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

Mike Hobbins - *NOAA-Physical Sciences Division / CIRES, Boulder, CO* and
Daniel McEvoy, Justin Huntington, Charles Morton - *Desert Research Institute, Reno, NV*
Andy Wood - *University Corporation for Atmospheric Research, Boulder, CO*
James Verdin - *USGS-EROS, Boulder, CO*

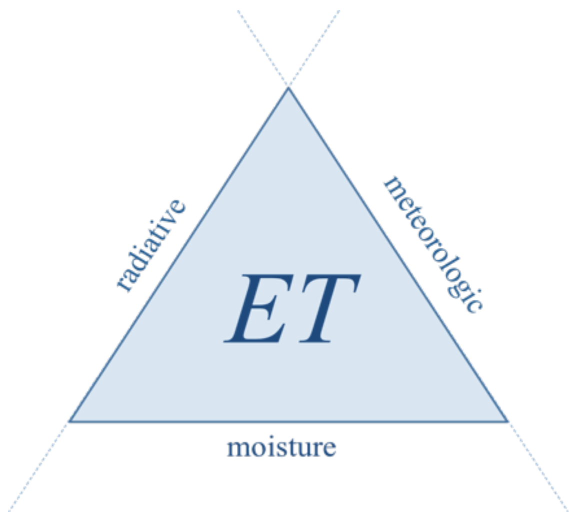
mike.hobbins@noaa.gov | 303-497-3092

ET / evaporative demand interactions

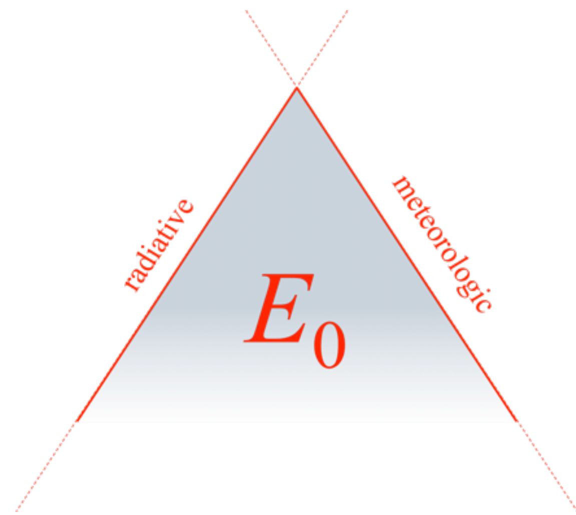
Supply and demand

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



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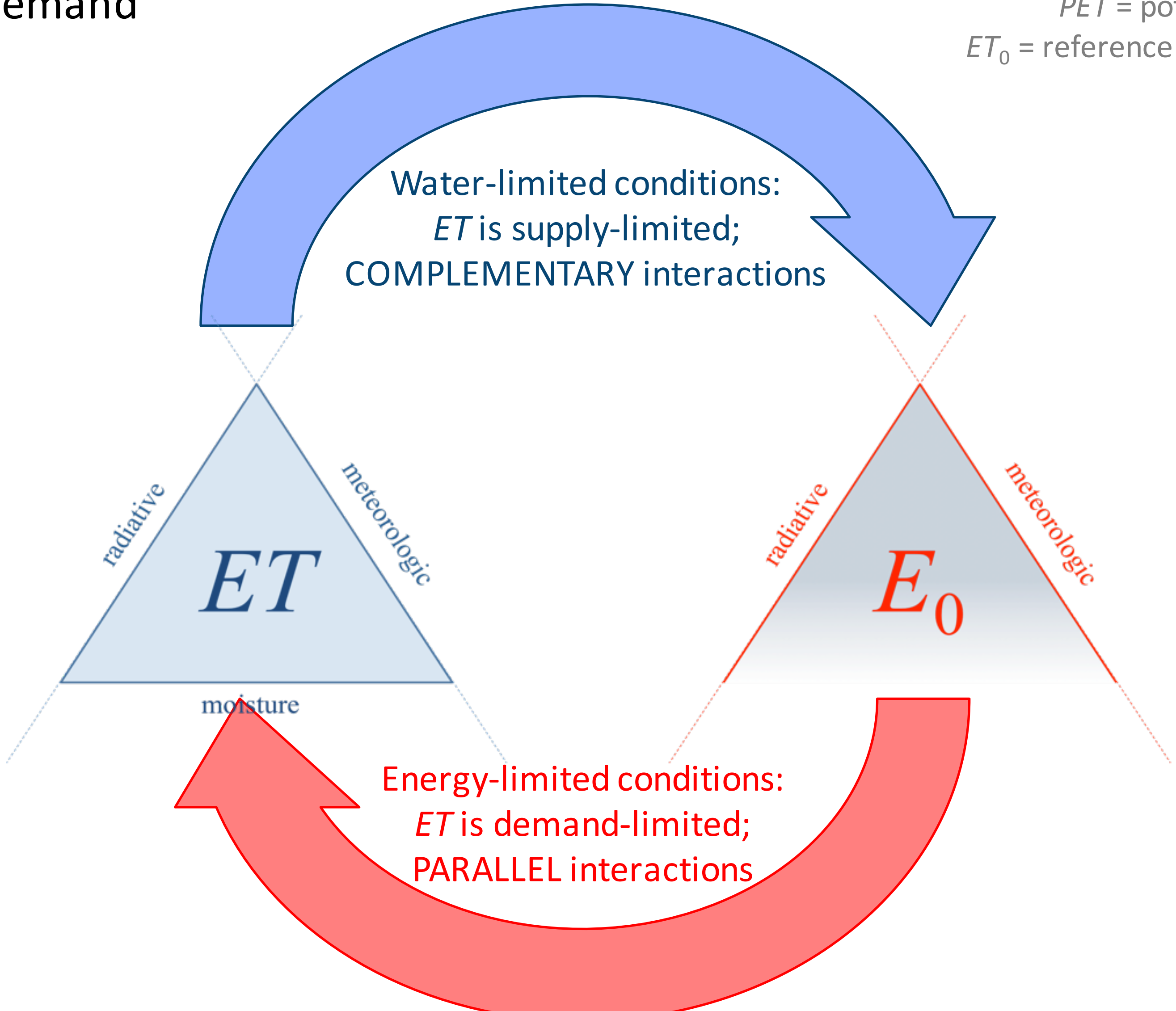
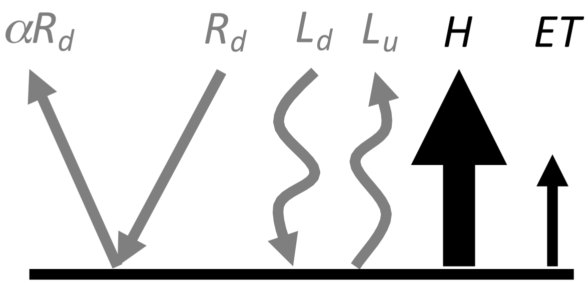


E_0 / ET interactions in drought

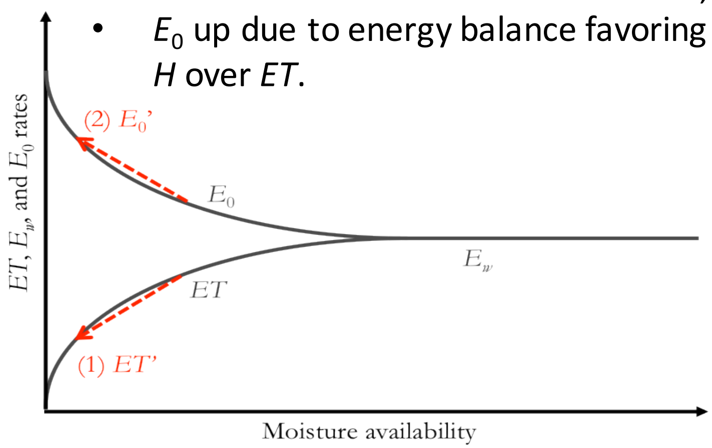
$$(R_d - R_u) + (L_d - L_u) - G = H + ET$$

Sustained drought - water limited



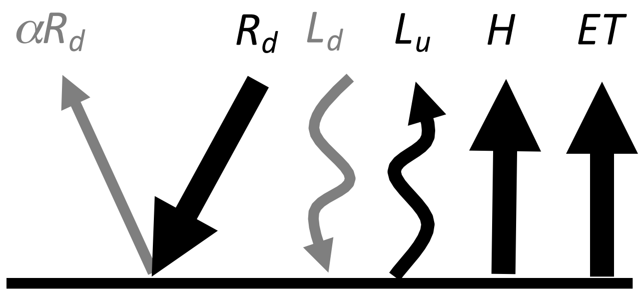
ET and E_0 vary in complementary directions:

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



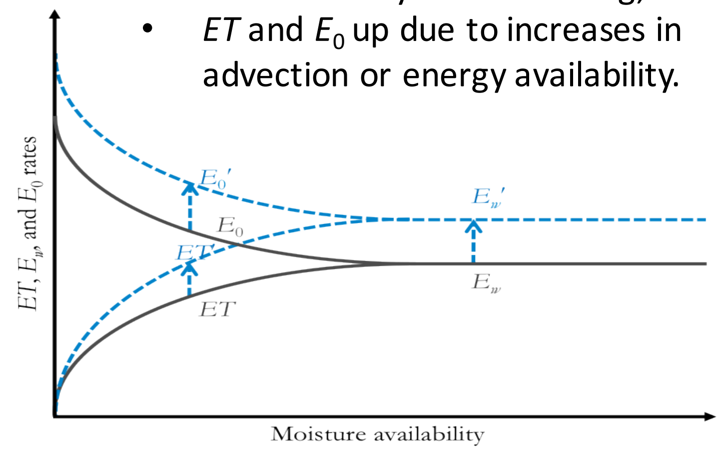
(Hobbins et al., 2004)

