Measuring, Quantifying and Reporting Drought Impacts Workshop

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Desert Research Institute

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University of Nevada Reno

Emerging Approaches to Measuring Drought Impacts

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USGS/Earth Resources Observation Systems

Evaporative demand: drought impacts and assessment

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and

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Environmental Modeling Center

National Centers for Environmental Prediction-NOAA

E_0 = evaporative demand

ET_{rc} = reference ET

Background

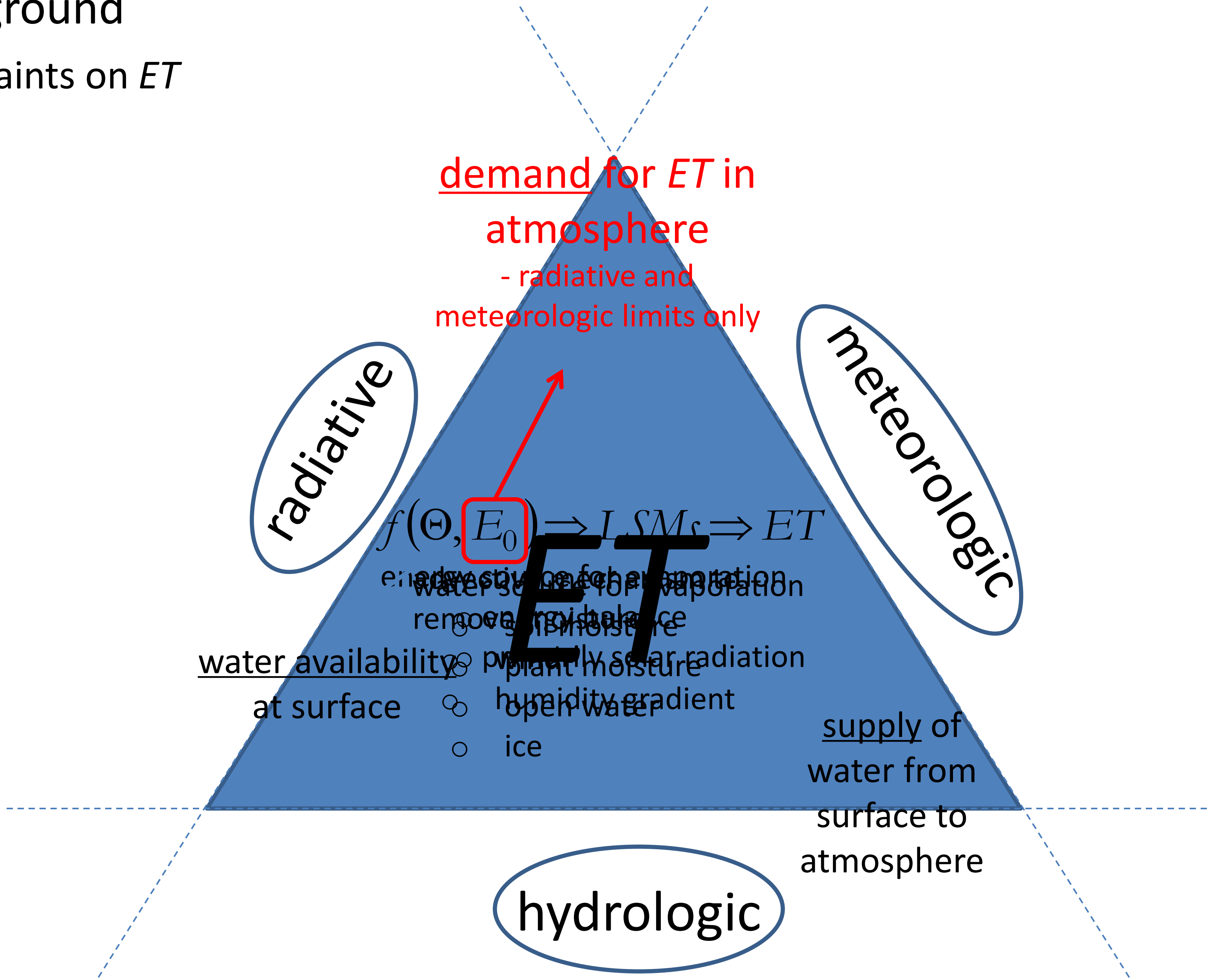
1. E_0 work at NOAA and NIDIS

2. E_0 as a stand-alone drought metric

3. ET_{rc} as a better drought model driver

Background

Constraints on *ET*



Background

Types of evaporative demand E_0

- potential evaporation
- reference crop *ET*, ET_{rc}

<u>MODELED</u>:

complete physics:
- SW radiation
- LW radiation
- air temperature
- humidity
- wind speed
- atmospheric pressure

temperature-based:
- air temperature
- T_{max}
- T_{min}

- pan evaporation

<u>OBSERVED</u>: physically integrates all above drivers

Background

ET_{rc} concept

Reference crop ET – idealized ET from a reference crop under strictly specified surface and moisture conditions:

- alfalfa, 0.5 m high
- actively growing,
- completely shading the ground,
- albedo = 0.23.

ASCE-EWRI formulation of Penman-Monteith ET_{rc} eqn

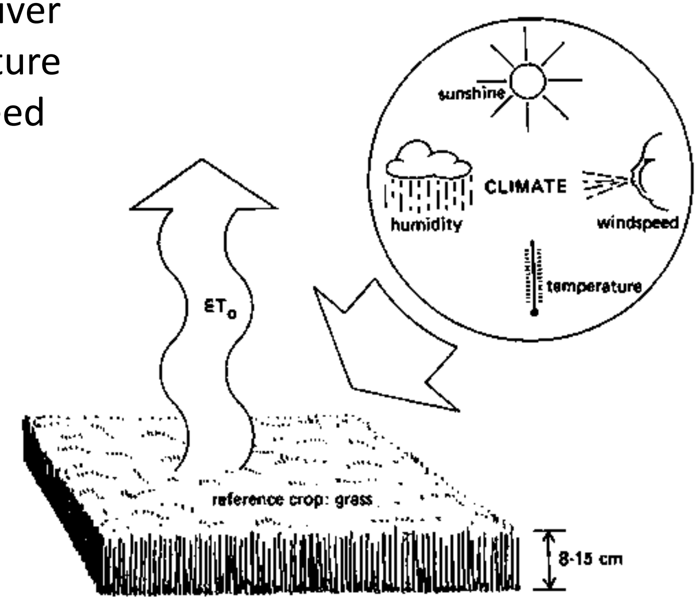
$$ET_{rc} = \frac{\Delta}{\Delta+\gamma(1+C_d U_2)}\frac{R_n - G}{\lambda} + \frac{\gamma}{\Delta+\gamma(1+C_d U_2)}\frac{C_n}{T}U_2\left(e_{sat}-e_a\right)$$

Radiative driver
- SW radiation
- LW radiation
- Ground heat flux

Advective driver
- Temperature
- Wind speed
- Humidity

$ET = ET_{fraction}.ET_{rc}$

ET_{rc} = reference crop ET
R_n = net radiation
G = ground heat flux
T = 2-m air temperature
e_{sat} = saturated vap. press.
e_a = actual vap. press.
U_2 = 2-m wind speed
λ = latent heat of vaporization
$\Delta = de_{sat}/dT$ at T
γ = psychrometric constant
C_d, C_n = constants



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1. E_0 work at NOAA and NIDIS

2. E_0 as a stand-alone drought metric

3. ET_{rc} as a better drought model driver

Goal of NOAA-NIDIS ET_{rc} project

Produce first consistently modeled, accurate CONUS-wide ET_{rc} dataset:

- up-to-date and temporally extensive, dynamic, physically based
- used/usable for:
  - National Water Census (NWC) as input to actual *ET* surface

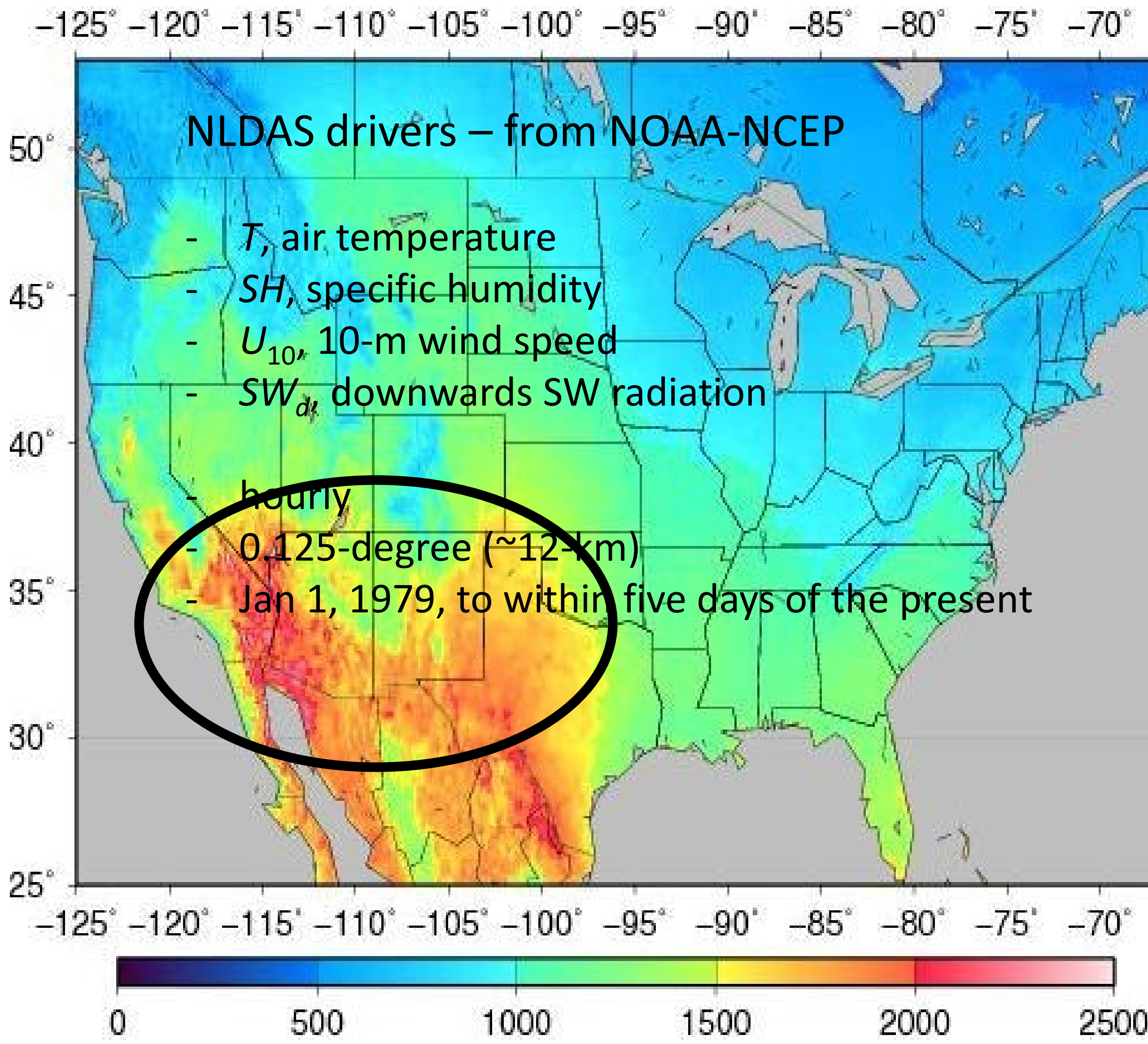
SECURE Water Act, 2009:

Provide stakeholders **technical information** and **tools** to answer two primary questions:

- Does the Nation have enough freshwater for human and ecological needs?
- Will this water be present for future needs?

