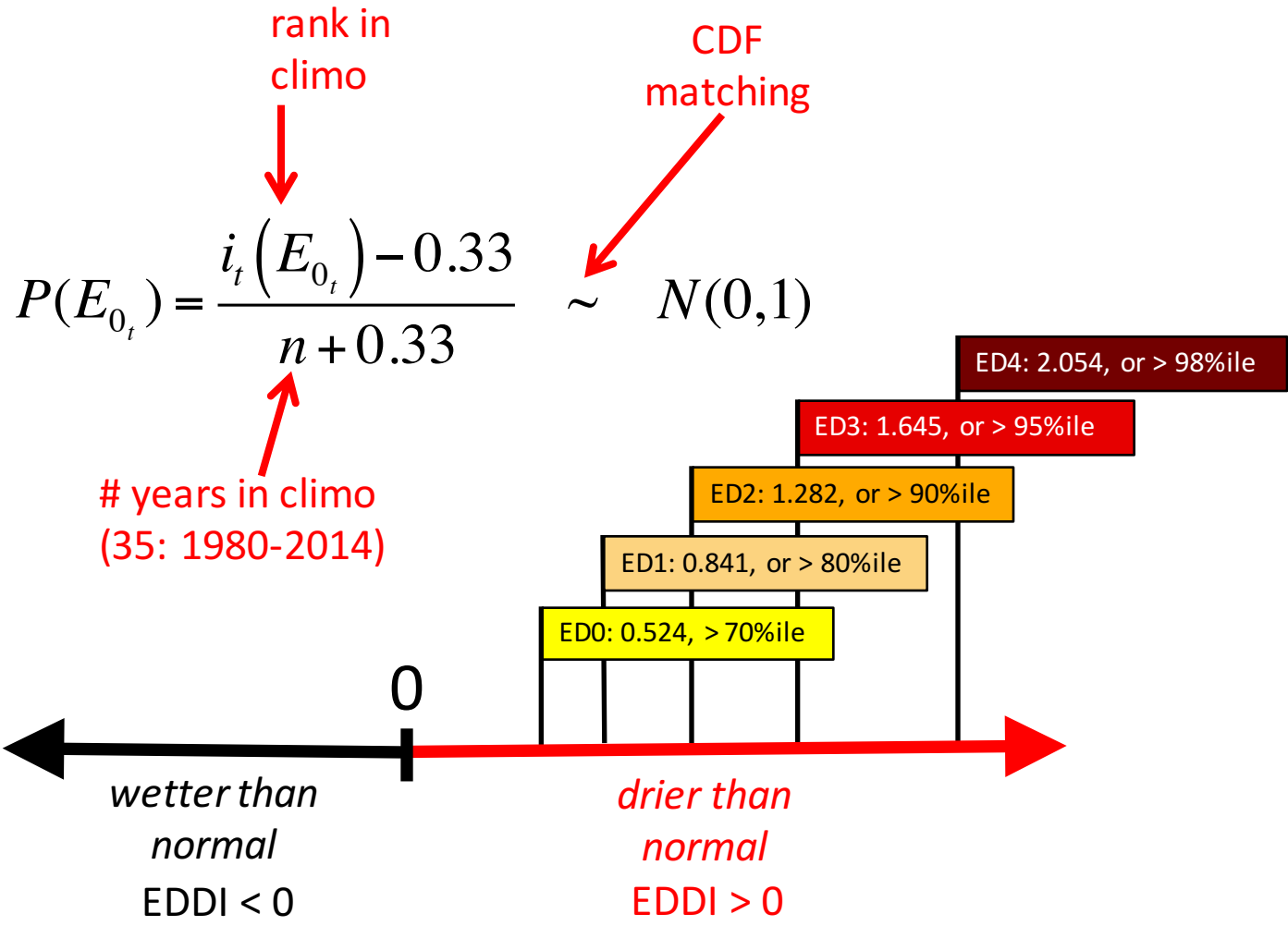
CDF matching

years in climo
(35: 1980-2014)

- Tukey plotting position – non-parameteric
- Recommended for comparing drought indices (*Hao and AghaKouchak, 2014*)
- t is period during which ET_0 is observed.
 - e.g., t for 2-month EDDI on Jan 31, 2015 starts on Dec 1, 2014.

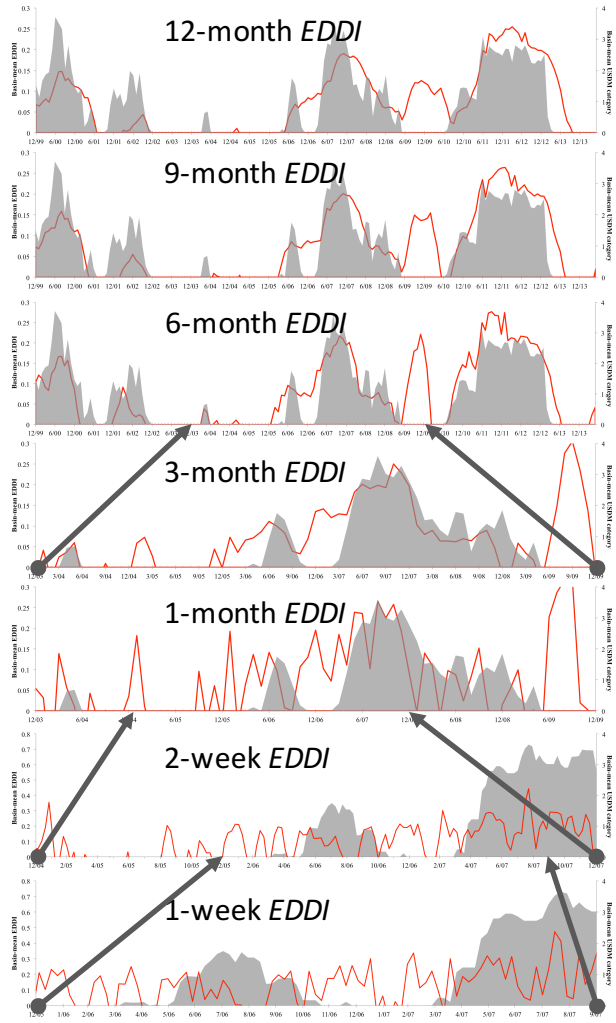
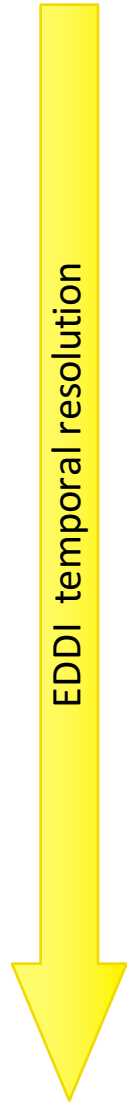
Uses of Generation-0 ET_0