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 complementa

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

(Hobbins et al., 2004)

in a parallel direction:

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

Evaporative demand (E_0) from reference *ET* (ET_0)

ASCE Standardized Reference *ET*

$$ET_0 = \frac{0.408\Delta}{\Delta+\gamma(1+C_dU_2)}(R_n+L_n-G)\frac{86400}{10^6} + \frac{\gamma\frac{C_n}{T}}{\Delta+\gamma(1+C_dU_2)}U_2\frac{(e_{sat}-e_a)}{10^3}$$

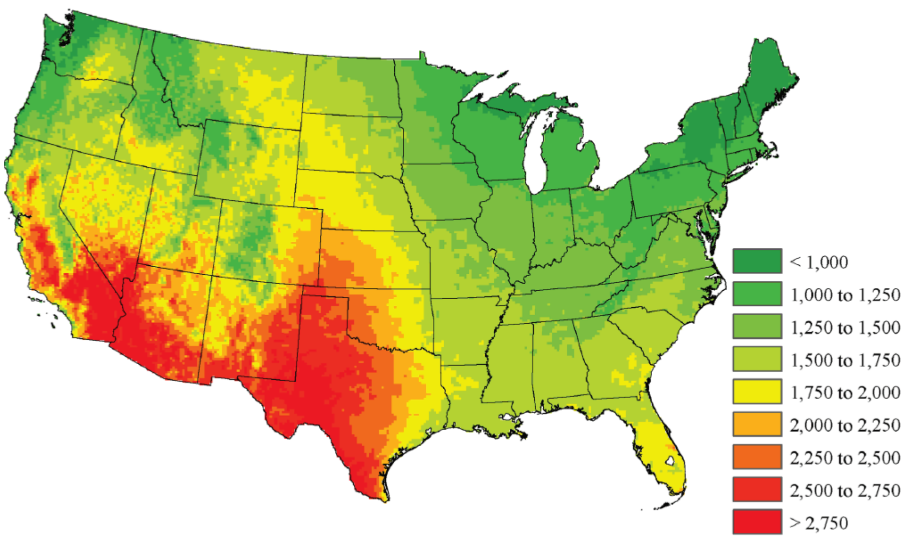
Radiative forcing — Advective forcing

(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).



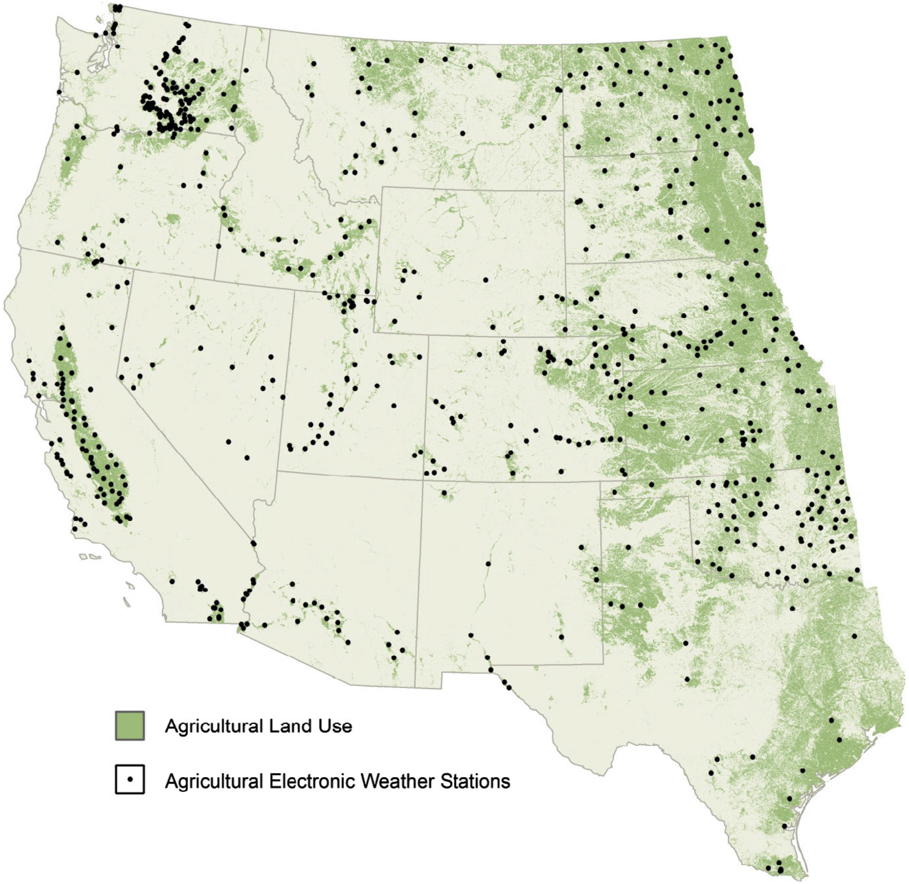
Future work on NOAA's ET_0

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 ET_0 forcings validation

(Lewis et al., 2013)



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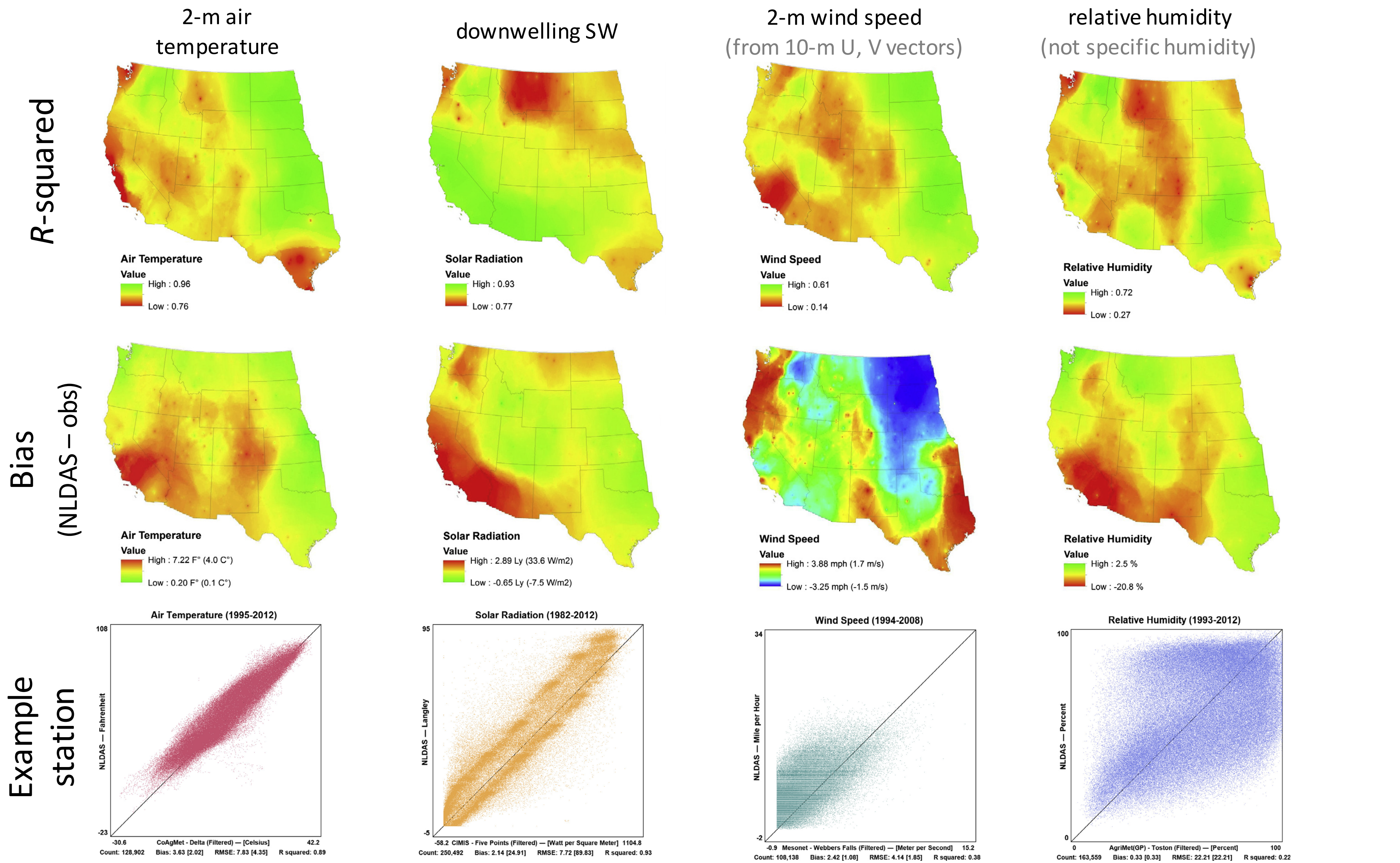
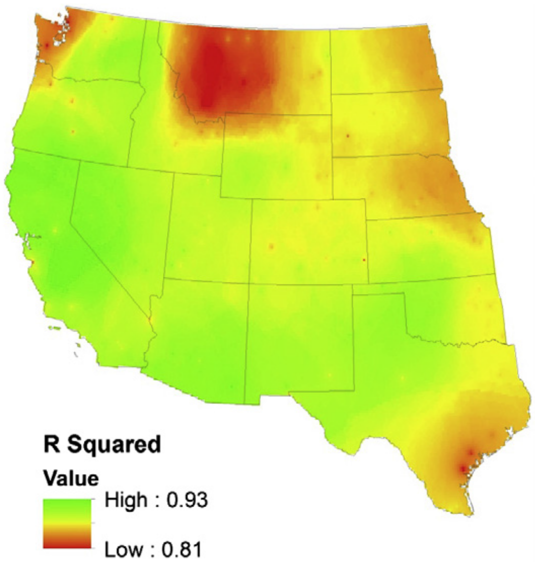