NWC implementation of ET_{rc} input to ET component

Mean annual ET_{rc} 1980-2009 (mm/year)



NLDAS drivers – from NOAA-NCEP

- T, air temperature
- SH, specific humidity
- U_{10}, 10-m wind speed
- SW_d, downwards SW radiation

- hourly
- 0.125-degree (~12-km)
- Jan 1, 1979, to within five days of the present

ET component of the NWC

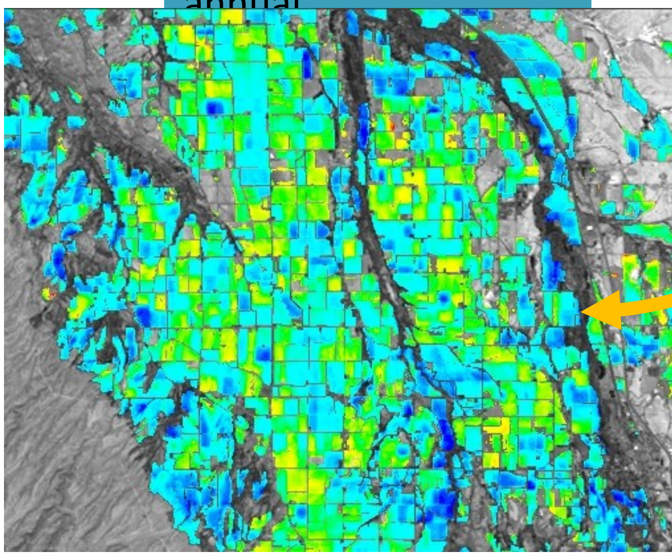
Initial capability

(lumped at HUC-12 level)

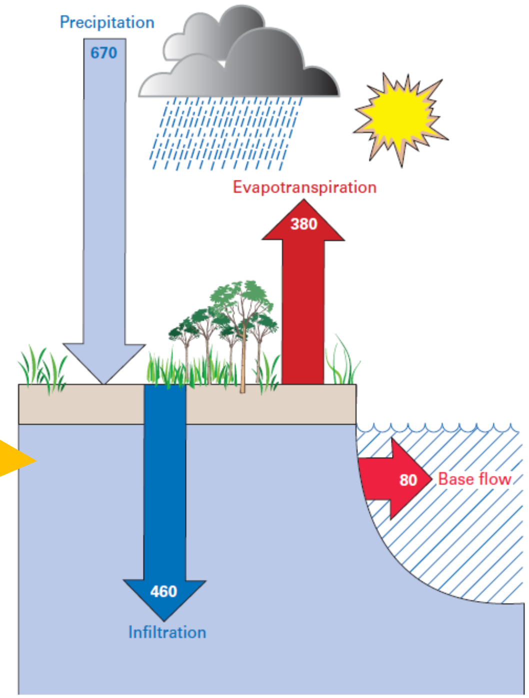
Crop location data
Cropland Data Layer
annual

Rem
LST,
16-d
30-1
USG

DIS)



Actual ET
- daily
- 100 m



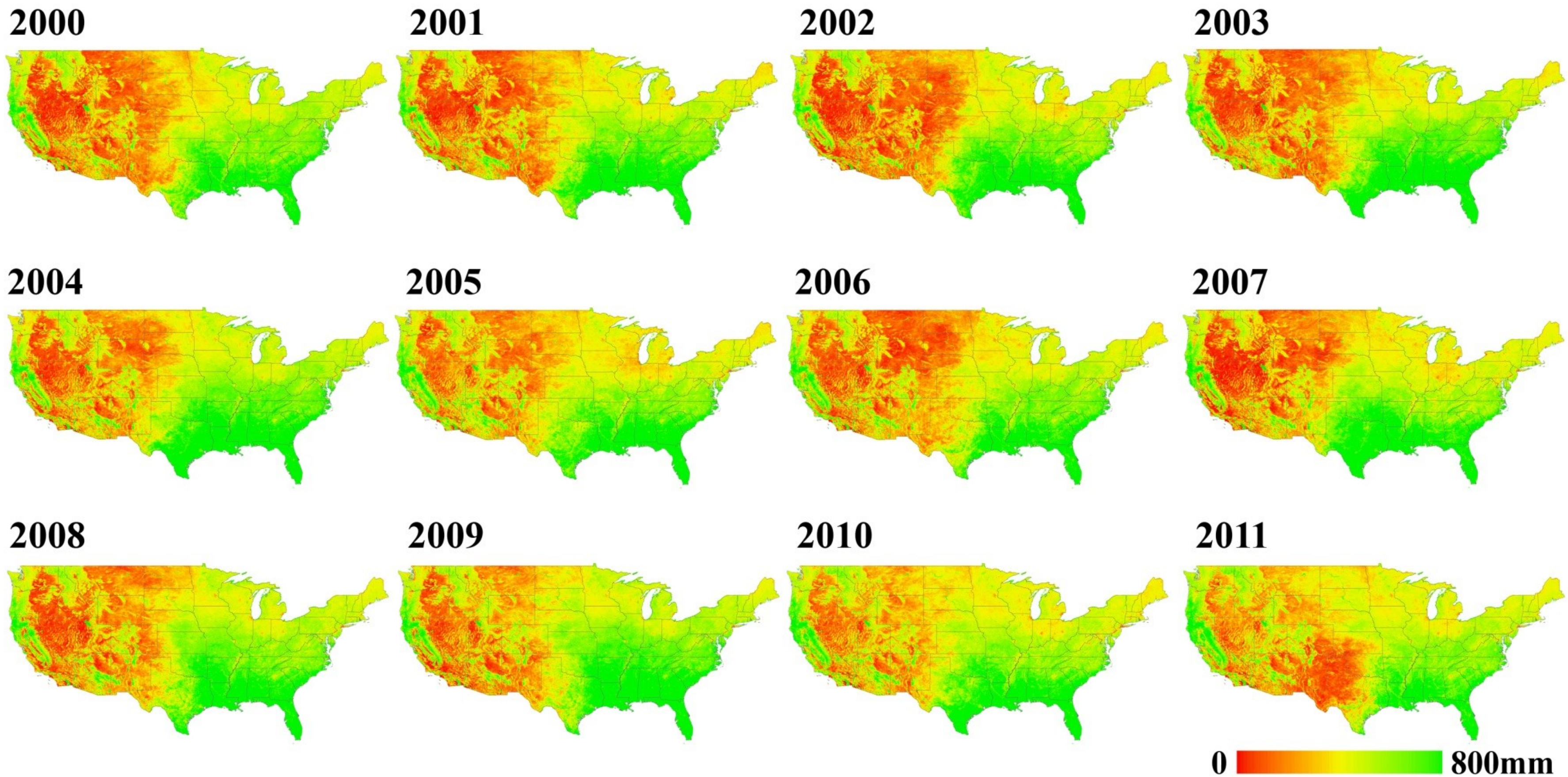
Water Use Evaluations:

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

Water Availability:

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

Annual CONUS-wide *ET* totals from MODIS



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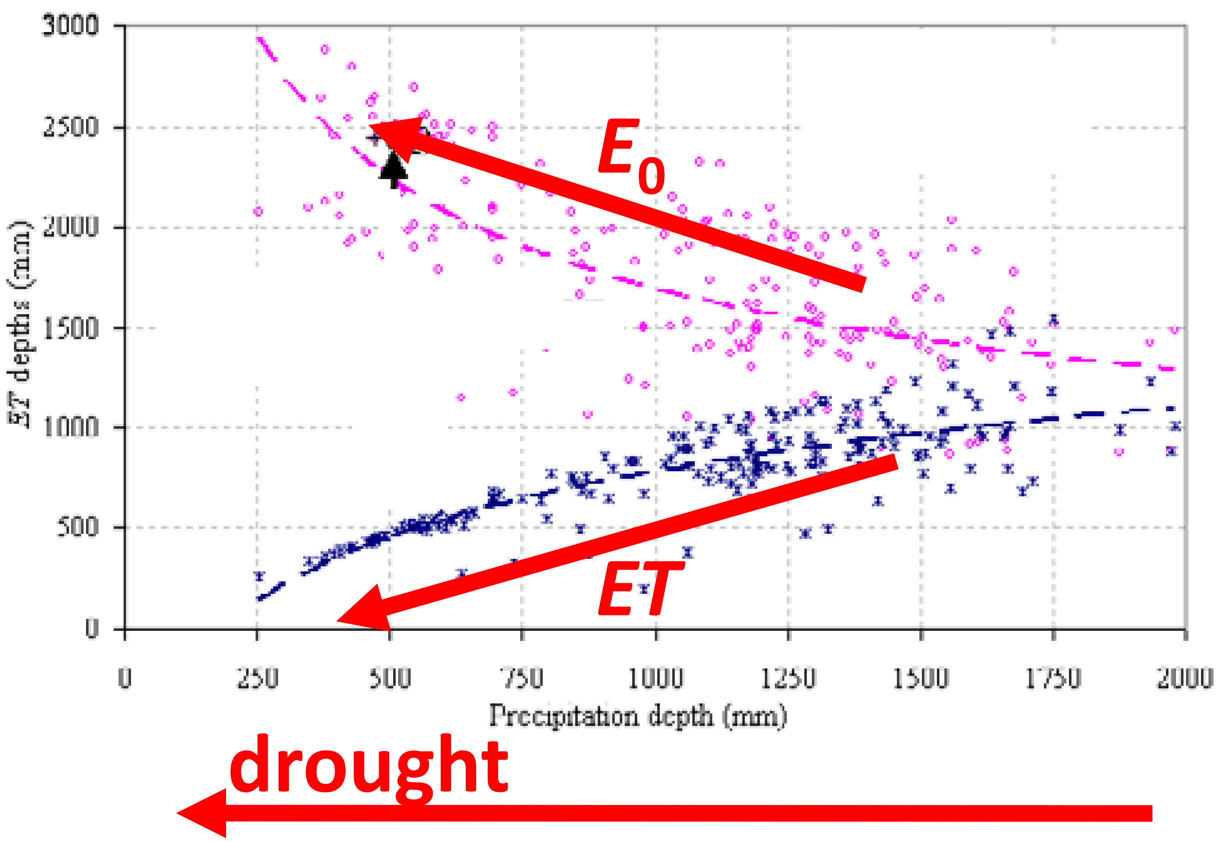
Evaporative Demand Drought Index, EDDI

E_0 reflects surface moisture anomalies, driven by actual *ET*

Droughts:

- *alter* decrease *ET* due to moisture limitations at the surface
- increase E_0 due to surface energy balance tipping in favor of sensible heat



Hobbins et al., GRL, 2004

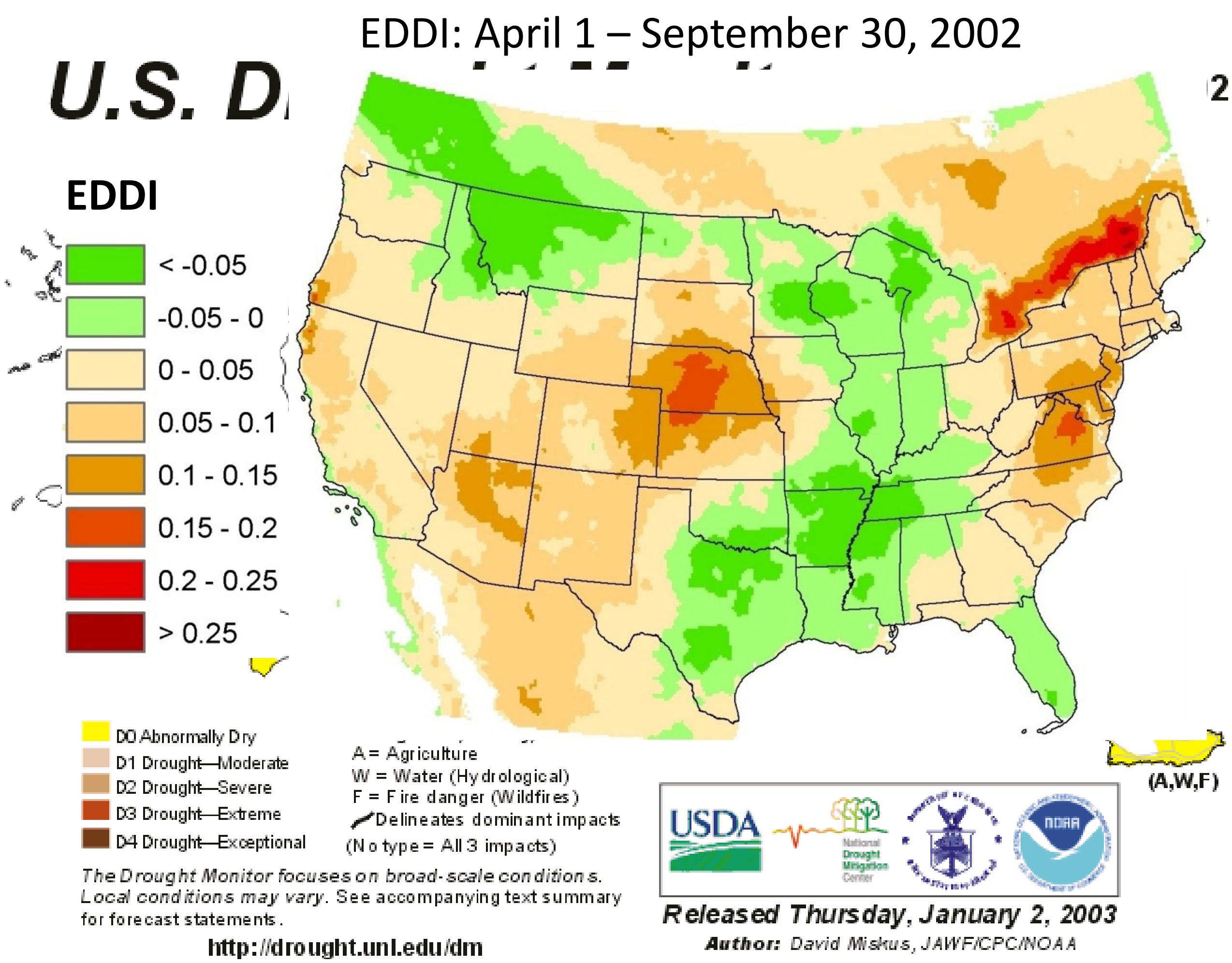
Evaporative Demand Drought Index, EDDI

$$EDDI_i = \frac{\sum_{\text{i=start}}^{\text{end}} \left\{ ET_{rc_i} - \overline{ET_{rc\,i}} \right\}}{\sum_{\text{i=start}}^{\text{end}} \overline{ET_{rc\,i}}}$$

$$EDDI \begin{cases} > 0 & \text{positive anomaly in } E_0\text{, } \textbf{DROUGHT} \\ = 0 & \text{climatologic } E_0 \\ < 0 & \text{negative anomaly in } E_0 \end{cases}$$