Evaporative Demand Drought Index (EDDI)



EDDI as multi-scalar drought estimator

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

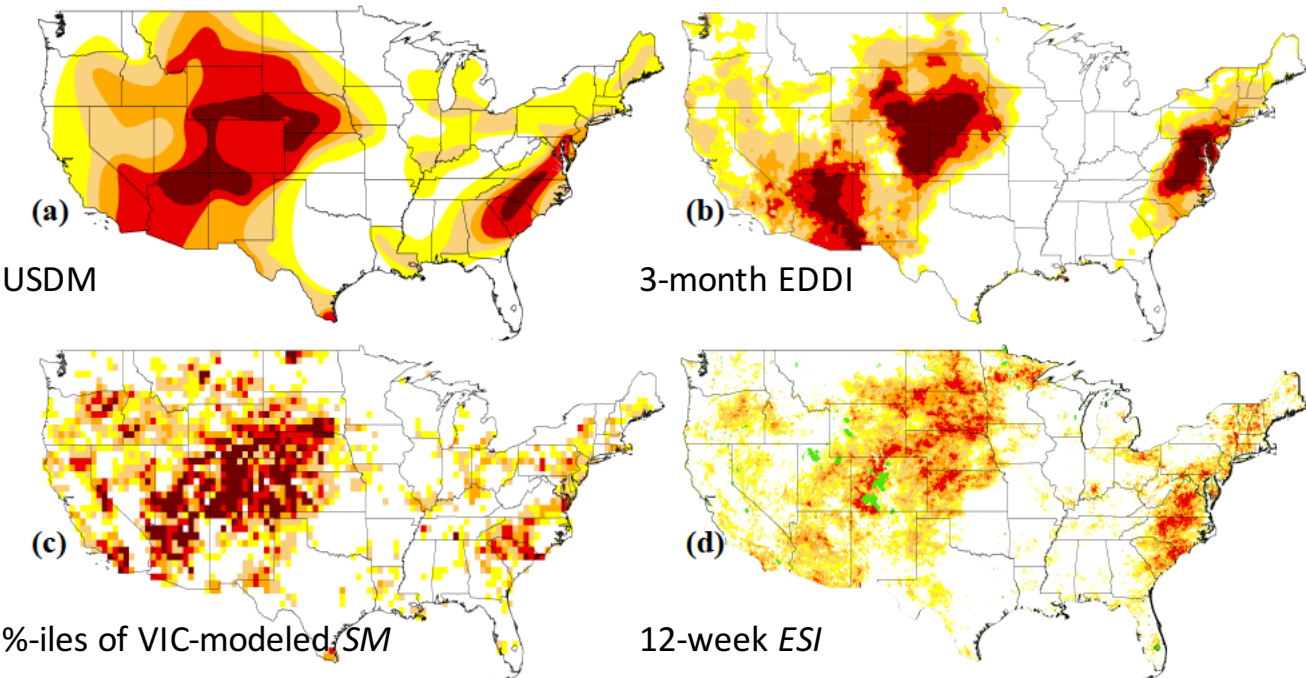







USDM (grey) and EDDI (red) across Apalachicola River basin at Chattahoochee, FL.

EDDI and agricultural drought

VIC = Variable Infiltration Capacity model
 ESI = Evaporative Stress Index

July 31, 2002



<i>EDDI, SM, and ESI percentiles</i>	<i>USDM drought categories</i>
> 70%	 D0, Abnormally dry
> 80%	 D1, Moderate drought
> 90%	 D2, Severe drought
> 95%	 D3, Extreme drought
> 98%	 D4, Exceptional drought