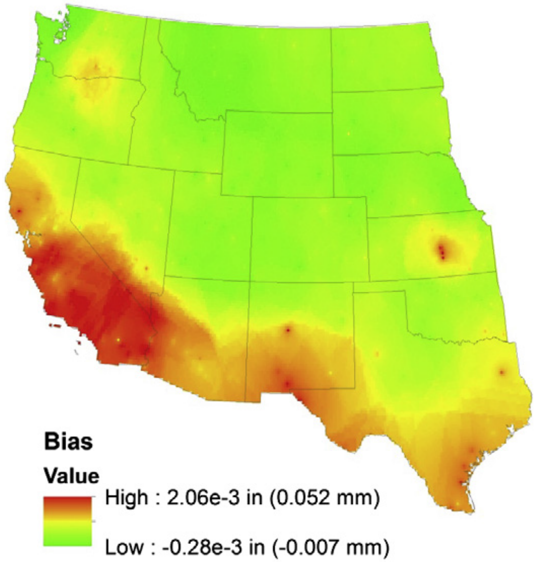
NLDAS-forced ET_0 validation

Generation-0 ET_0

R-squared



Bias



(Lewis et al., 2013)

Uses of Generation-0 ET_0

ET component of National Water Census

Crop location data
Cropland Data Layer
annual
50m
USDA

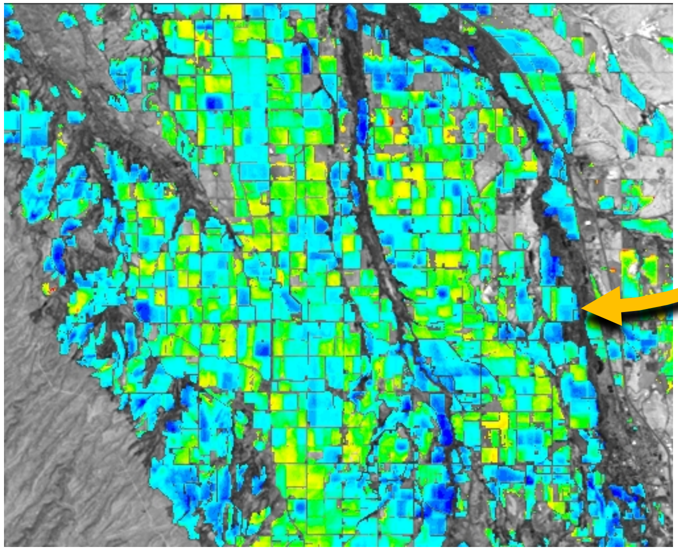
Remotely sensed data
LST, NDVI (LANDSAT/MODIS)
16-day/1-2 days
30-100 m/1 km
USGS

Weather data
ET_{rc} (NLDAS)
daily
0.125° / 13 km
NWS

Actual ET
- daily
- 100 m

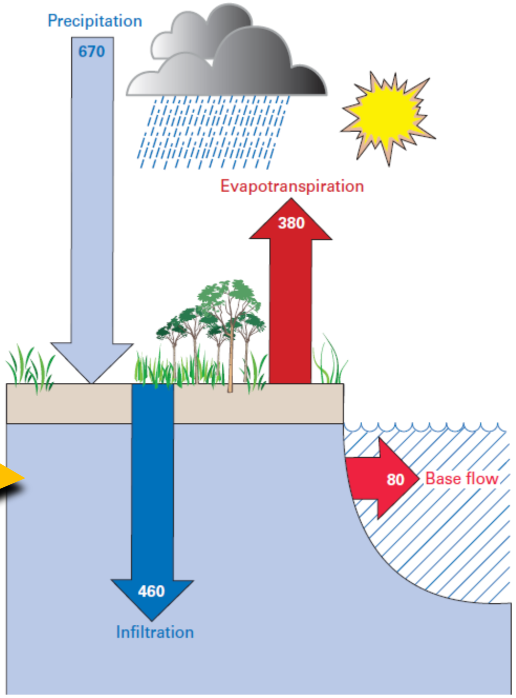
Uses of Generation-0 ET_0

ET component of National Water Census



Initial capability

(lumped at HUC-12 level)



Actual ET
- daily
- 100 m

Water Use Evaluations:

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

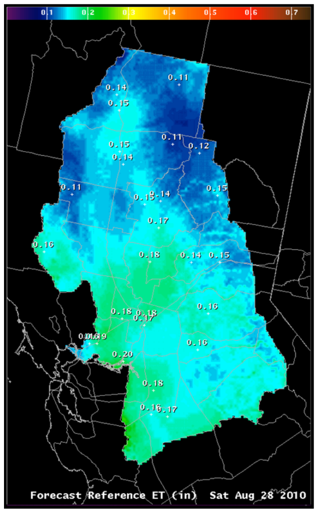
Water Availability:

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

Uses of Generation-0 ET_0

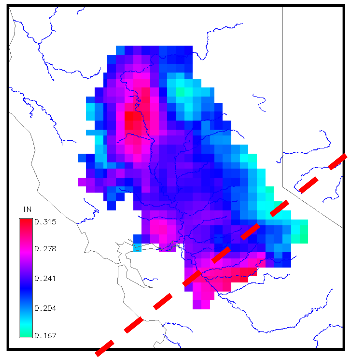
Forecasting ET_0 at daily to weekly time-scales