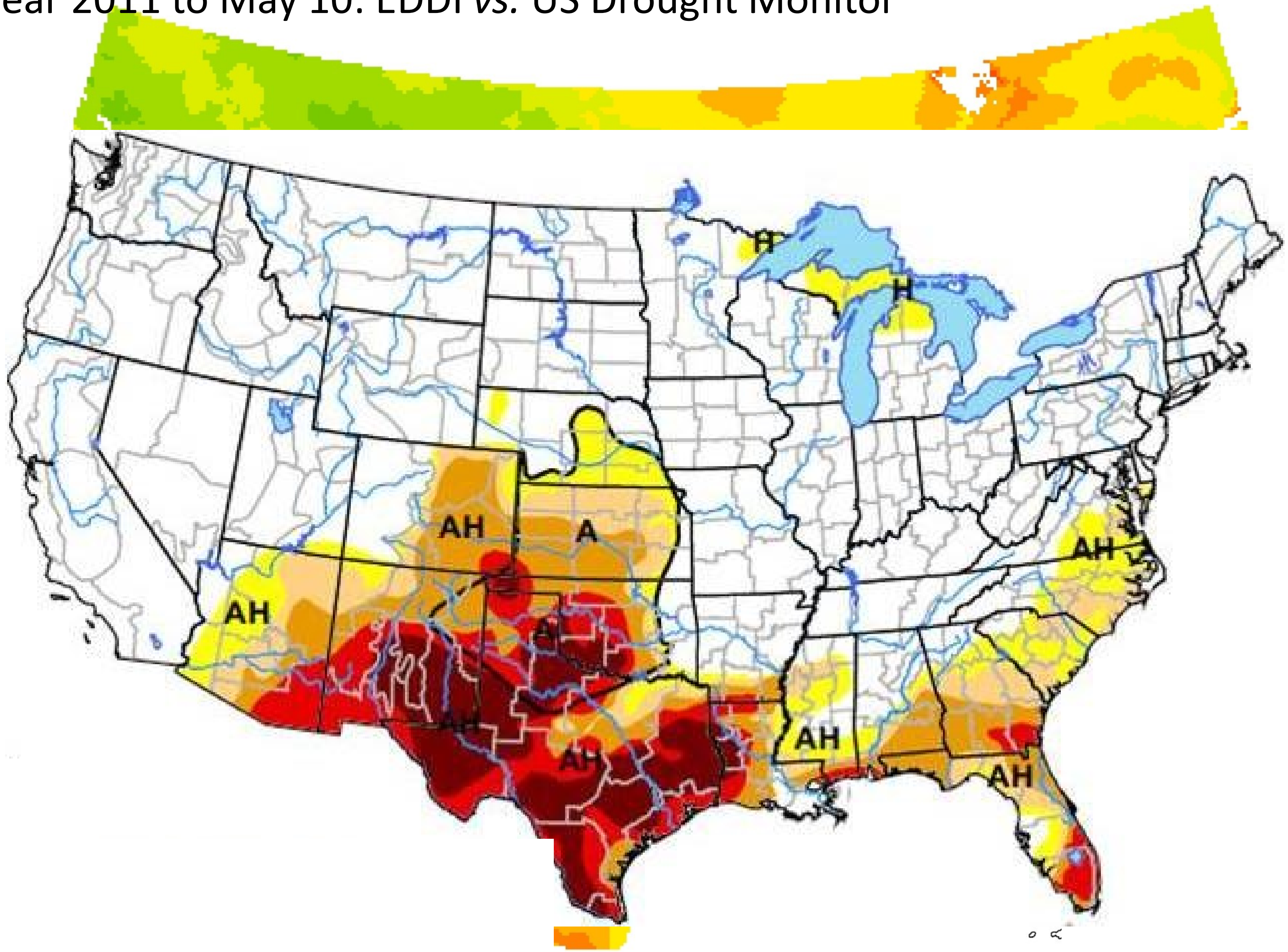
Evaporative Demand Drought Index, EDDI:

2002 drought: EDDI *vs.* US Drought Monitor



Evaporative Demand Drought Index, EDDI:

Water Year 2011 to May 10: EDDI *vs.* US Drought Monitor

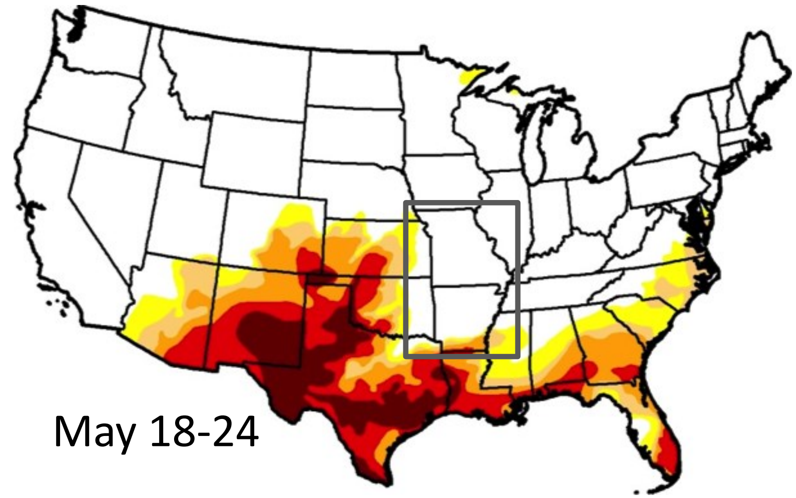


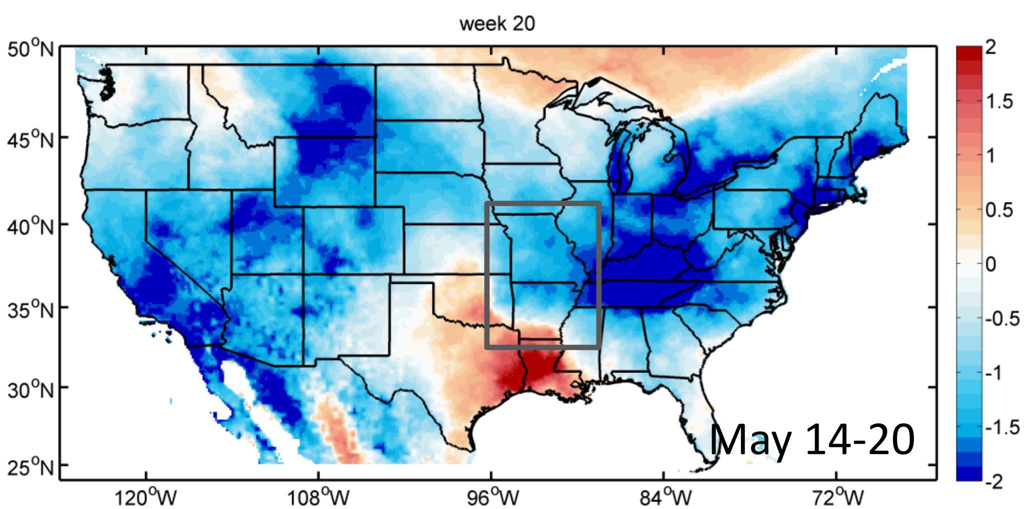
http://www.drought.unl.edu/dm/archive/20110510/pdfs/total_dm_110510.pdf - accessed May 17, 2011

Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor

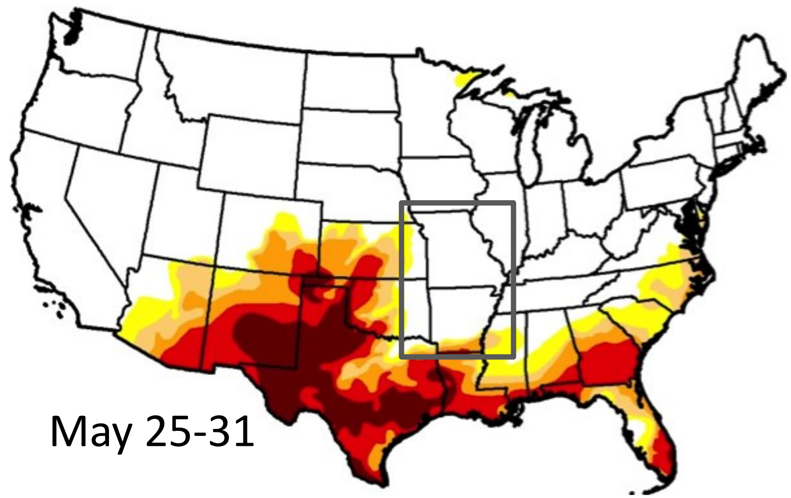
Flash drought:
- not initiated by Prcp deficits but by heat, wind, radiation, or low humidity, or combination.



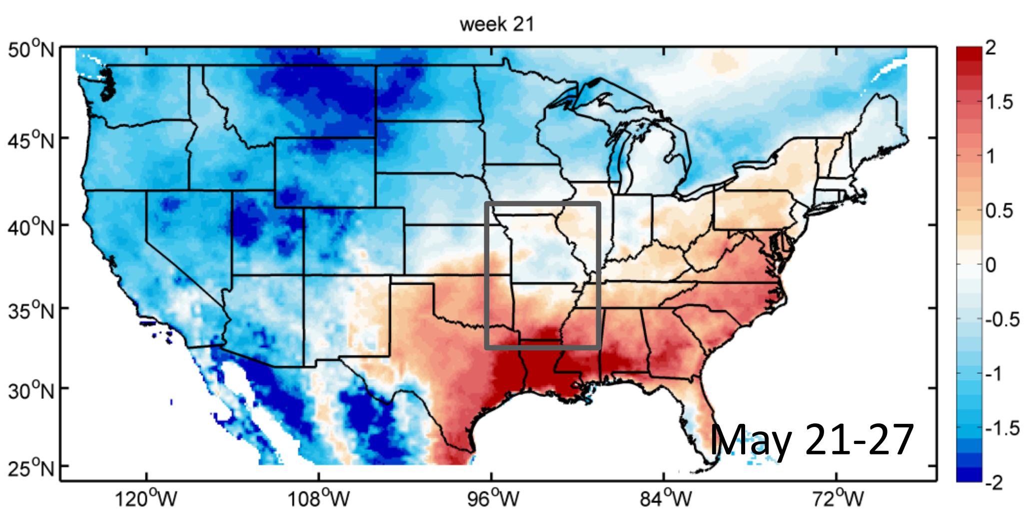


Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



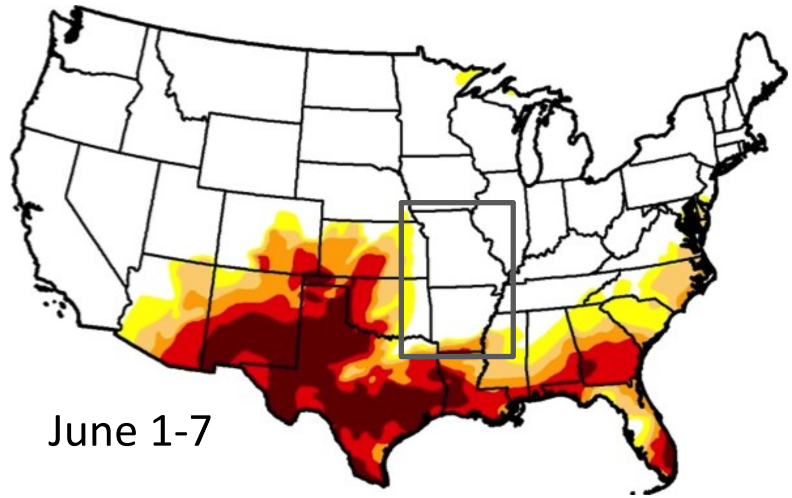
EDDI: drought creeps into AR, MO



USDM: no drought in AR, MO

Evaporative Demand Drought Index, EDDI:

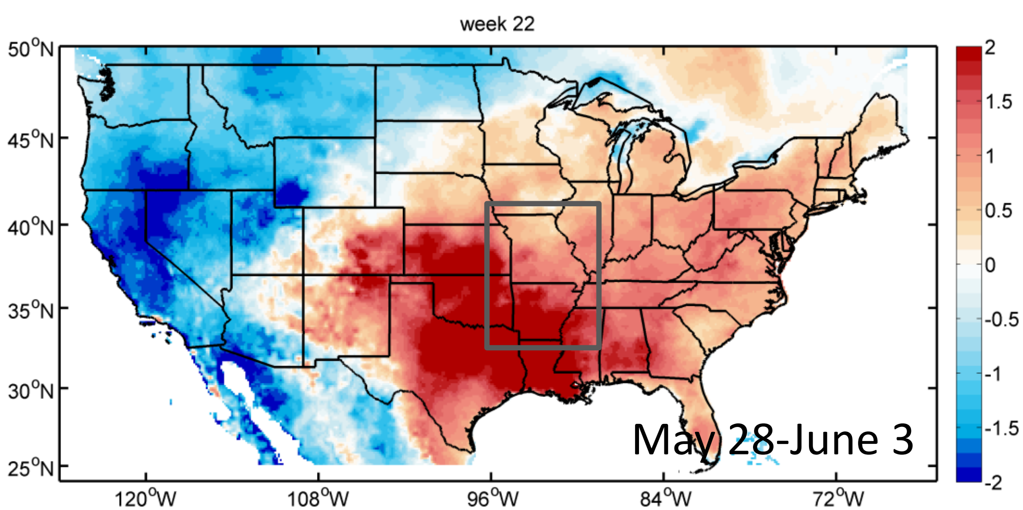
2011 flash drought: EDDI *vs.* US Drought Monitor



June 1-7

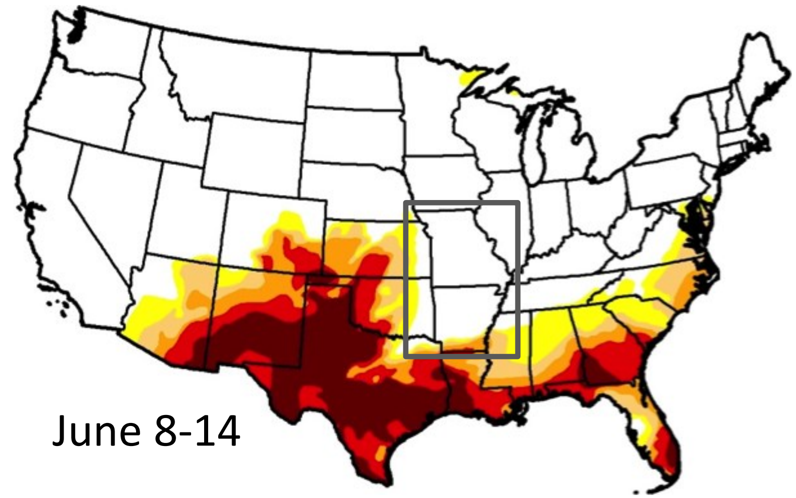
EDDI: drought intensifies, persists over AR, MO

USDM: almost no change over AR, MO

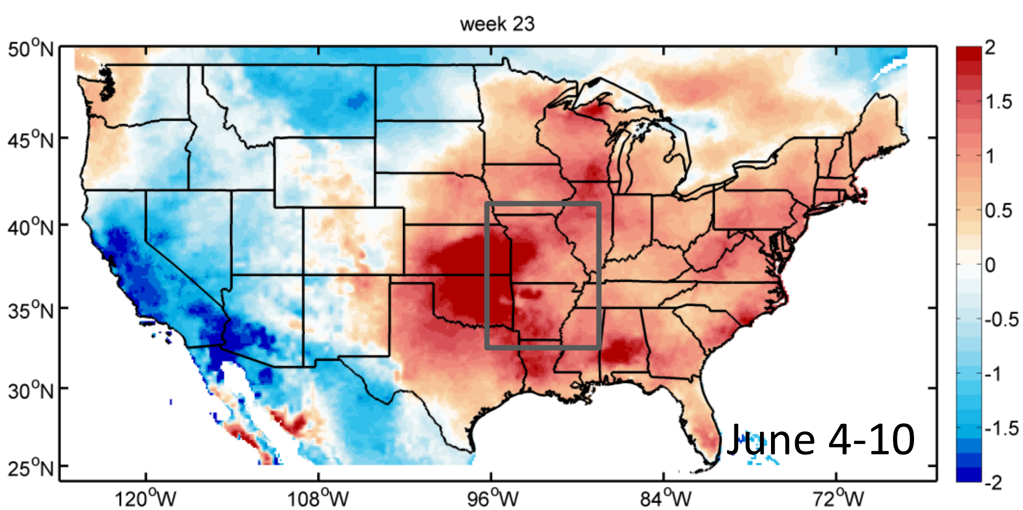


Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



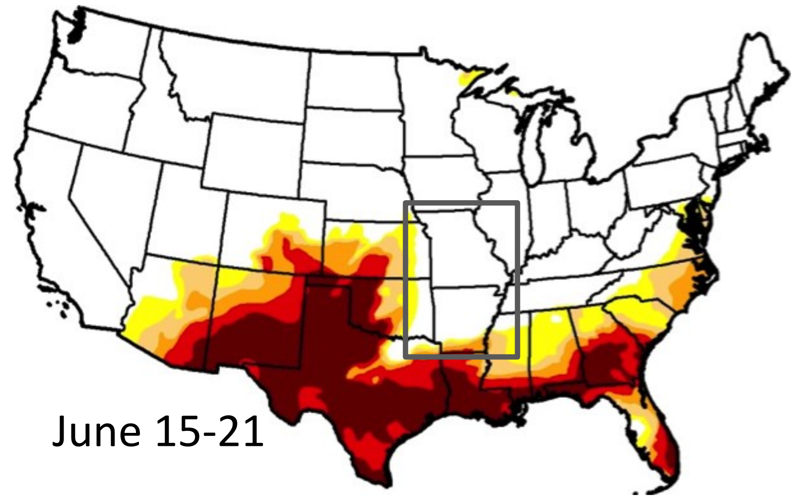
EDDI: drought intensifies, persists over AR, MO

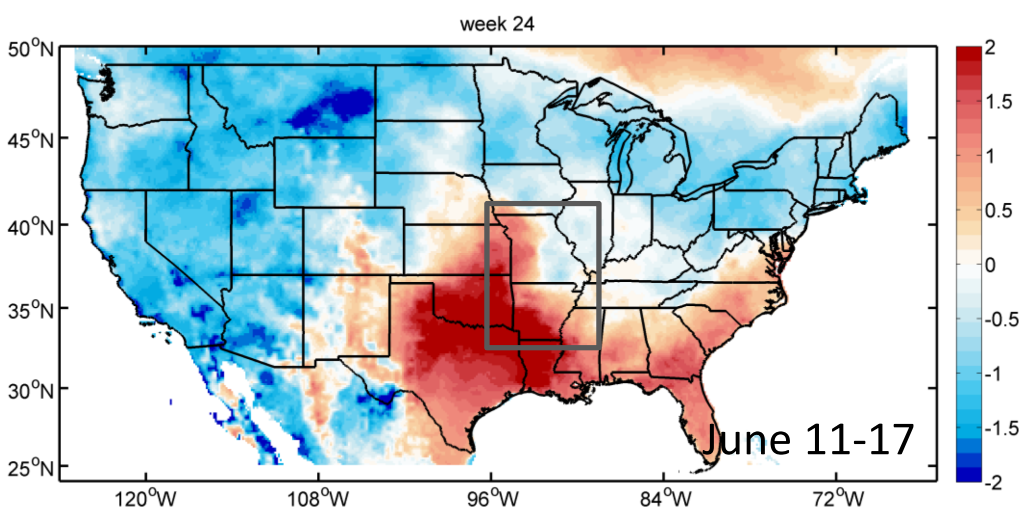


USDM: almost no change over AR, MO

Evaporative Demand Drought Index, EDDI:

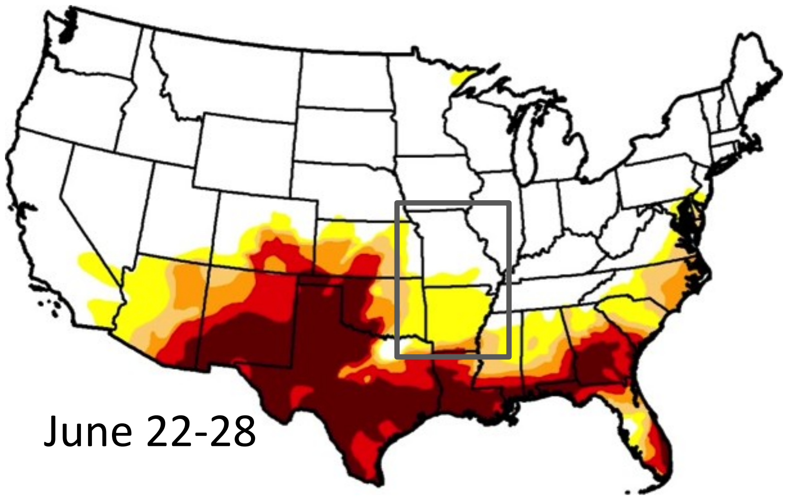
2011 flash drought: EDDI *vs.* US Drought Monitor