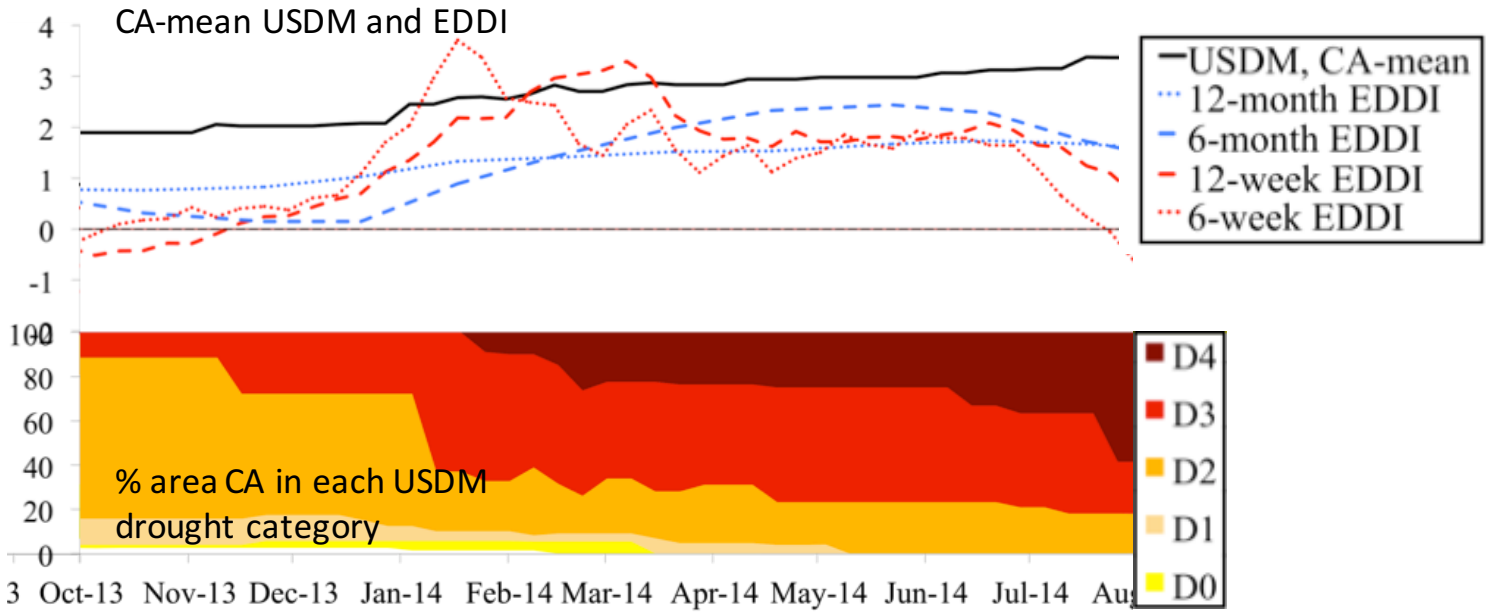


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CA drought intensification attribution

February - July 2014



CA drought intensification attribution

February - July 2014

E_0 signal of drought intensification:

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

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

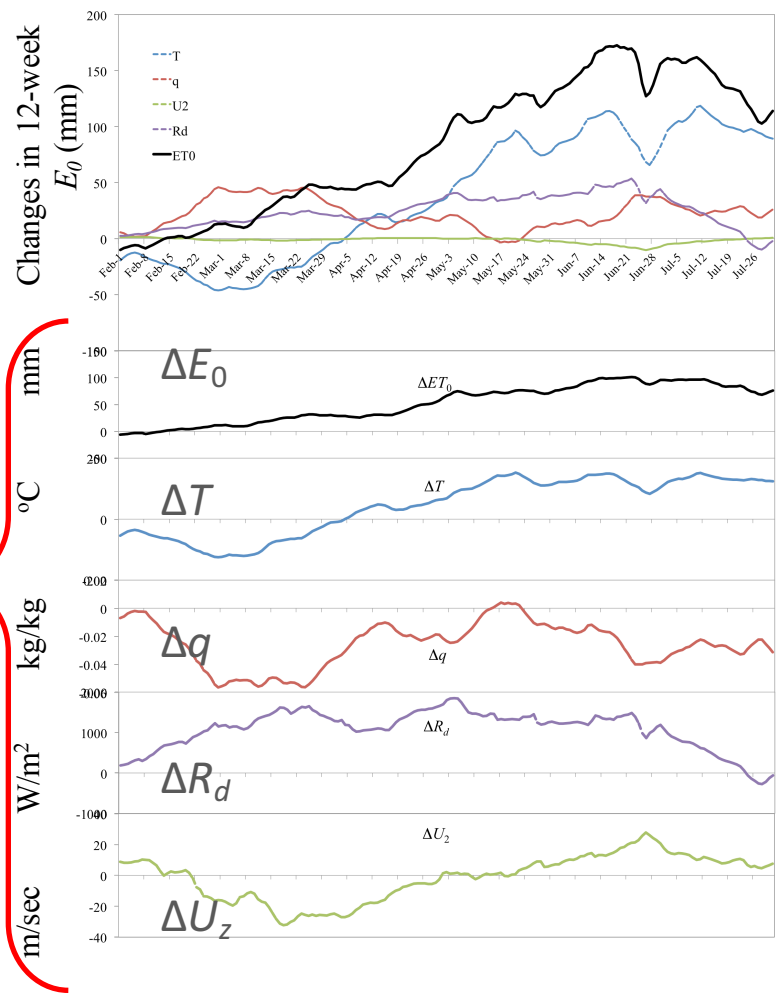
anomalies observed in reanalyses (circled in red in equation)

derived analytically (Hobbins, 2016) (circled in blue in equation)

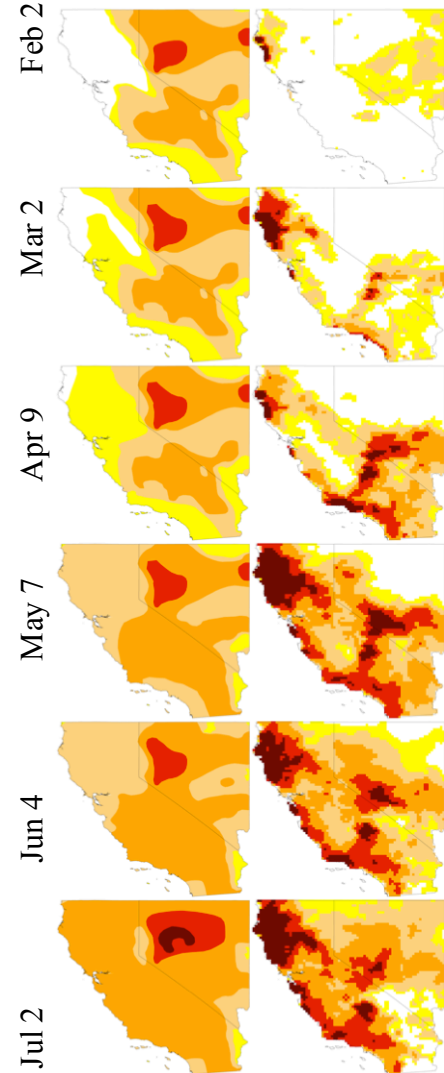
Drought intensification (increasing E_0) forced by:

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

E_0 signal in Sacramento River basin



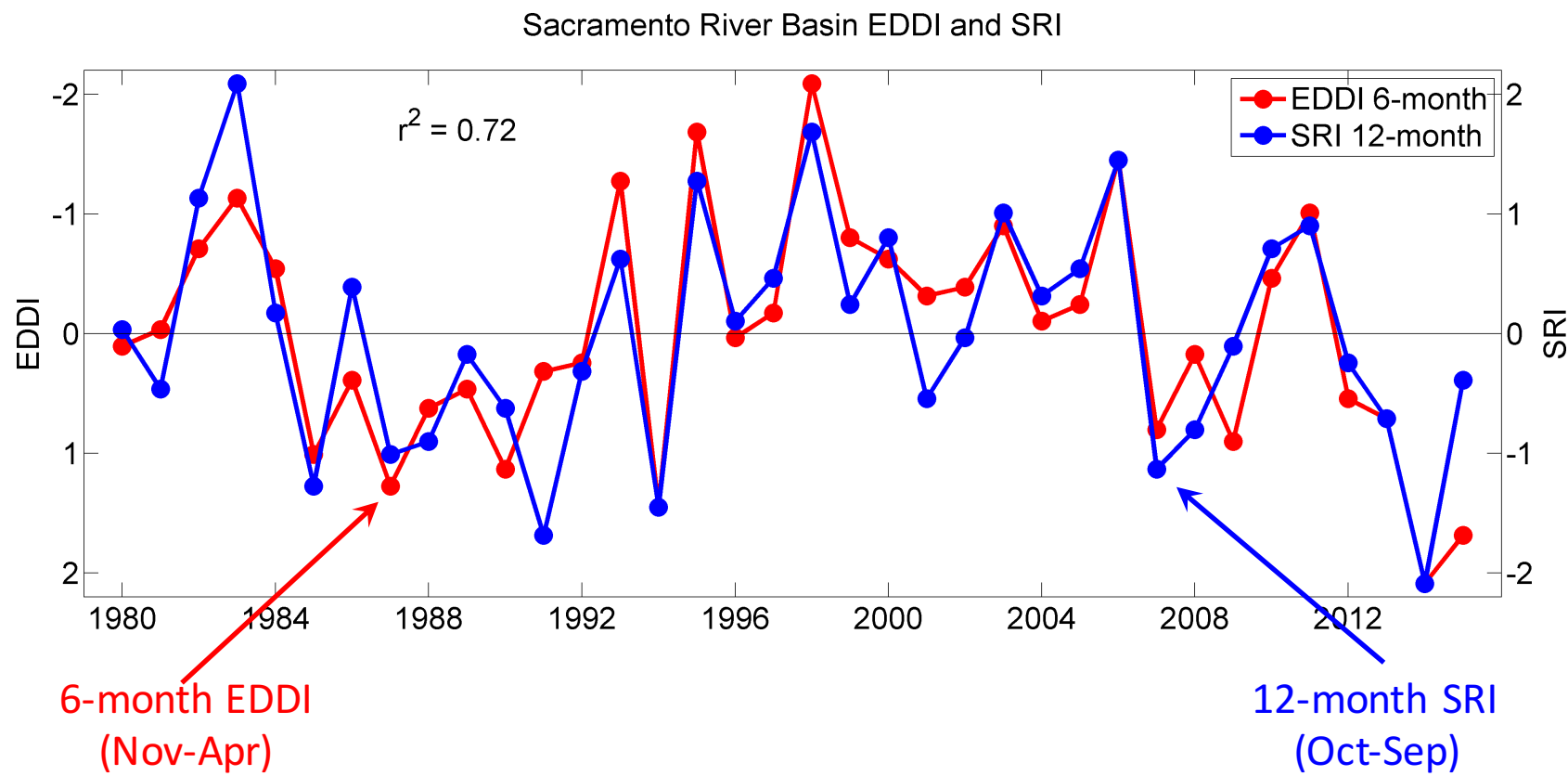
12-week USDM EDDI



EDDI and hydrologic drought

EDDI and the Standardized Runoff Index (SRI)

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



(McEvoy et al., 2014 - EDDI)
(Shukla and Wood, 2008 - SRI)