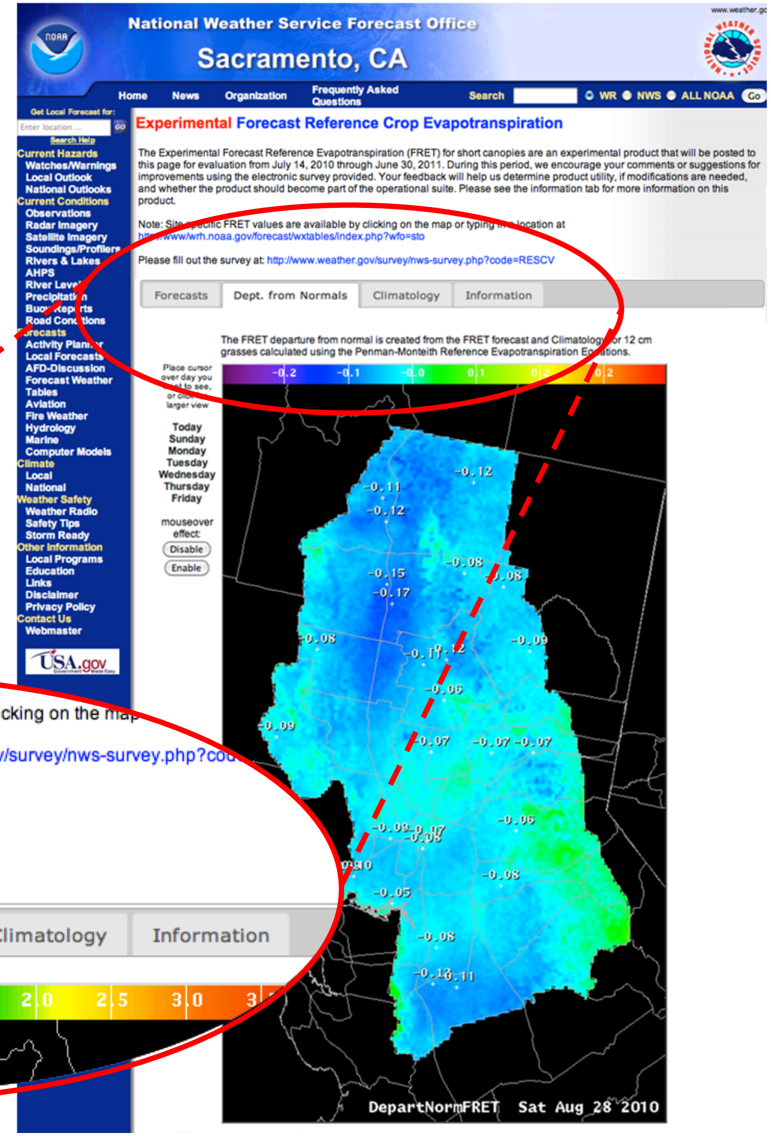
NDFD forecast surface, generated at NWC

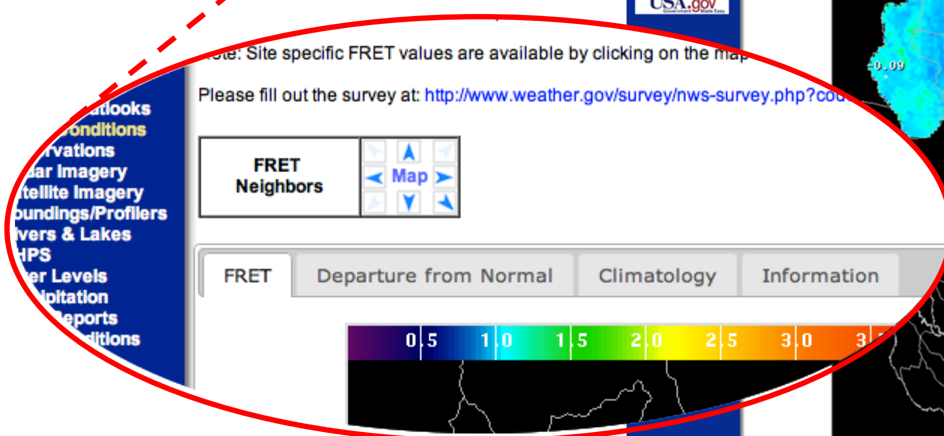


+

NLDAS climatology surface, specific to date







CIRES

Cooperative Institute for Research in Environmental Sciences

UNIVERSITY OF COLORADO **BOULDER** and **NOAA**

http://www.wrh.noaa.gov/forecast/evap/FRET/FRET.php?wfo=sto

Uses of Generation-0 ET_0

Evaporative Demand Drought Index (EDDI)

rank in climo

CDF matching

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

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)

rank in climo

CDF matching

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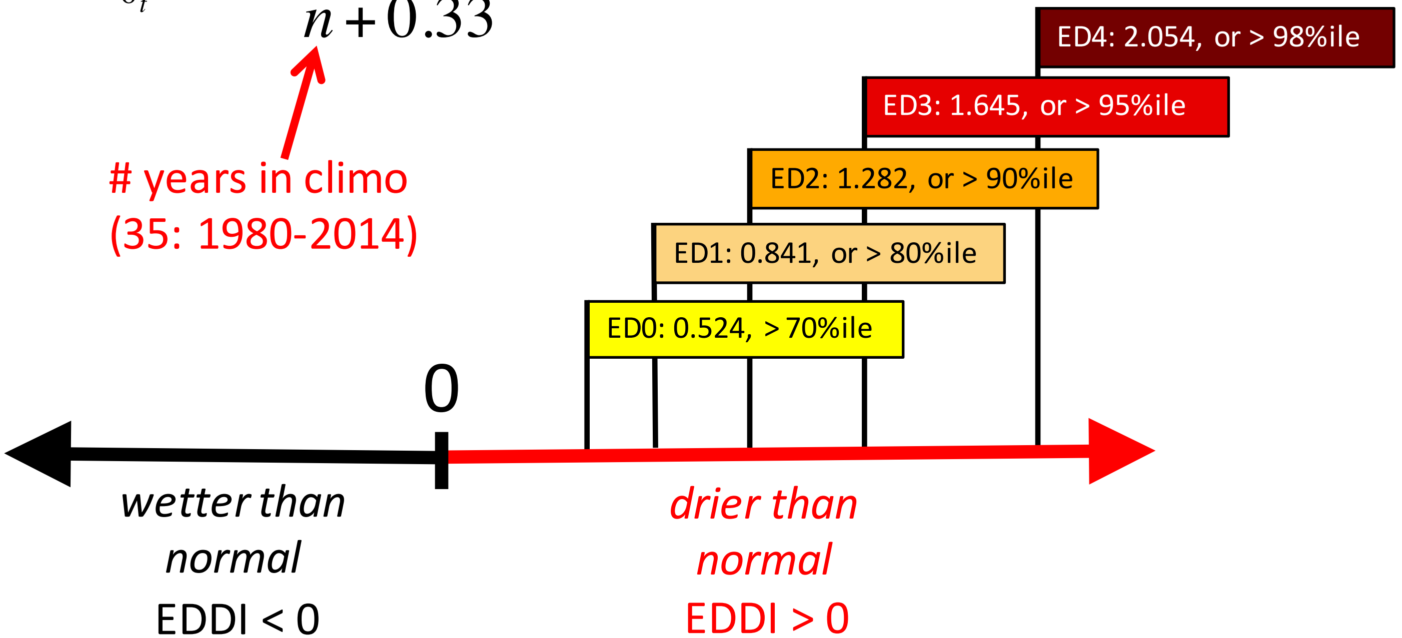
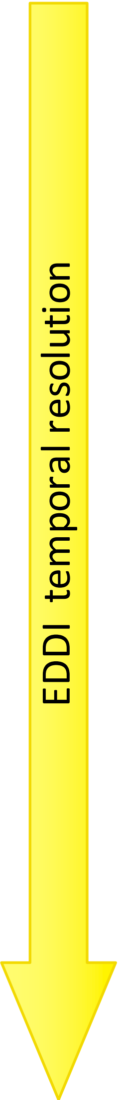
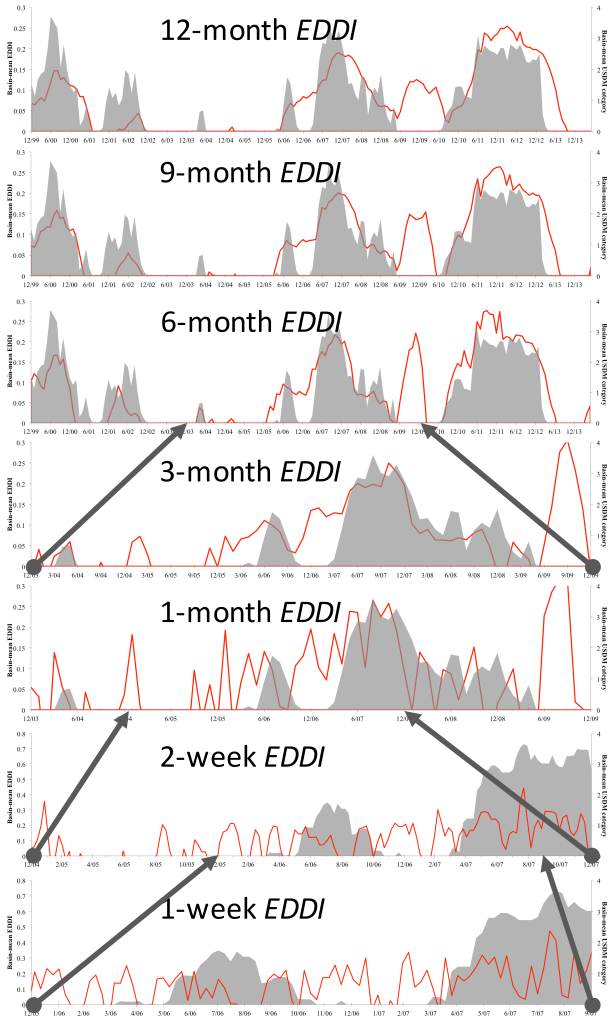