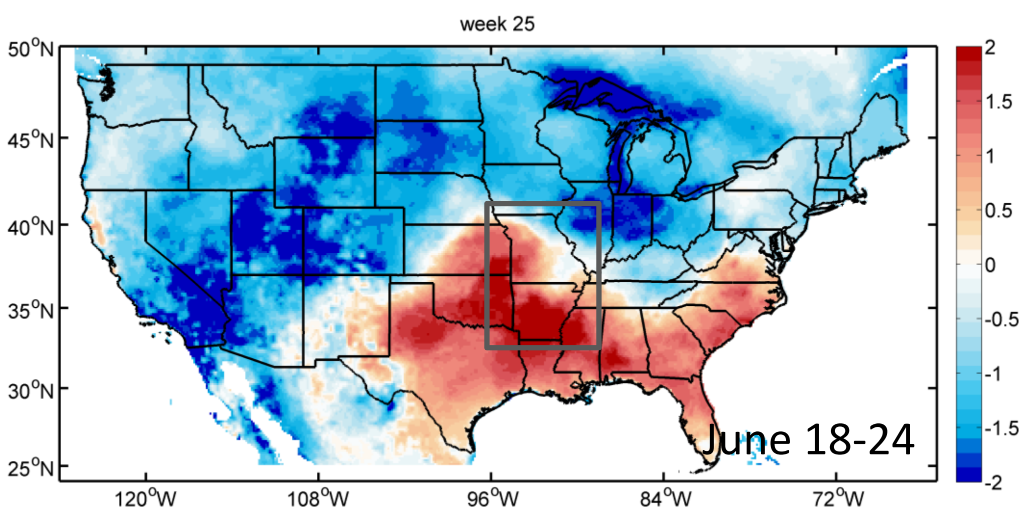


Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



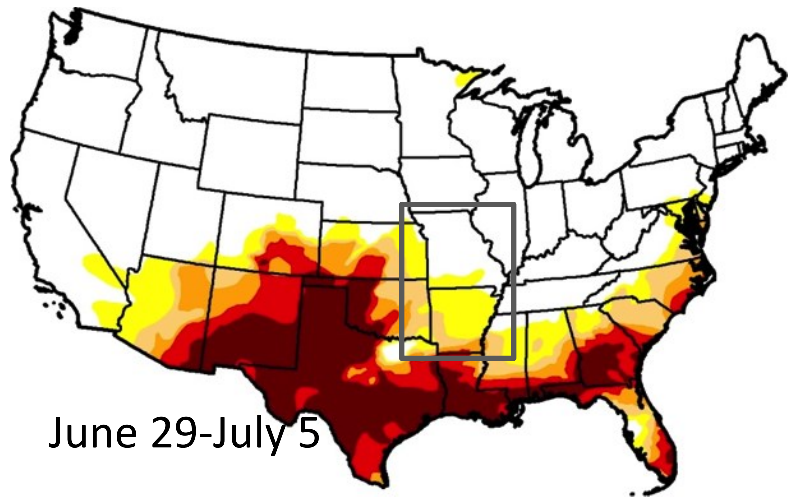
EDDI: persistent drought



USDM: D1 finally introduced into AR

Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



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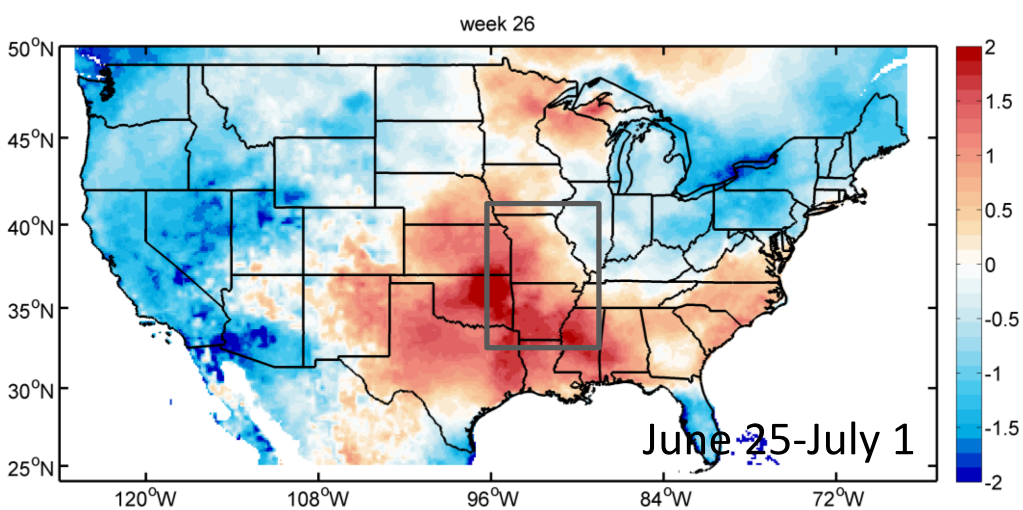
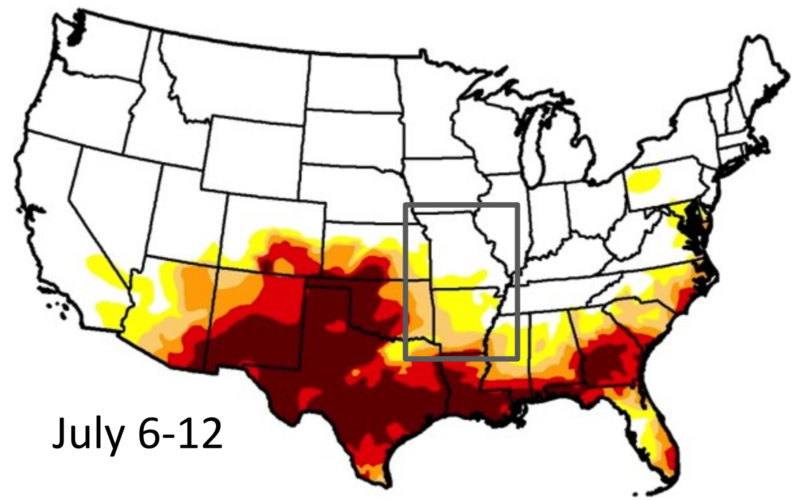
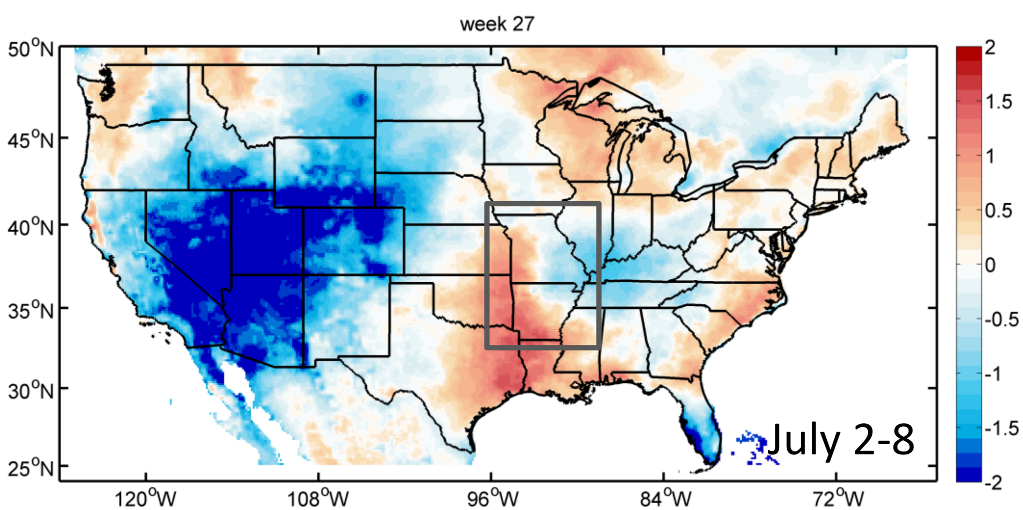


Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor





Evaporative Demand Drought Index, EDDI:

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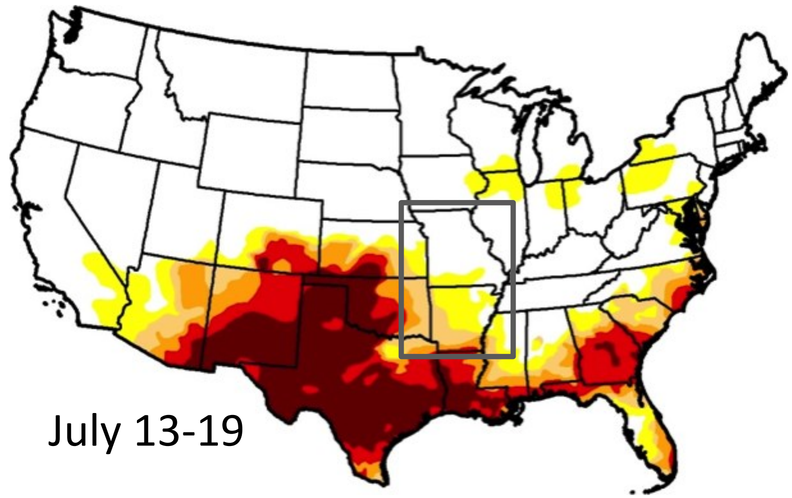
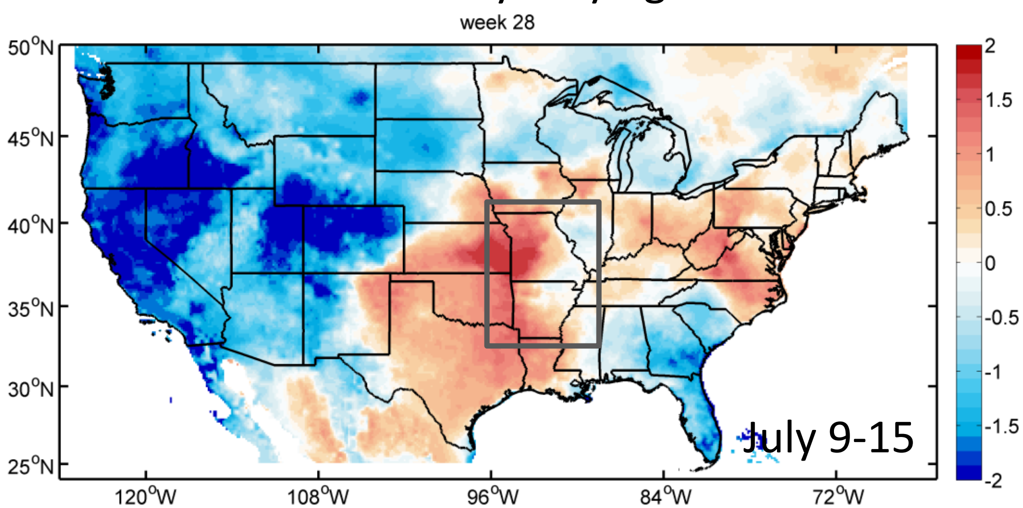


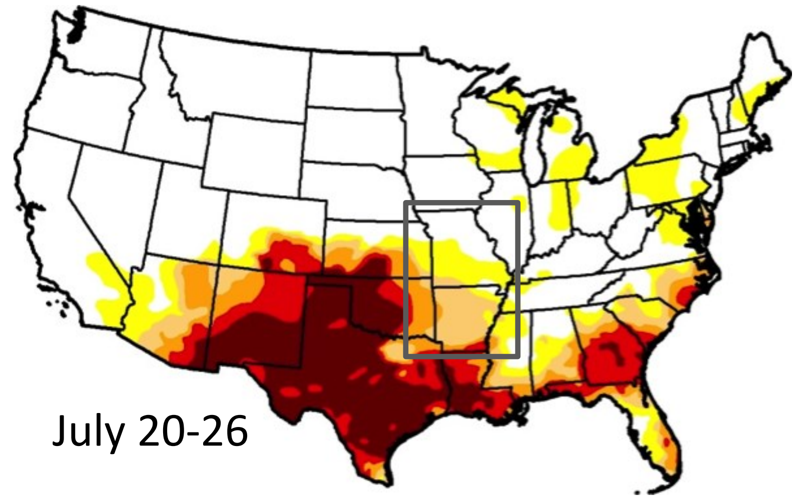
USDM: D1 slowly introduced into MO, D2 into AR

EDDI: continues to show drought in both AR and MO, intensity varying



Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



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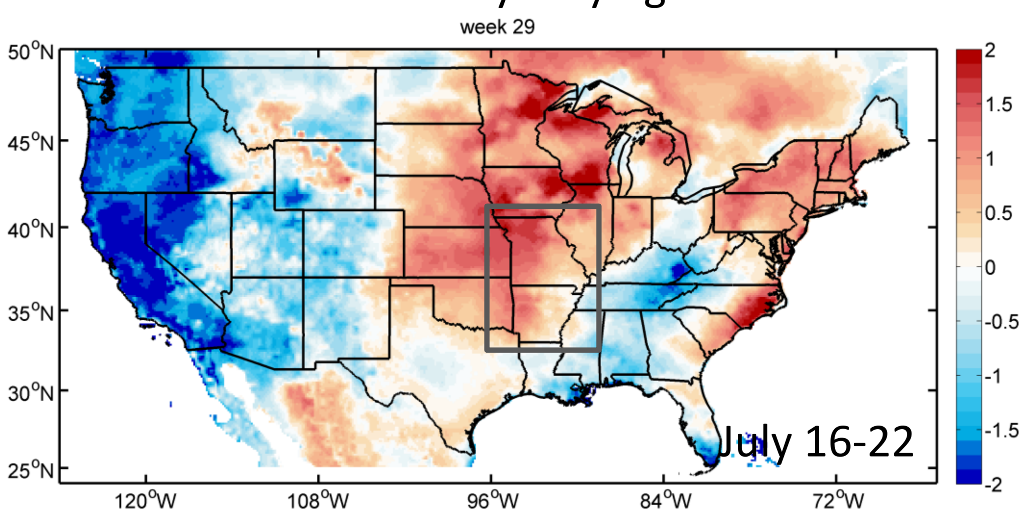
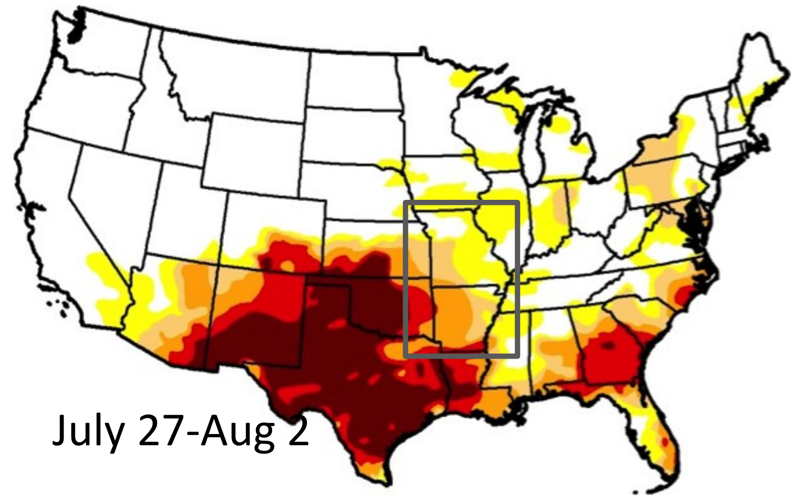