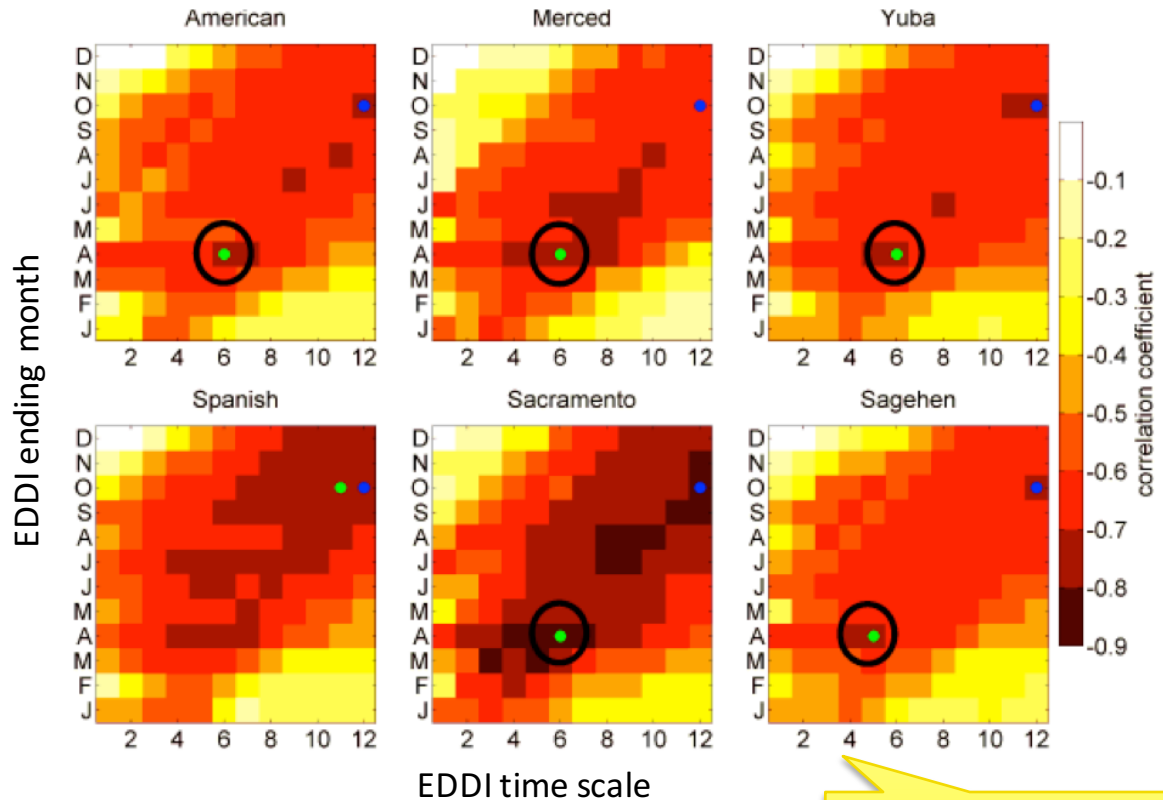
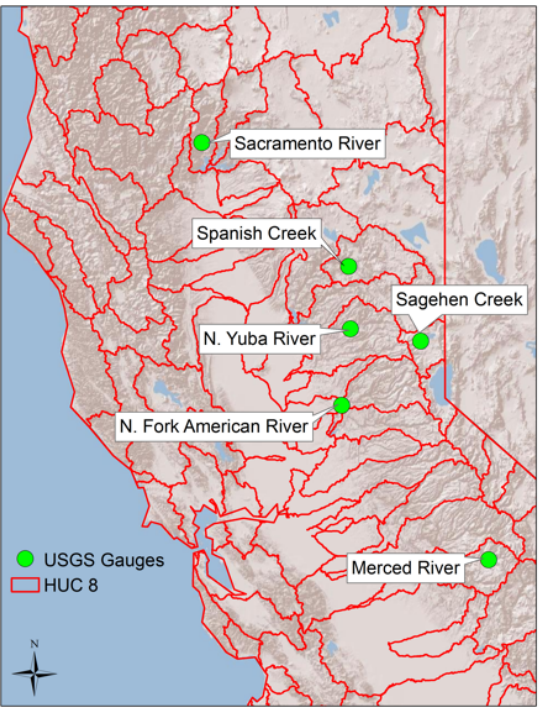