EDDI as multi-scalar drought estimator

USDM = United States Drought Monitor

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



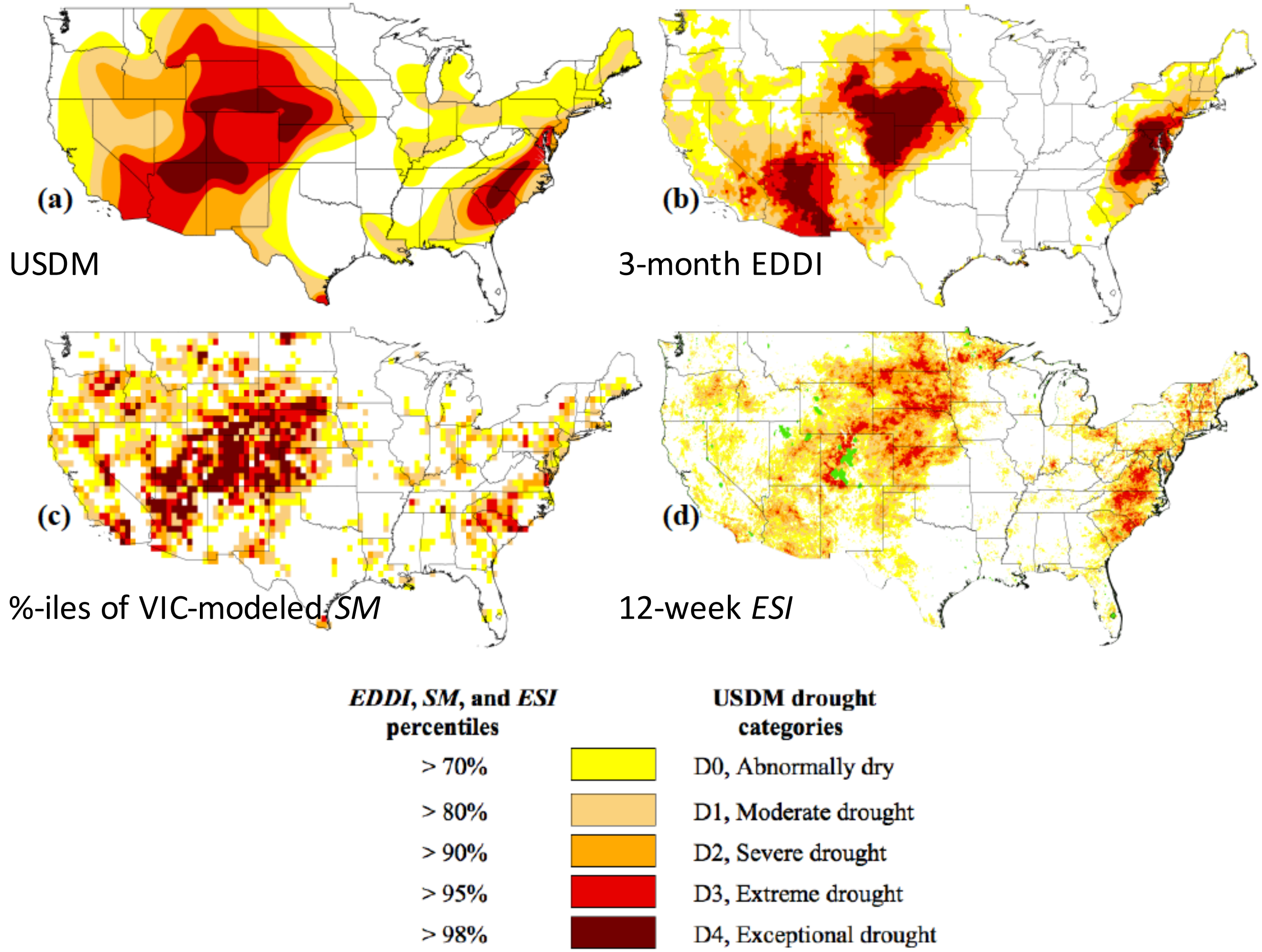


USDM (grey) and EDDI (red) across Apalachicola River basin at Chattahoochee, FL.

EDDI and agricultural drought

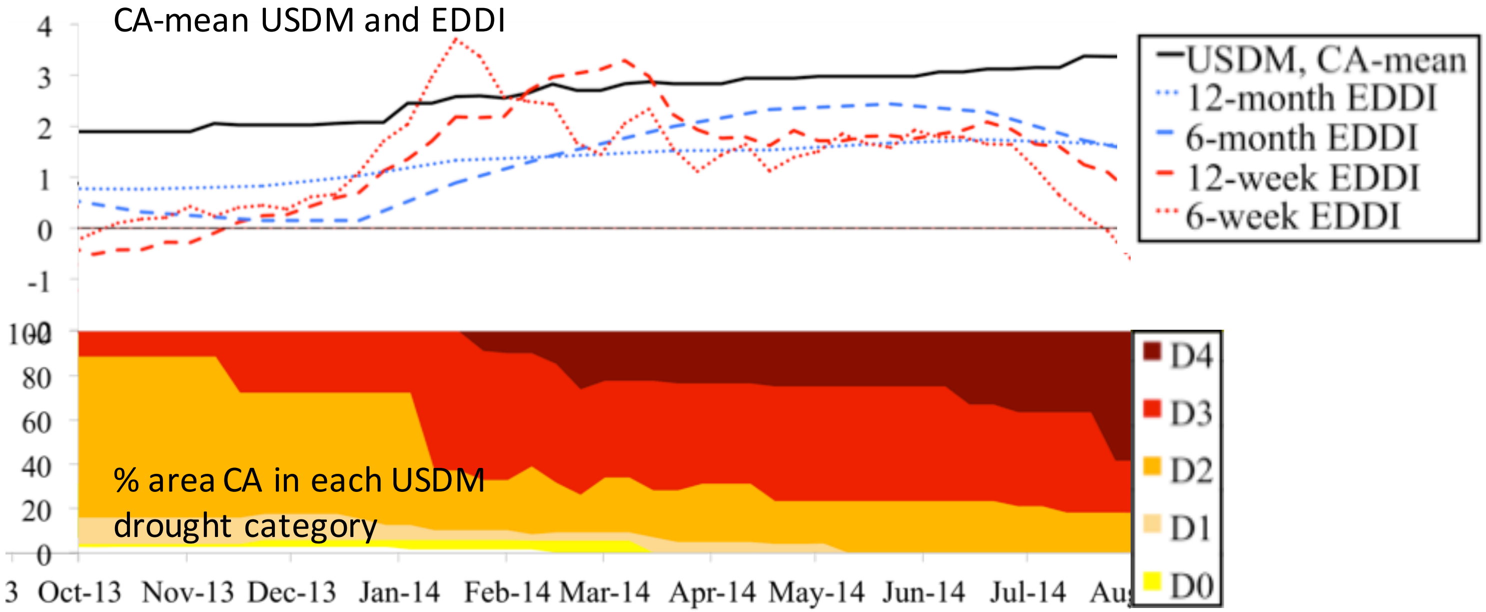
July 31, 2002

VIC = Variable Infiltration Capacity model
ESI = Evaporative Stress Index



CA drought intensification attribution

February - July 2014



CA drought intensification attribution

February - July 2014

E_0 signal of drought intensification:

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

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

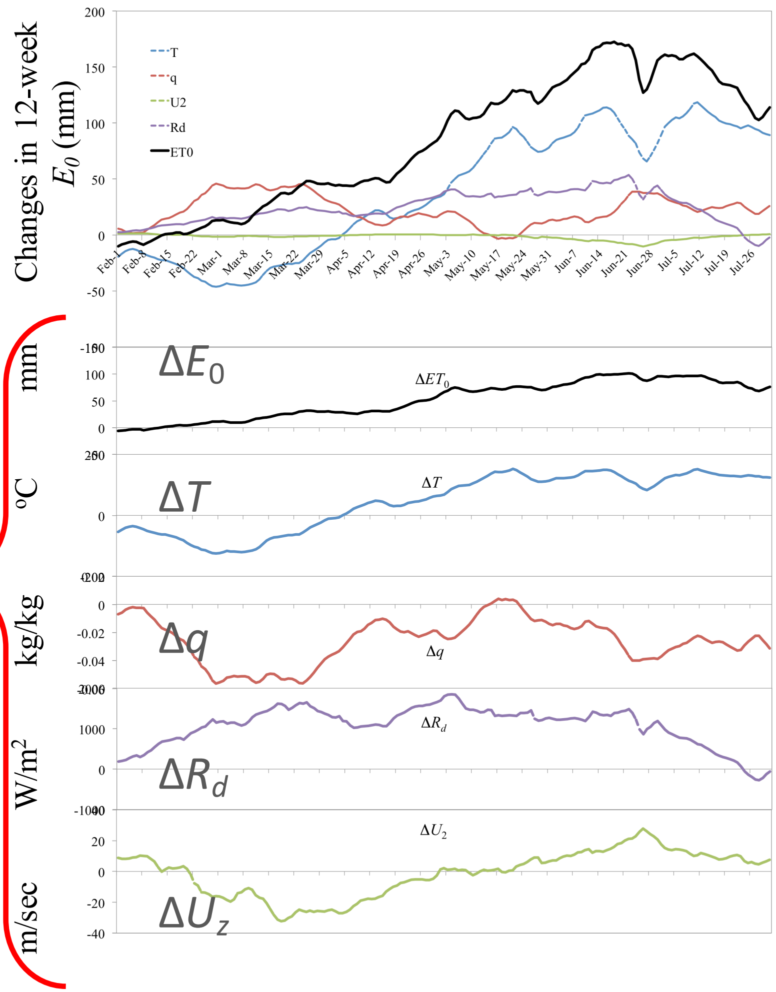
anomalies observed in reanalyses

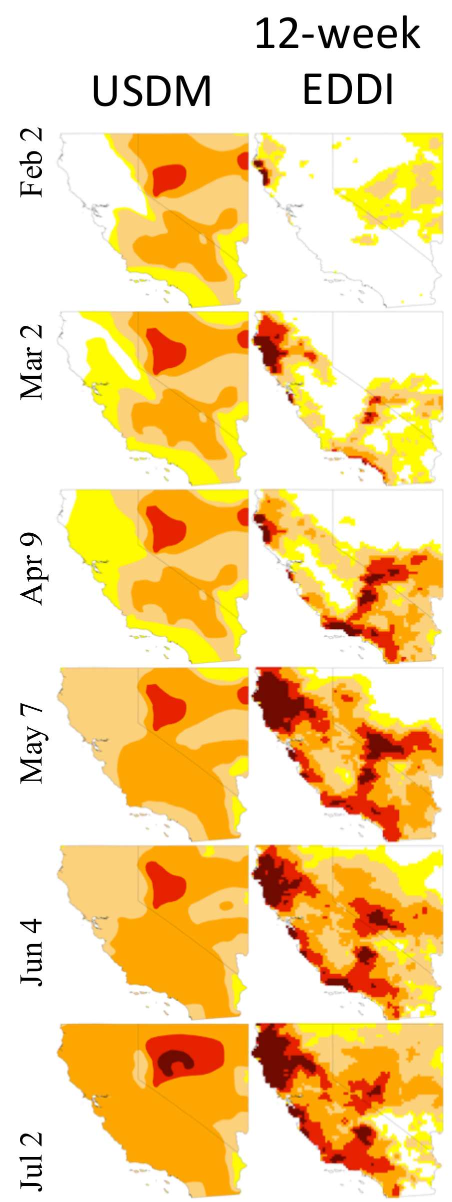
derived analytically (*Hobbins*, 2016)