USDM: D1 slowly introduced into MO, D2 into AR

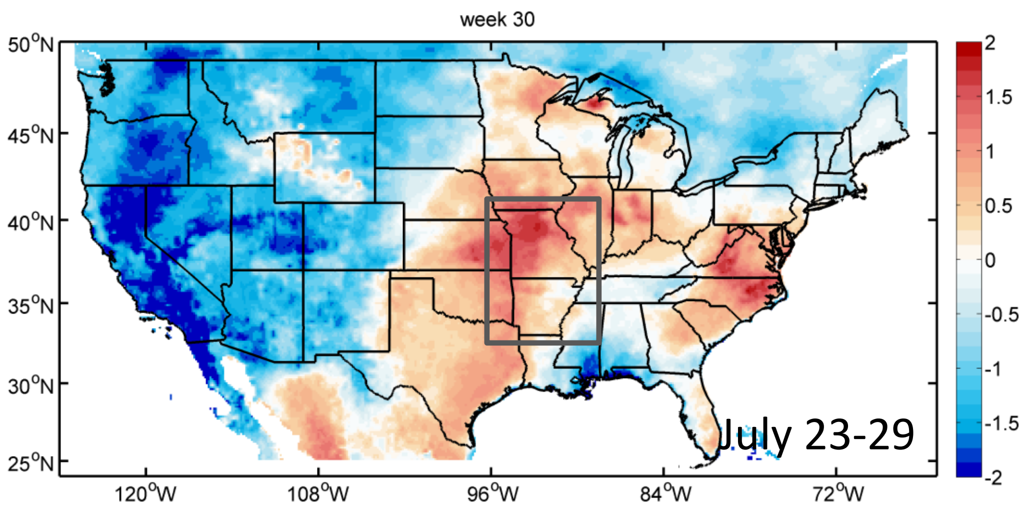
Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



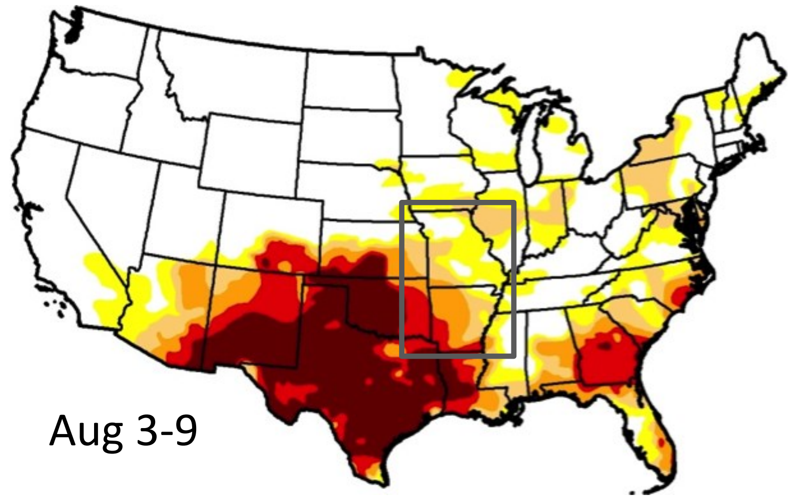
EDDI: drought persisting

USDM: introduces D2 into MO, D3 into parts of AR

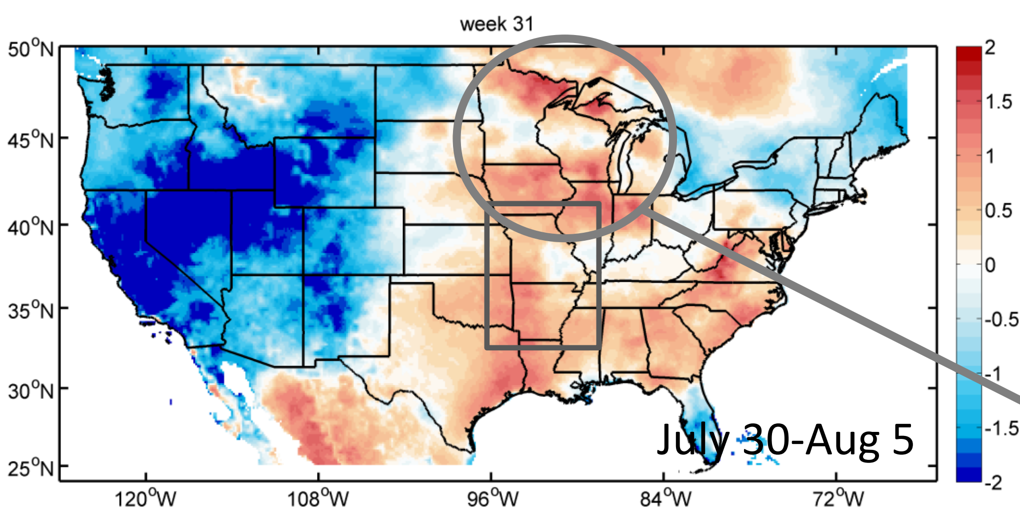


Evaporative Demand Drought Index, EDDI:

2011 flash drought: EDDI *vs.* US Drought Monitor



EDDI: drought persisting



USDM: introduces D2 into MO,
D3 into parts of AR

… from September, USDM shows drought spreading into upper Midwest. EDDI shows this a month prior.

Background

1. E_0 work at NOAA and NIDIS

2. E_0 as a stand-alone drought metric

3. ET_{rc} as a better drought model driver

Dangers of T-based E_0 parameterizations

Regional long-term trends and the Palmer Drought Severity Index (PDSI)

IPCC AR4 concluded that warming results in:

- globally, drou ... ed to grow,
- droughts exp ... extensive.

PDSI hydrology model forced by E_0 based on T alone.

BUT:

comparing physically based E_0 vs. T-based E_0:

- E_0 trends (30-year, observed) driven by wind, not T

  – Australia [Roderick et al., GRL, 2007]

- PDSI-derived water balance trends vary significantly

  ... L, 2008]

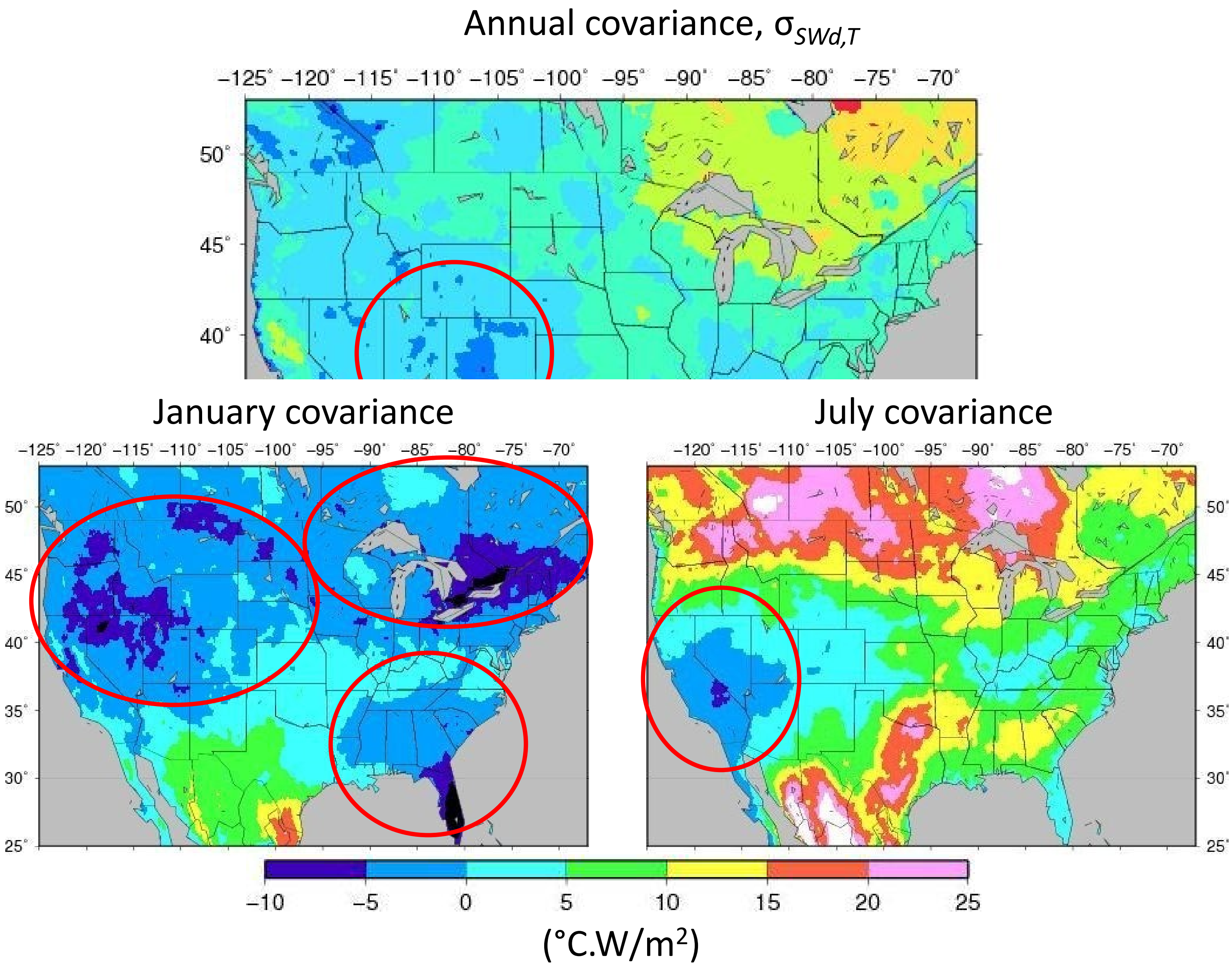
Causal link in T-based drought analyses is often reversed: increased T often results from drought, doesn't force it.

  - differences in E_0 trends (T-based E_0 +ve everywhere, physical only ~60%): global dimming; stilling; *VPD* changes
  - differences in signs of PDSI trend signs (T-based +ve over 7x physical-based area)

  – global [Sheffield et al., Nature, 2012]

Debunking the T-driven E_0 philosophy

How do T and SW_d co-vary?



Hobbins at el., JHM, 2012

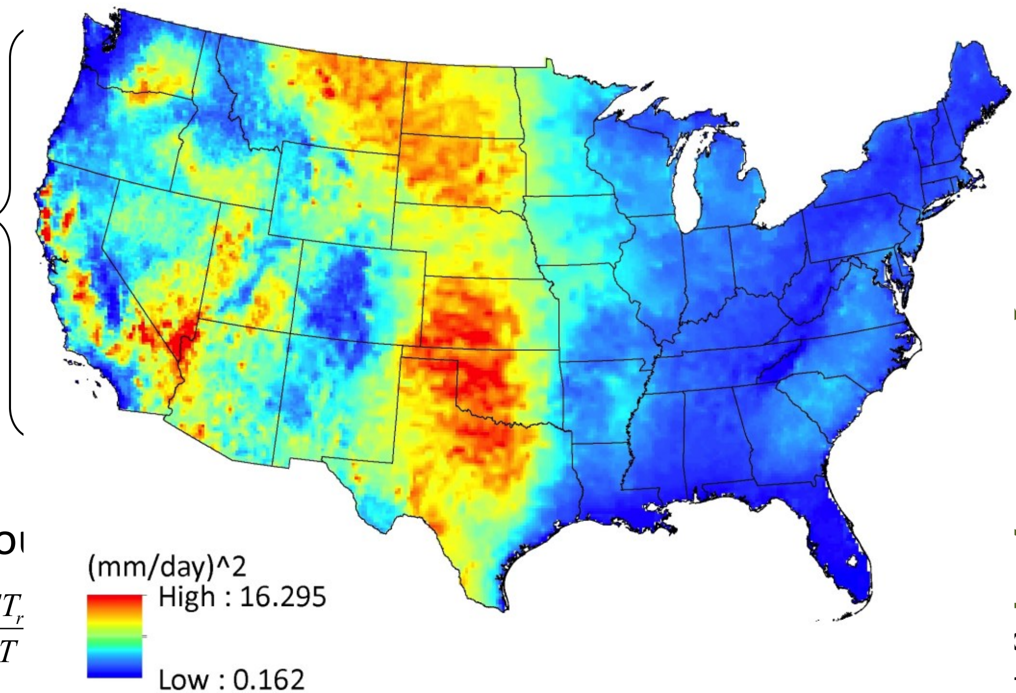
Analytic decomposition of ET_{rc} changes

Two opportunities in drought analysis

$$ET_{rc} = \frac{\Delta}{\Delta+\gamma(1+C_d U_2)}\frac{R_n - G}{\lambda} + \frac{\gamma}{\Delta+\gamma(1+C_d U_2)}\frac{C_n}{T}U_2(e_{sat}-e_a) \boxed{= g\{(T, SH, U_{10}, SW_d\}}$$