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EDDI and hydrologic drought

EDDI vs. 12-month SRI

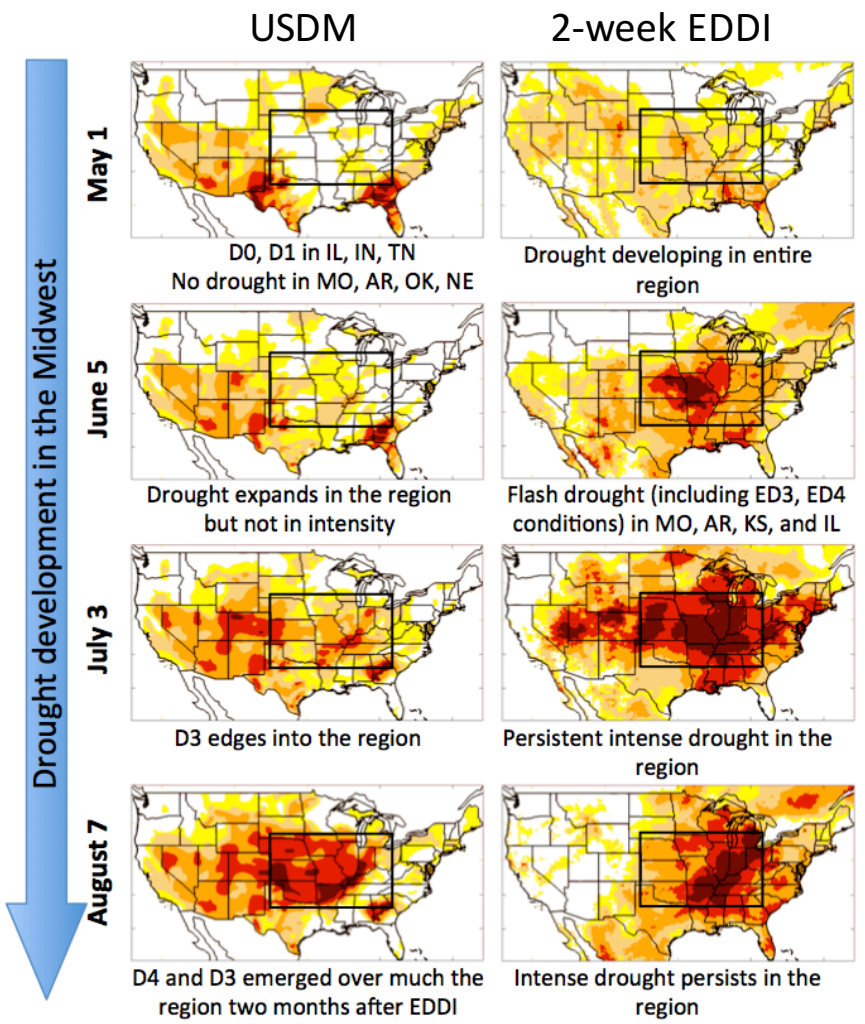


EDDI contains no Prcp information!

- 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.