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

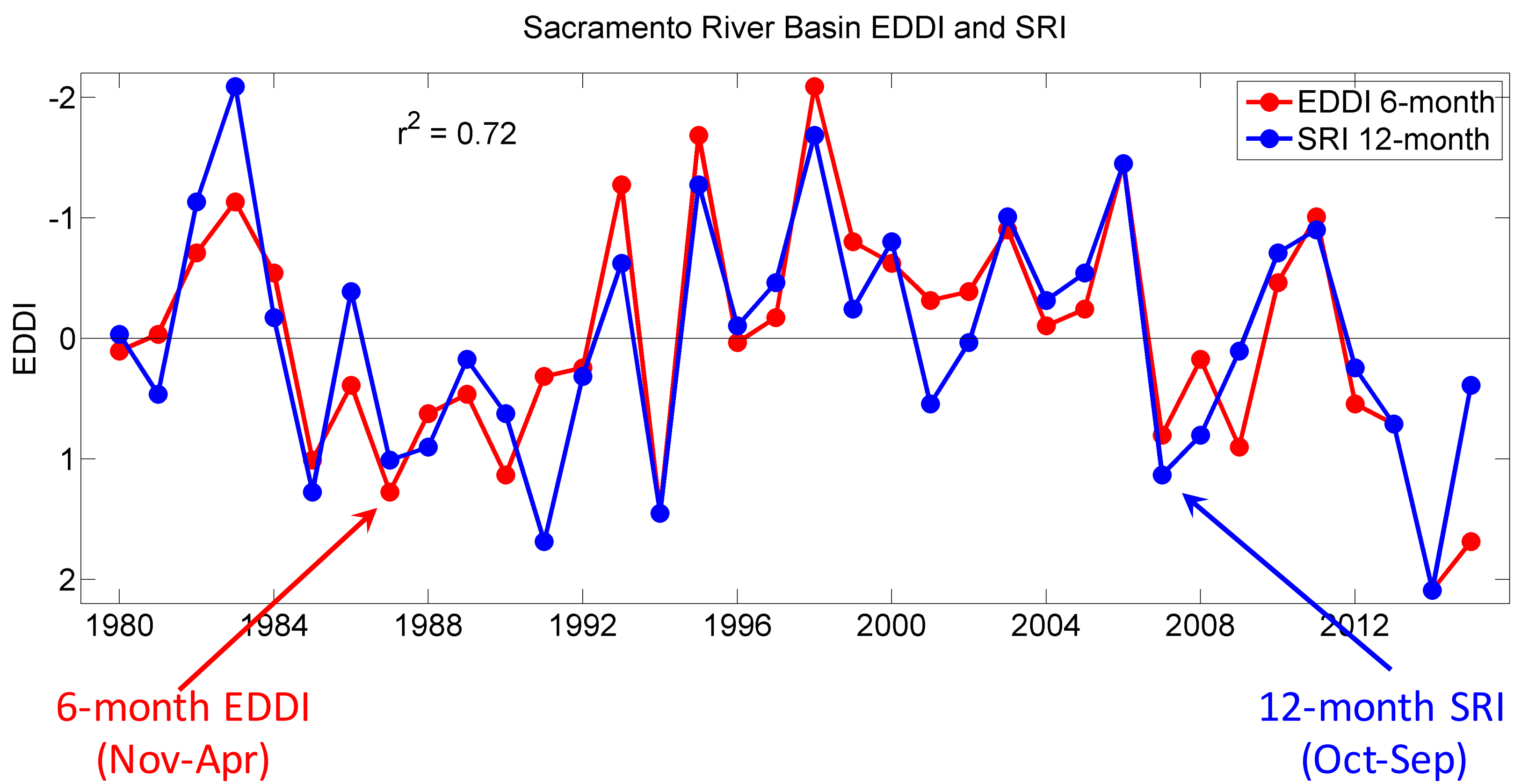




EDDI and hydrologic drought

EDDI and the Standardized Runoff Index (SRI)

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

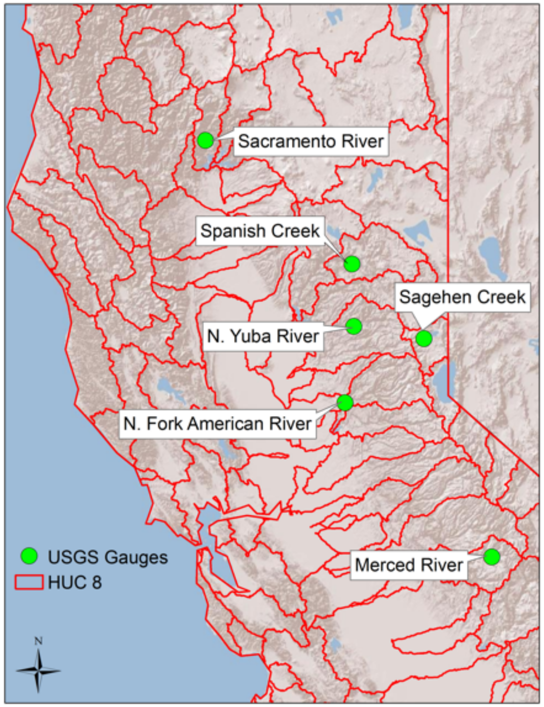


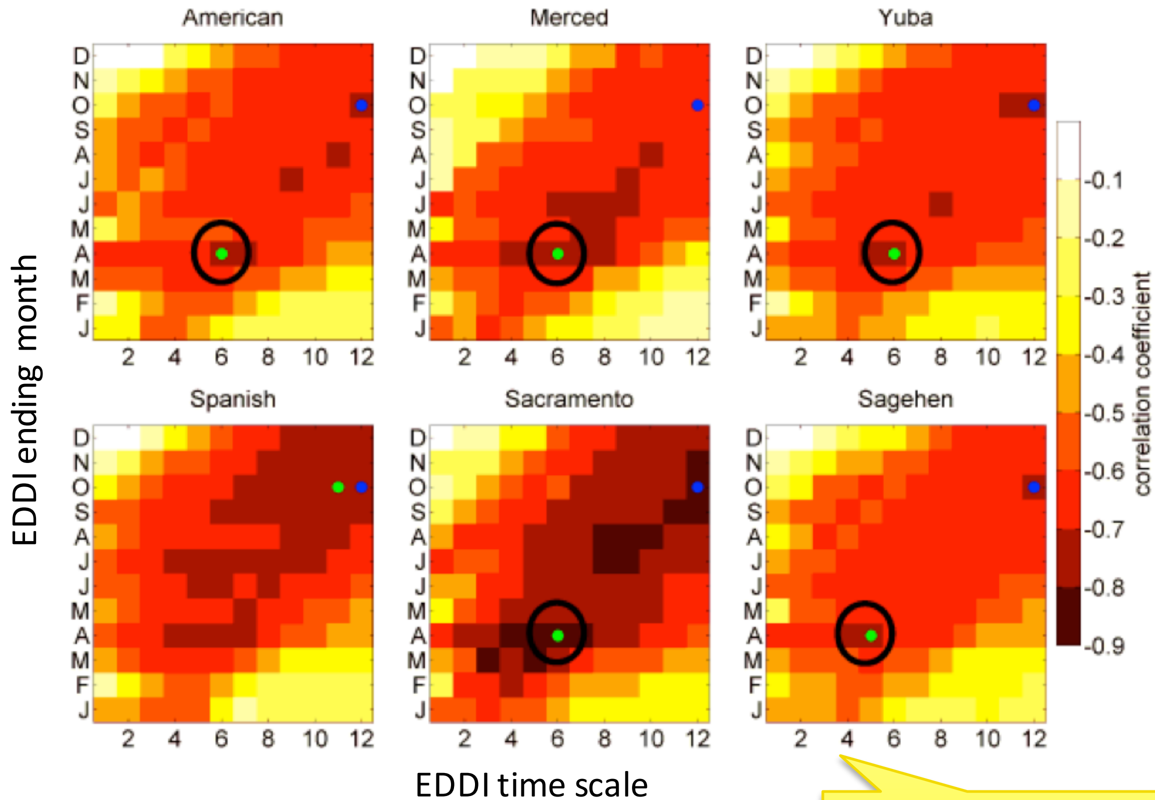
(McEvoy et al., 2014 - EDDI)

(Shukla and Wood, 2008 - SRI)