(1) Rigorous variability analysis

$$\sigma^2_{ET_{rc}} \square \{$$



(2) Flash drou

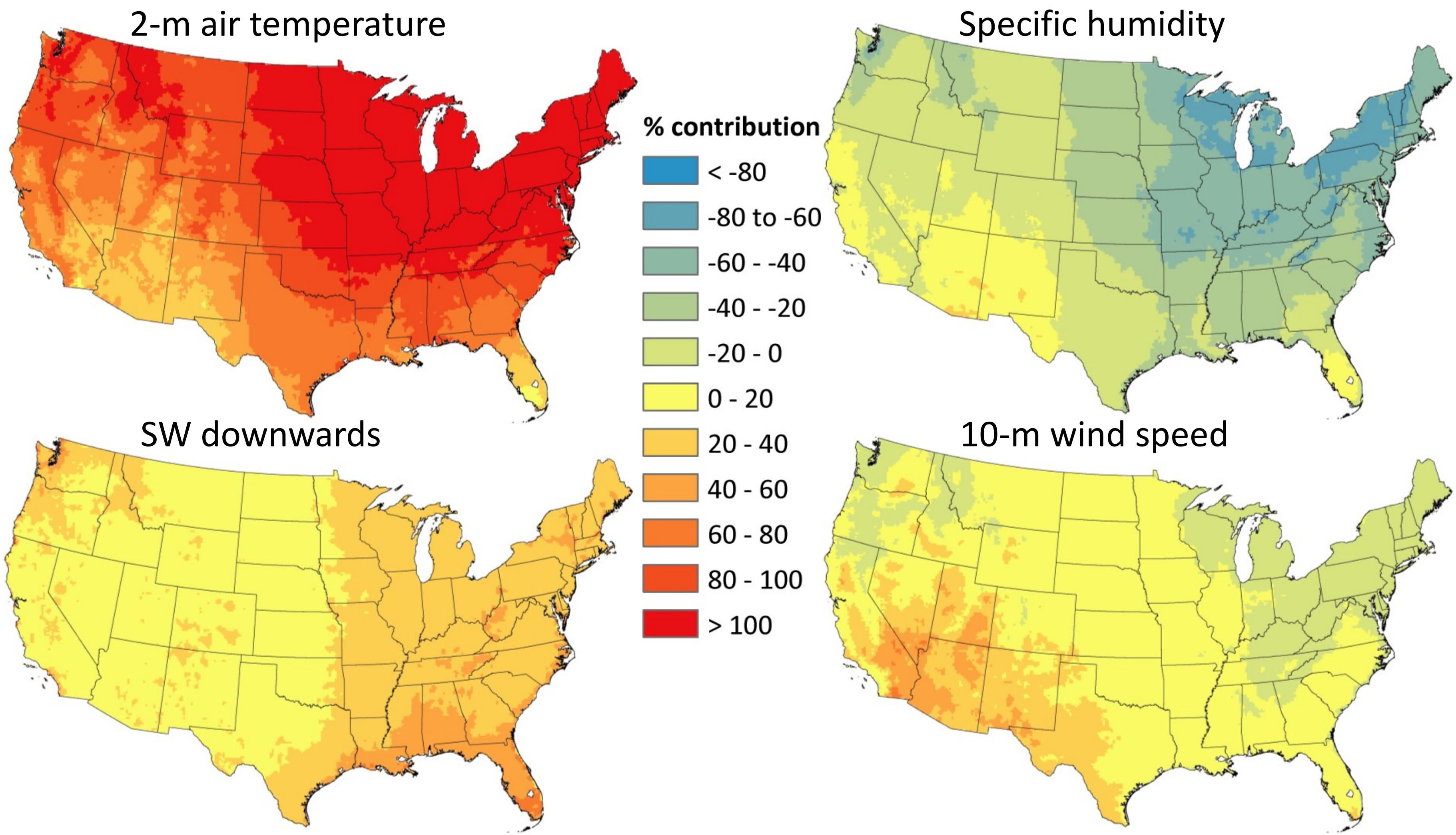
$$\Delta ET_{rc} = \frac{\partial ET_{r}}{\partial T}$$

Sensitivities in (1) and (2) derived analytically from model formulation

ces, covariances in (1) and
nulated deviations in (2)
derived empirically from dataset

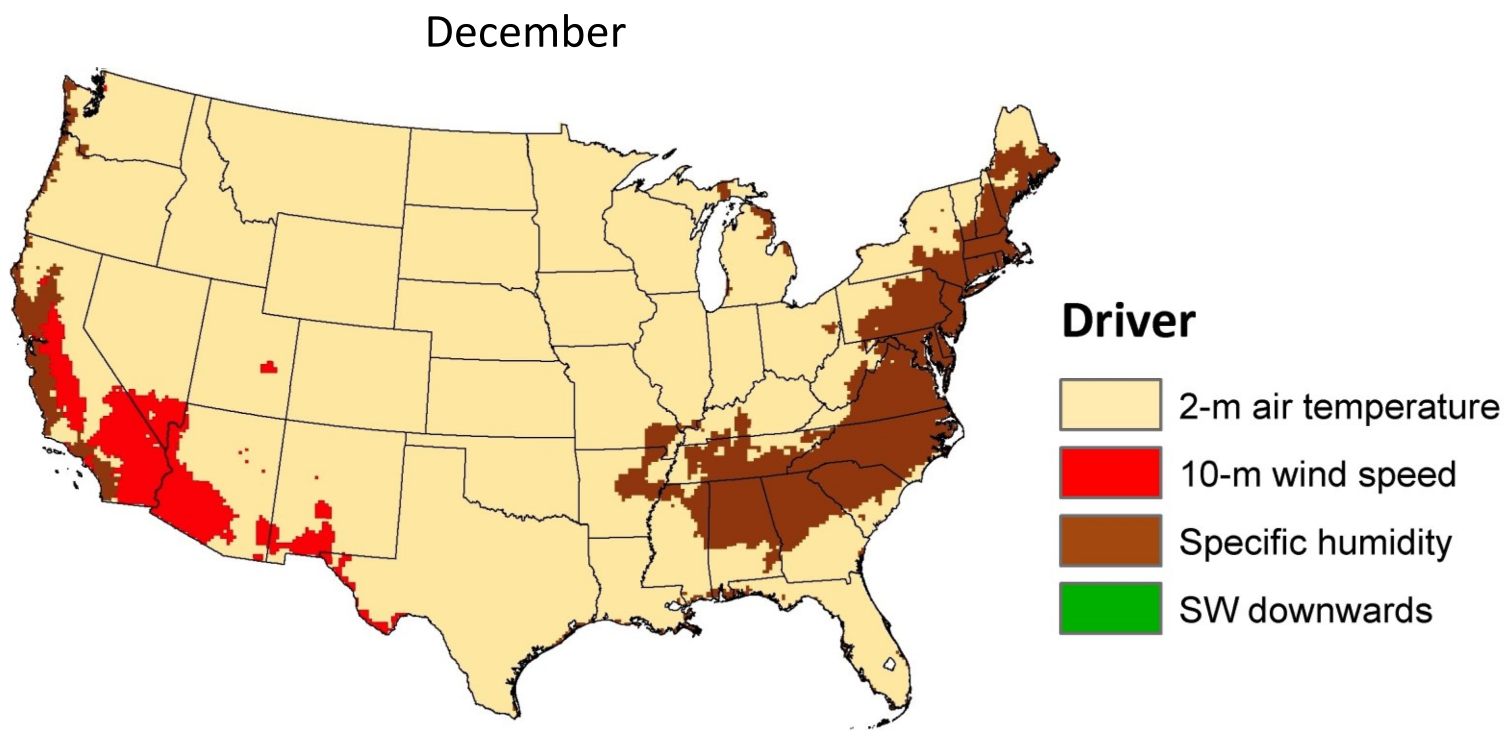
Rigorous E_0 variability analysis

MJJASO variability contributions, daily ET_{rc}, by driver



Rigorous E_0 variability analysis

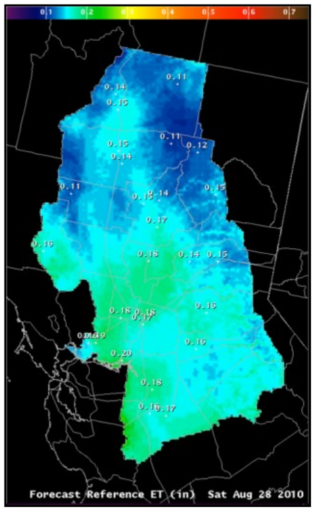
Top driver of daily variability, by month



Short-term forecasting of drought – an opportunity

NWS forecast ET_{rc} product

NDFD forecast surface, generated at NWS WFO



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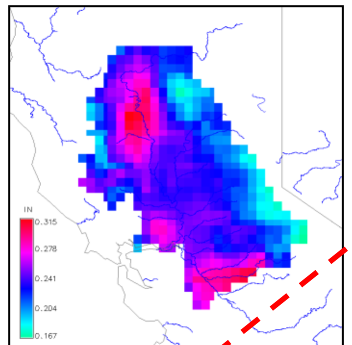
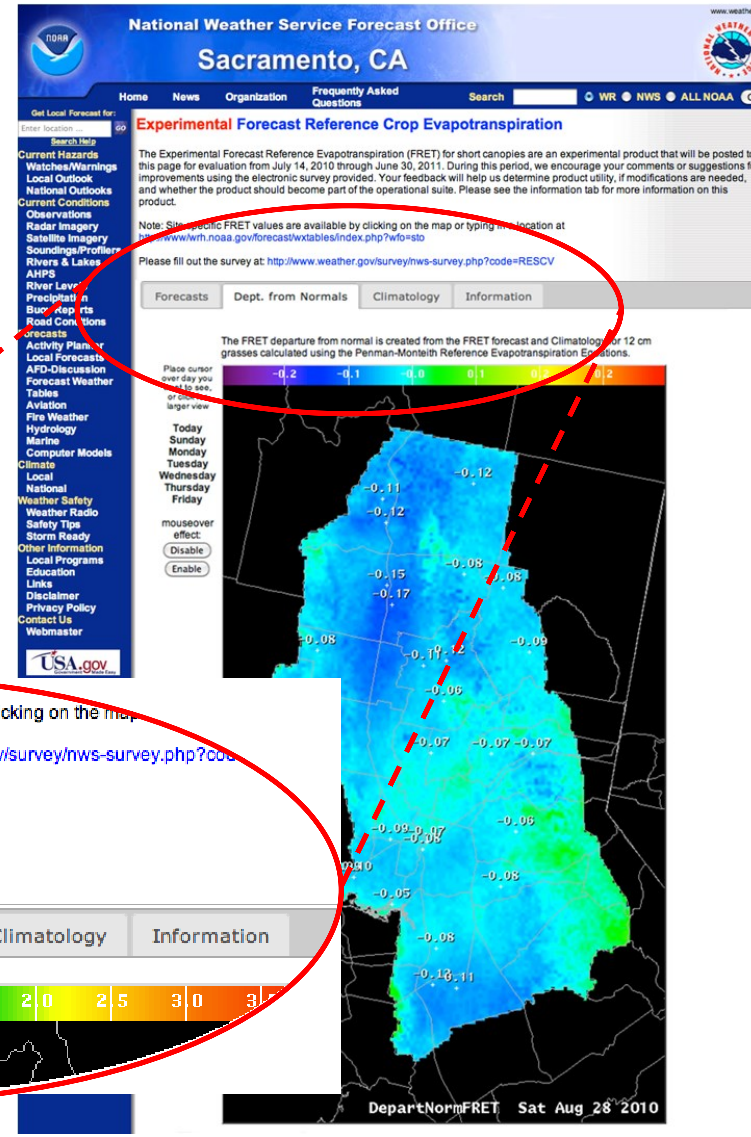
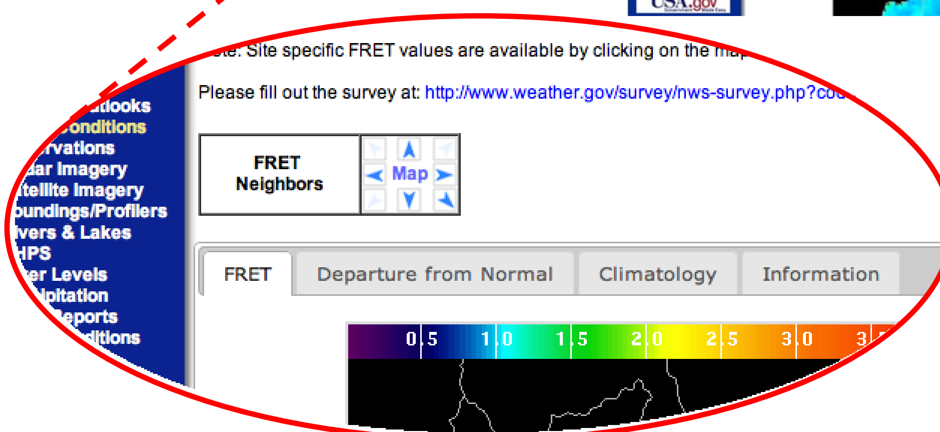
NLDAS climatology surface, specific to date and WFO







FRET website for Sacramento, CA:
http://www.wrh.noaa.gov/forecast/evap/FRET/FRET.php?wfo=sto

Summary

Generation-1 ET_{rc} dataset released within the year:

- hourly, daily ET_{rc} from ASCE standardized ET_{rc} equation, 1979 to present
- verification ongoing, then bias-correction and release as Gen-1 ET_{rc} product

- **physically based $\boldsymbol{E_0}$** for use by USDM analysts

Drought assessment opportunities:

- EDDI matches USDM well; great potential for **drought early warning**
- **attribution** of flash drought
- **forecasting** E_0, and ongoing drought in short term

Spare slides follow

Who's using the data so far?