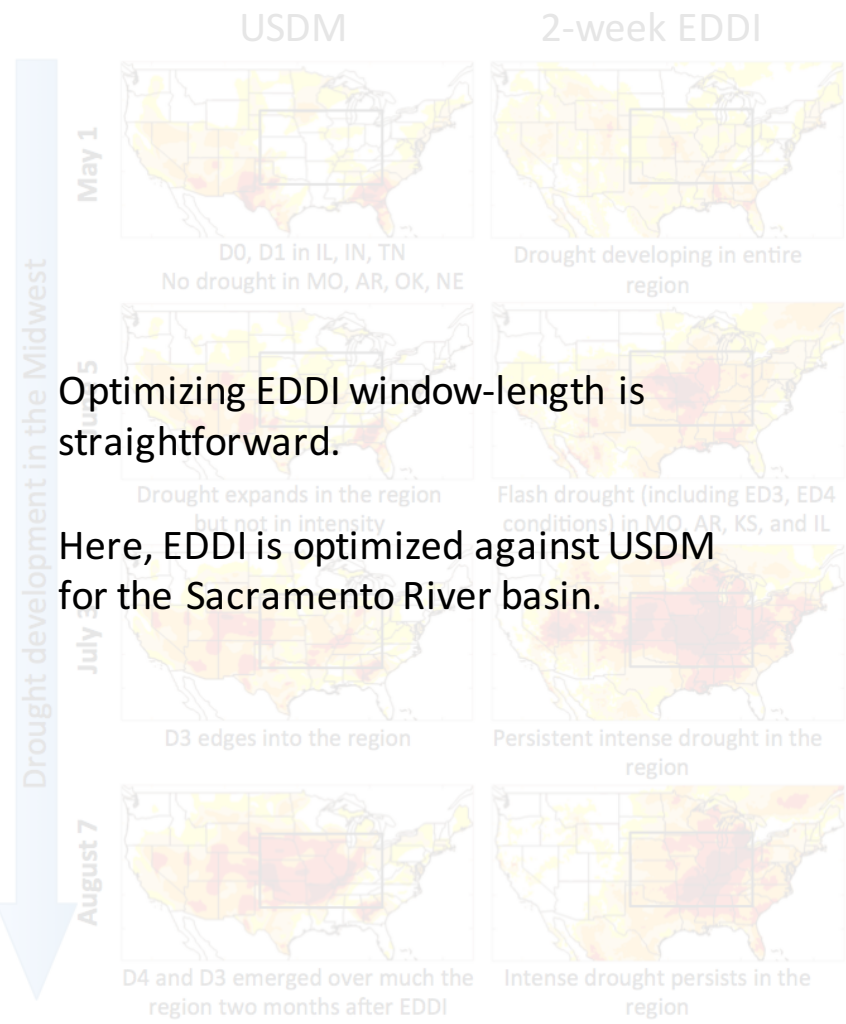
EDDI as a leading indicator of drought

Flash drought in the Midwest, 2012



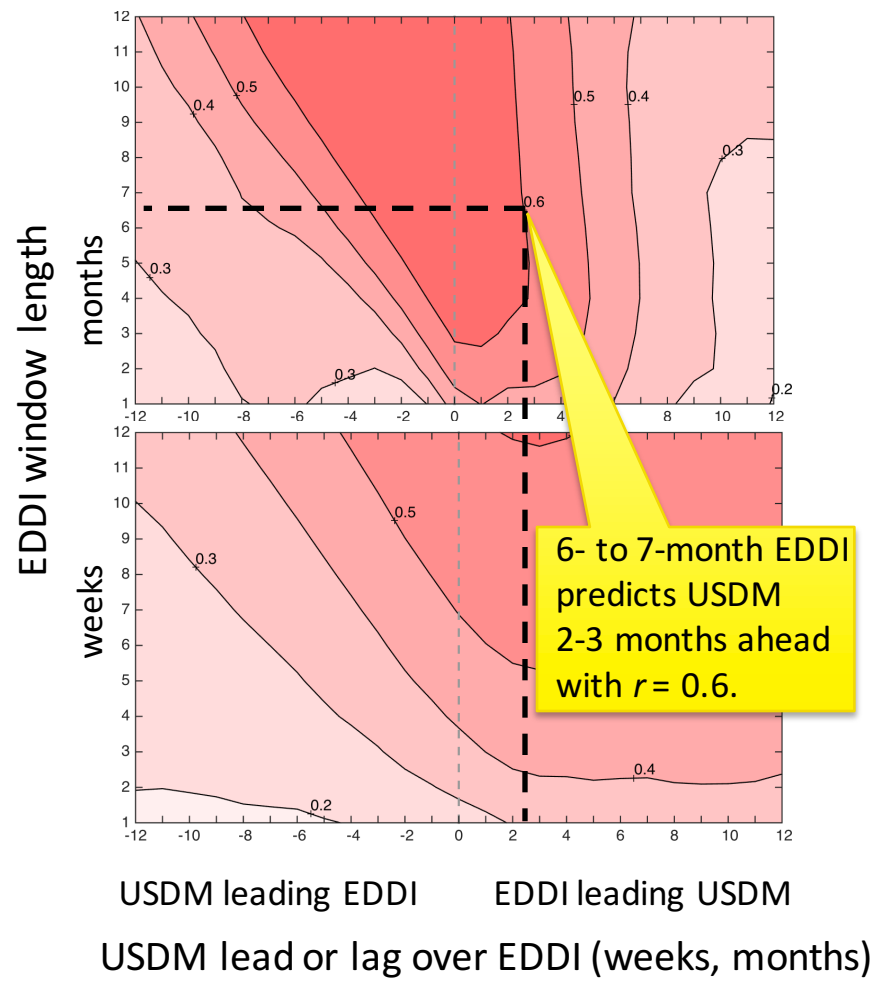
EDDI as a leading indicator of drought

Flash drought in the Midwest, 2012



Optimizing EDDI window-length is straightforward.
 Here, EDDI is optimized against USDM for the Sacramento River basin.

Sacramento River basin, CA

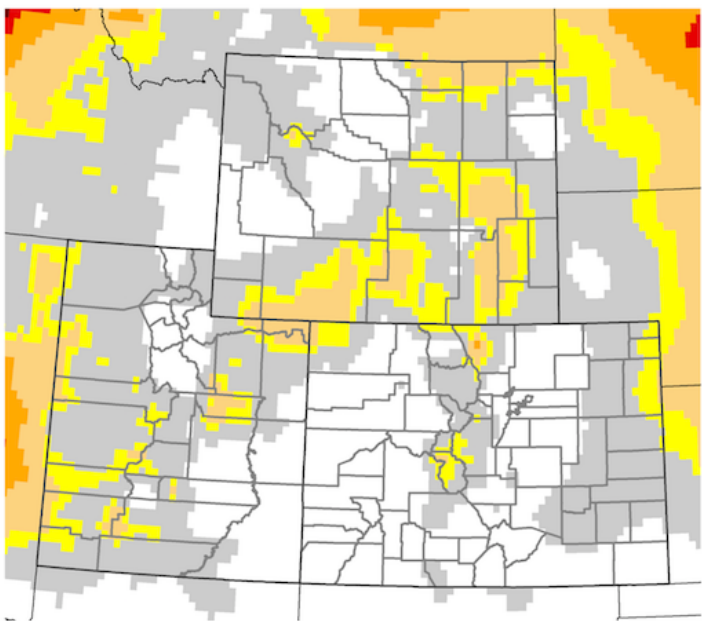


Example products

EDDI for December, 2015

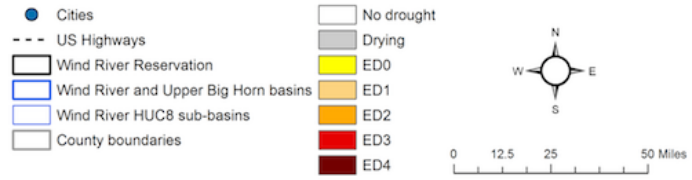
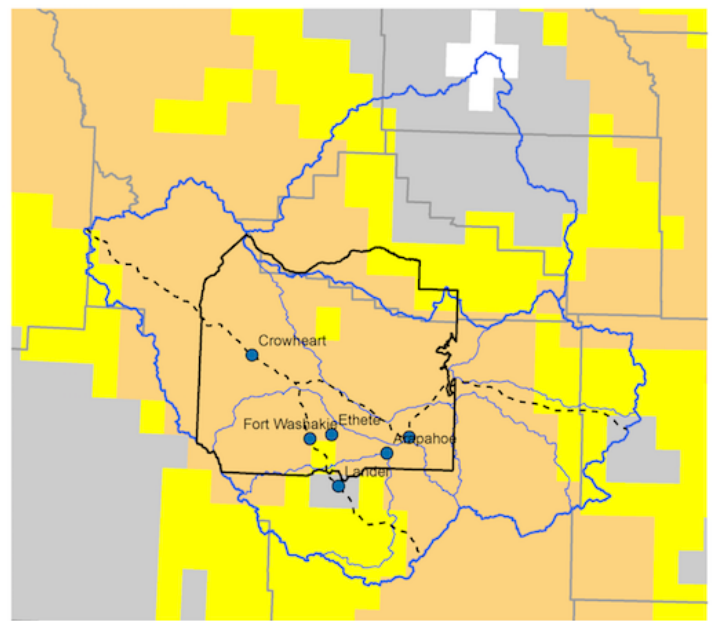
For Colorado Climate Center / Upper Colorado River Basin Drought Early Warning System