EDDI and hydrologic drought

EDDI vs. 12-month SRI

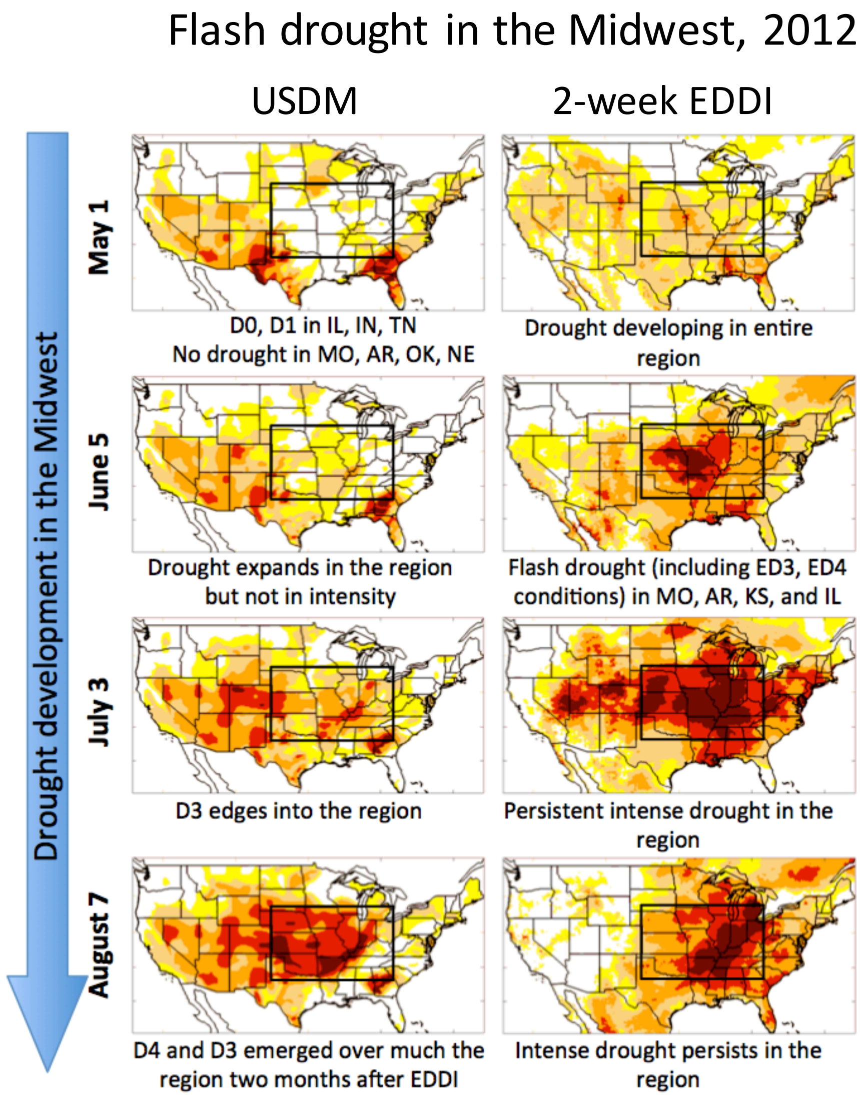




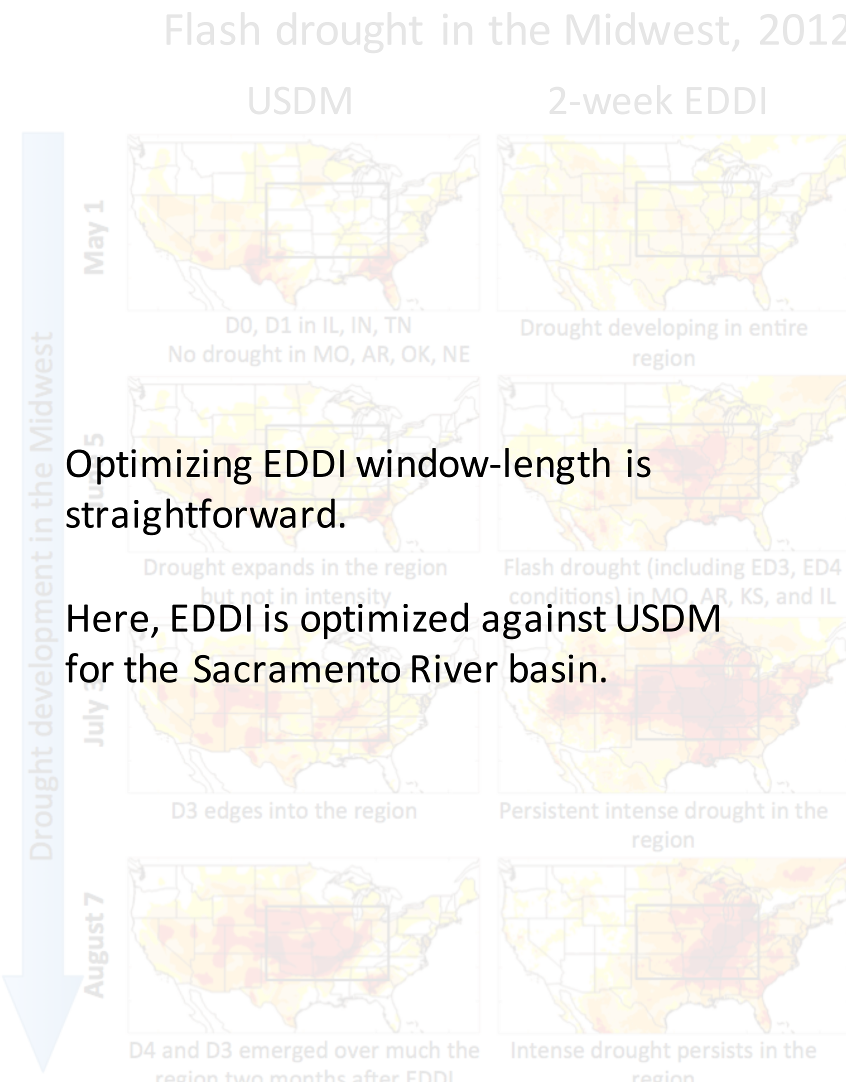
- At 5 sites, 6-month EDDI (Nov-Apr) shows strongest relationship to SRI.
- October-April E_0 explains greatest variance in WY streamflow (i.e., Oct 1-Sep 30).
- Highlights EDDI's predictive capability.

EDDI contains no Prcp information!

EDDI as a leading indicator of drought

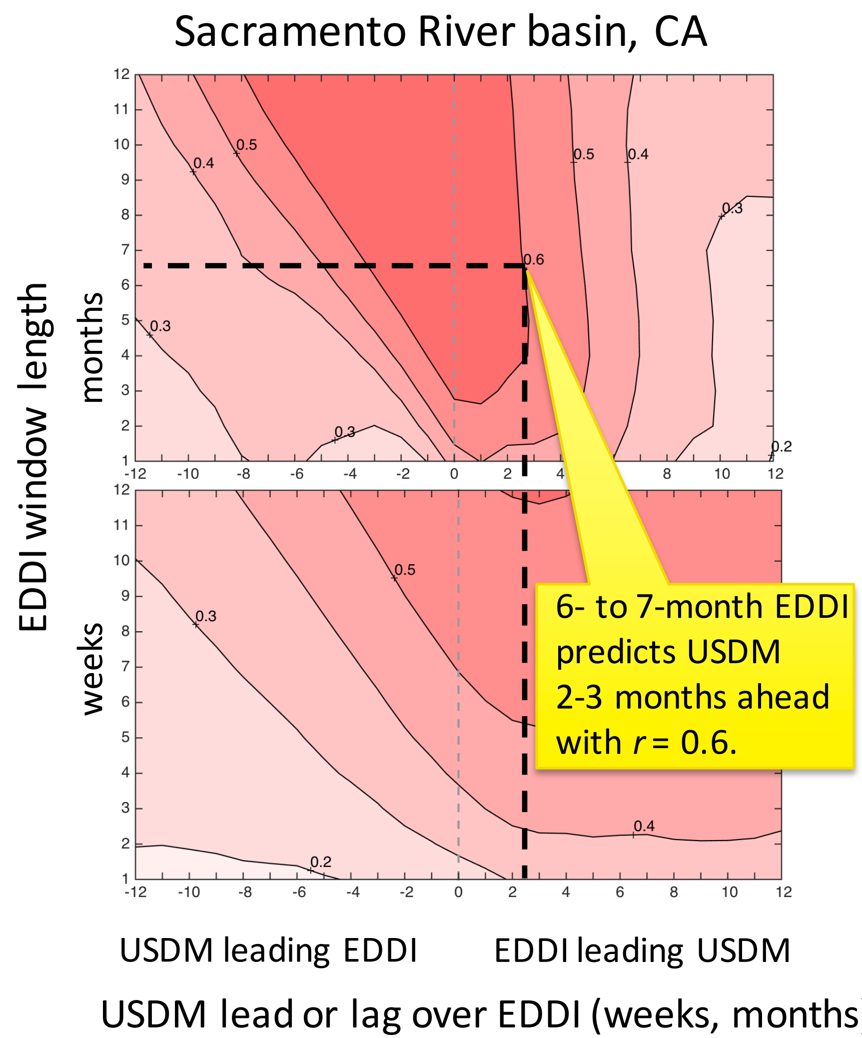


EDDI as a leading indicator of drought



Optimizing EDDI window-length is straightforward.