12-month EDDI, December 31



For USDM / Wind River reservation

12-week EDDI, December 2

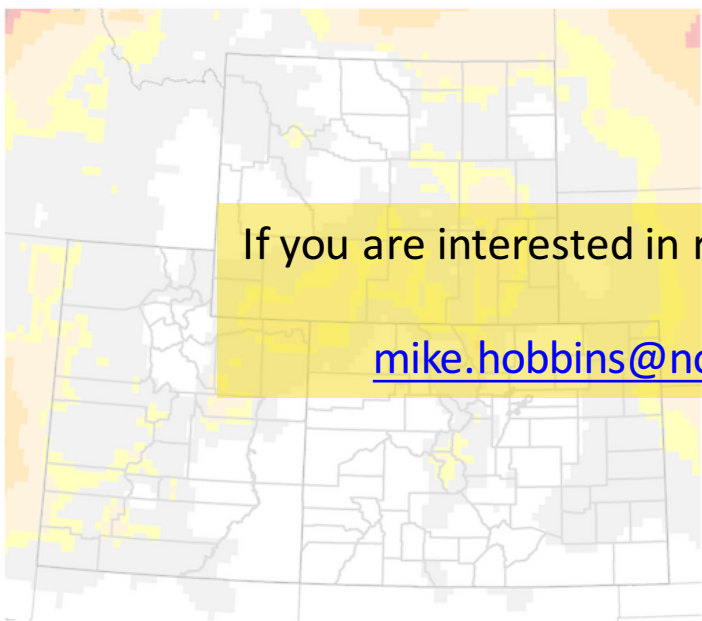


Example products

EDDI for December, 2015

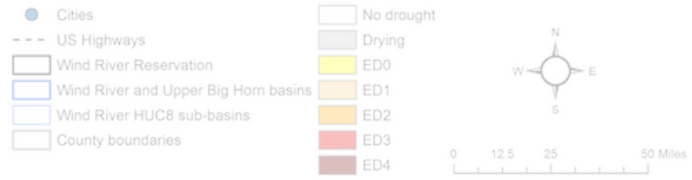
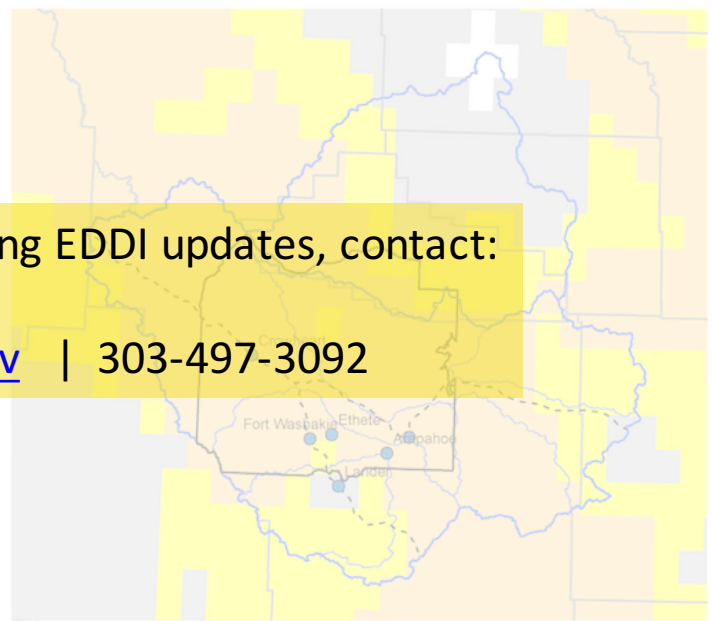
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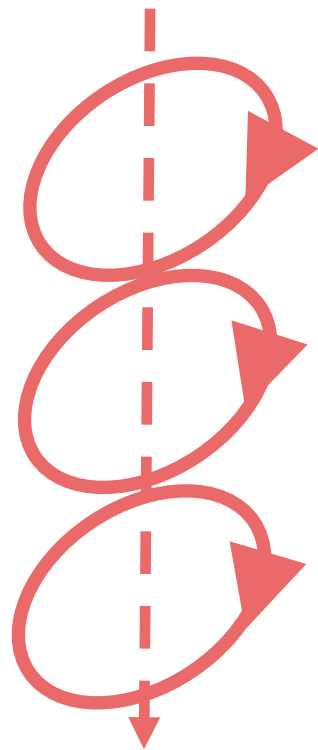
If you are interested in receiving EDDI updates, contact:
mike.hobbins@noaa.gov | 303-497-3092

Future work on EDDI

Operationalizing EDDI at National Water Center

- Two papers to appear in Journal of Hydrometeorology
- Research Transitions Acceleration Proposal (RTAP)
- Roll out EDDI to stakeholders in three waves:
 - Current stakeholders:
 - Colorado Climate Center –UCRB DEWS
 - USGS North Central CSC / USDM – Wind River drought information
 - USFS Rocky Mountain Research Station – fire-suppression costs modeling
 - Regional stakeholders:
 - Western RFCs – CBRFC, CNRFC, NWRFC
 - USDM regional authors
 - western RISAs – e.g., Western Water Assessment
 - NIDIS regional pilots and DEWS
 - CAL FIRE
 - National stakeholders:
 - USDM national authors
 - NOAA Climate Prediction Center
 - additional RISAs and DEWS
 - National Interagency Fire Center
 - Remaining RFCs
 - USDA – NRCS
 - DOI – BLM and NPS

experimental at ESRL /
Physical Sciences Division
FY16



Iterative
process
with expanding
stakeholder
groups

operational at National
Water Center
FY19



Summary

- E_0 is often more readily available than ET (than $Prcp$, often)
 - low latency ~5 days.
- E_0 is physically rational, responding...
 - rapidly to drying and wetting,
 - to both sustained and flash droughts.
- E_0 permits decomposition of evaporative drought drivers.
- EDDI:
 - is completely independent of $Prcp$ data,
 - is multi-scalar in time and space,
 - gives near real-time drought monitoring / early warning,
 - is consistent with USDM (and other monitors), but not duplicative.
- EDDI aggregation window may be calibrated for:
 - early warning relative to other monitors,
 - demands specific to hydroclimates, and sectors.
- E_0 (and EDDI, and drought) can be forecast:
 - daily, weekly - FRET
 - seasonally with much greater skill than $Prcp$. (*McEvoy et al.*, 2015 – GRL)