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

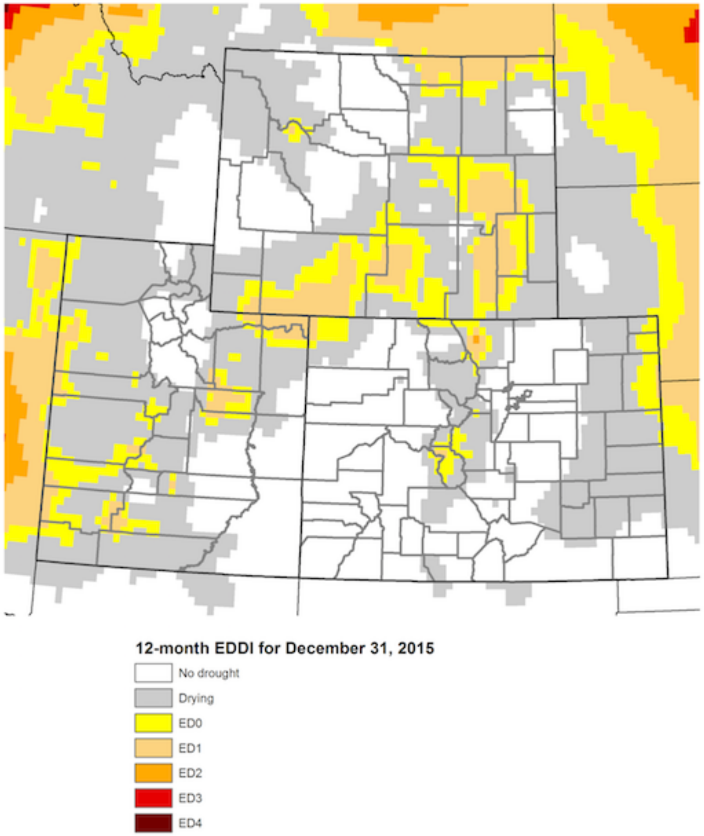


Example products

EDDI for December, 2015

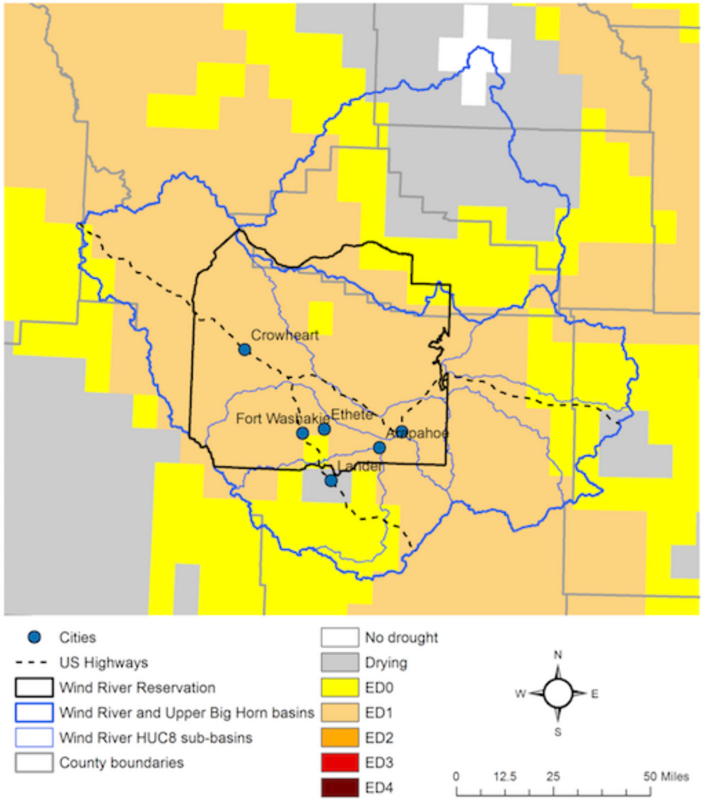
For Colorado Climate Center / Upper Colorado River Basin Drought Early Warning System

12-month EDDI, December 31



For USDM / Wind River reservation

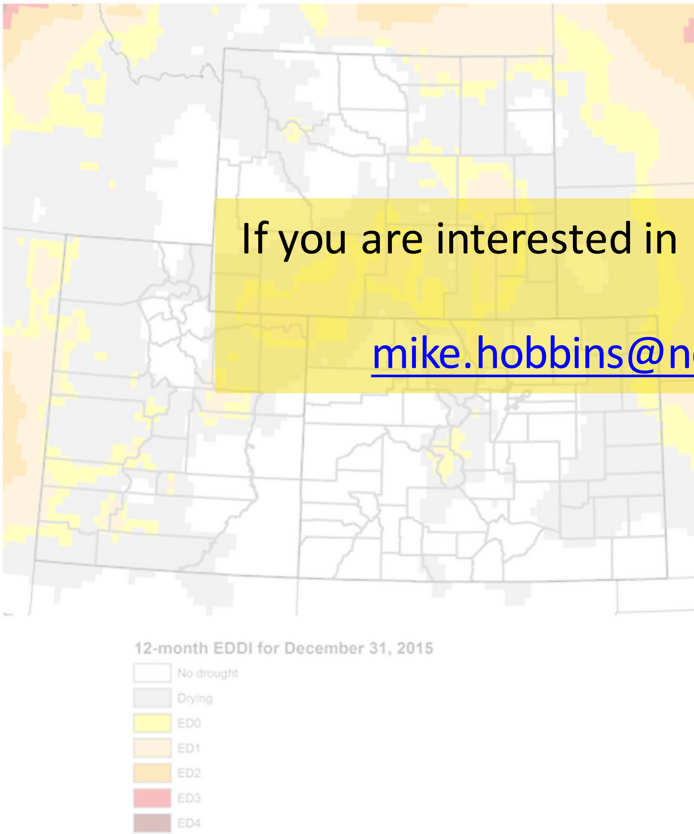
12-week EDDI, December 2



Example products
EDDI for December, 2015

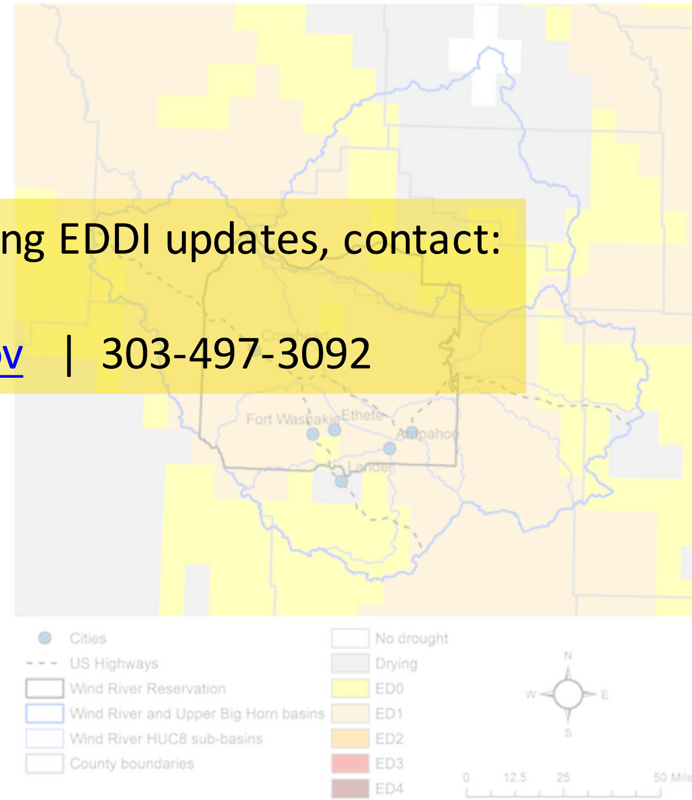
For Colorado Climate Center / Upper Colorado River Basin Drought Early Warning System

12-month EDDI, December 31



For USDM / Wind River reservation

12-week EDDI, December 2



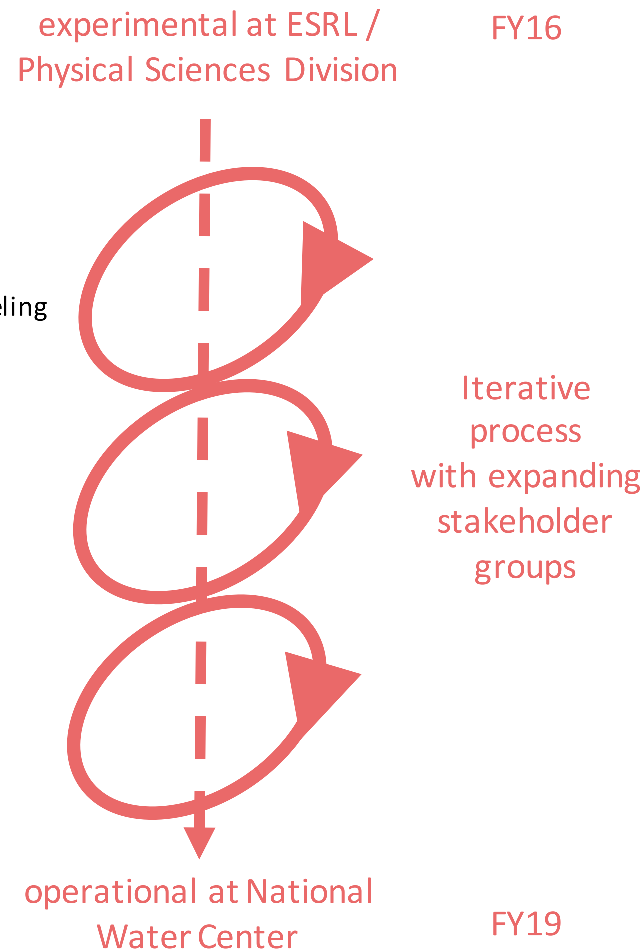
If you are interested in receiving EDDI updates, contact:

mike.hobbins@noaa.gov | 303-497-3092

Future work on EDDI

Operationalizing EDDI at National Water Center

- Two papers to appear in <u>Journal of Hydrometeorology</u>
- 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



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)