- ongoing collaborations:

  Utah State U – Common Framework of Practice for *ET* and remote sensing

  U of Idaho (Prof. Rick Allen) and DRI – ambient conditioning development

  NWS Western Region – FRET climatology to underpin ET_{rc} forecasts

  USDA-ARS (Prasanna Gowda) – Bushland, TX

- future collaborators:

  Australian National University – E_0 trends

  Australia BoM – interest in FRET

- one-way data transfers:

  NOAA-NWRFC (Andy Wood) – examining dynamic E_0 in river forecasting

  USGS, Northern Prairie Wildlife Research Center (Amy Symstad) – fire ecology

  NOAA-CBRFC (Tim Bardsley) – climate resilience study

  UCLA/Colorado School of Mines (Prof. Terri Hogue) – MODIS/PET in river forecasting study

- related work in-house:

  drought index testing of Evaporative Demand Drought Index (EDDI):

  - collaboration with NWRFC (Andy Wood)
  - early results indicate good match of EDDI with USDM and potential in drought early warning

  ongoing support of NWS's Forecast Reference Evapotranspiration (FRET) product:

  - testing by NASA-AMES (Forrest Melton and NWS colleagues)

Technical challenges - ET_{rc}

Validation of gridded ET_{rc} against station-based estimates:

- gathering ET_{rc} point data from in-situ weather station networks
- western US validation only? (Agrimet, CIMIS, Mesonet, state DNR networks, NICENet in NV, High Plains Network, etc.)

Early validation results: NLDAS-derived ET_{rc} in western US irrigated areas biased wrt station-based ET_{rc}:

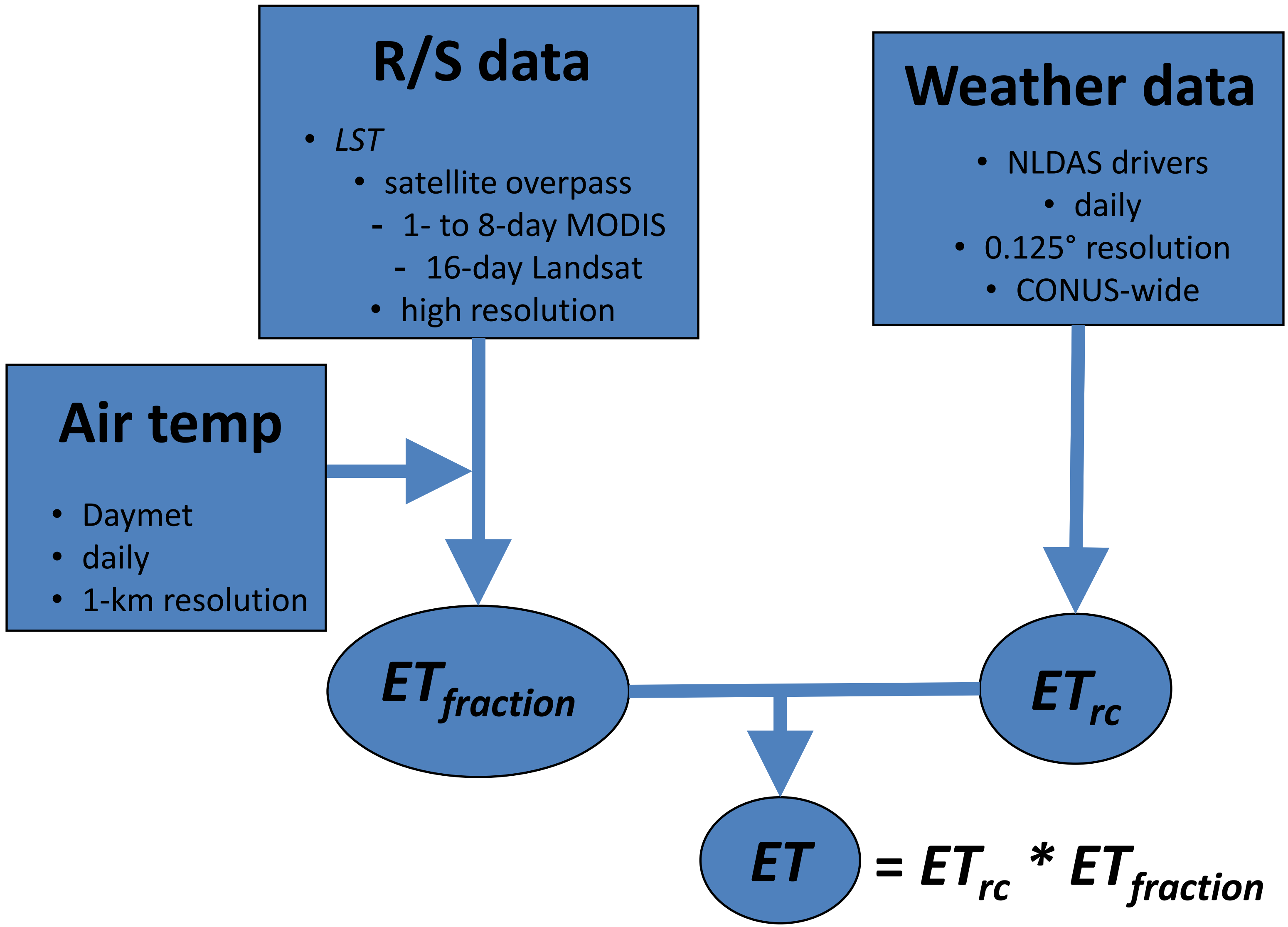
- does not reflect ambient conditioning of dynamic boundary layer of atmosphere
- fine-scale surface is poorly characterized
  - is this a resolution issue?
  - is it resolvable by atmospheric correction and Rick Allen's ambient conditioning algorithms and irrigated USDA cropland polygons?

1st-order, 2nd-moment uncertainty analysis will indicate space- and time-variability drivers requiring most attention.

H44A-06: 1715 Thurs.: *The Drivers of Spatial and Temporal Variability of Potential Evaporation Across CONUS*

Fusion of ET_{rc} with R/S data

Operational Simplified Surface Energy Balance (SSEBop) approach



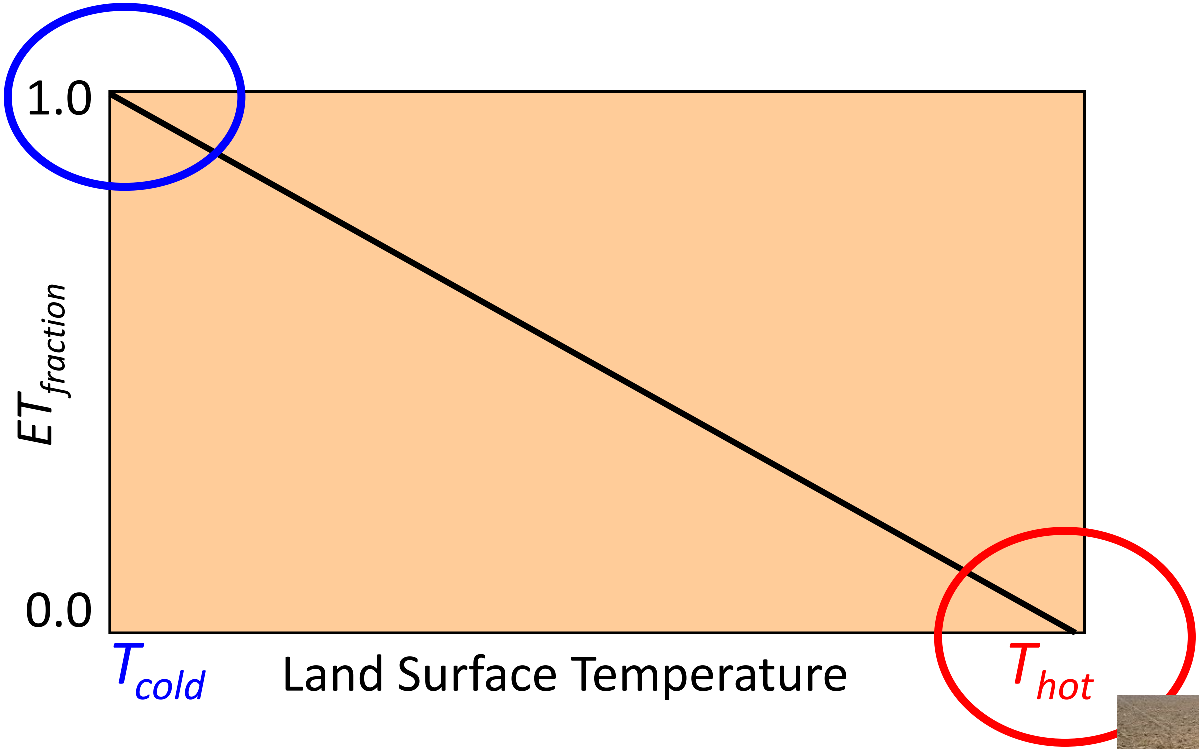
Fusion of ET_{rc} with R/S data

The $ET_{fraction}$ concept

after SEBAL (Bastiaanssen et al., 1998)
and METRIC (Allen et al., 2005).

irigated fields

$R_n = ET \Rightarrow T_{cold}$



bare, dry pixels

$R_n = H \Rightarrow T_{hot}$

Opportunities

Potential duplication of effort

- but good reason for "own numbers"
- states/agencies have already invested resources in developing R/S *ET* datasets

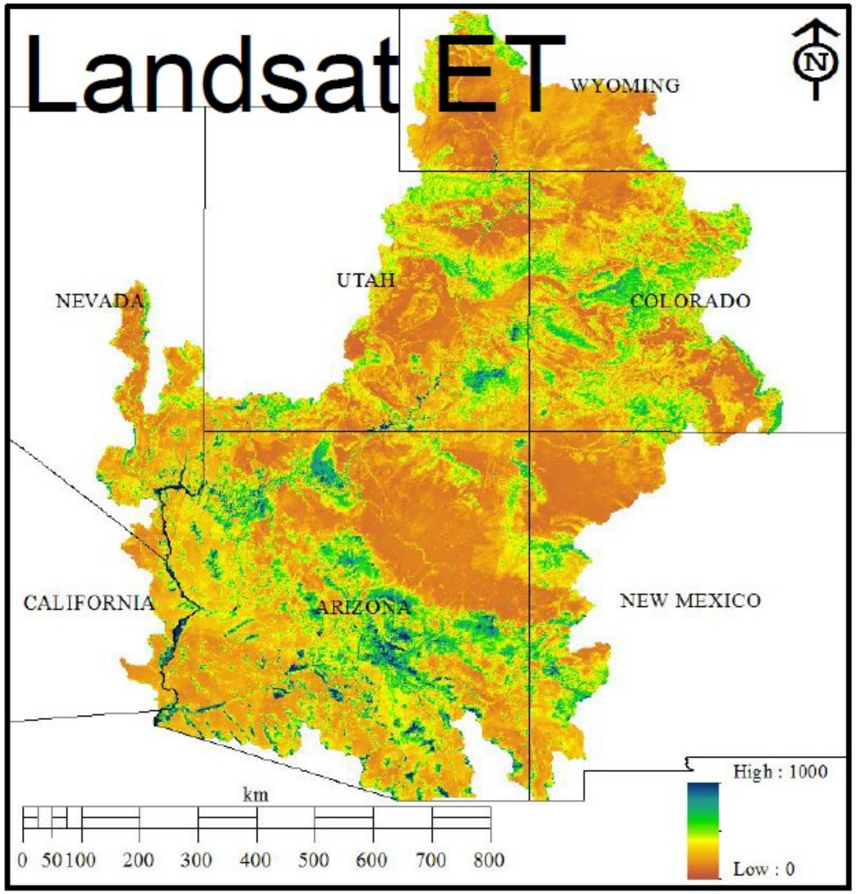
Solution: a Common Framework of Practice: guidelines and specifications under development at Utah State University

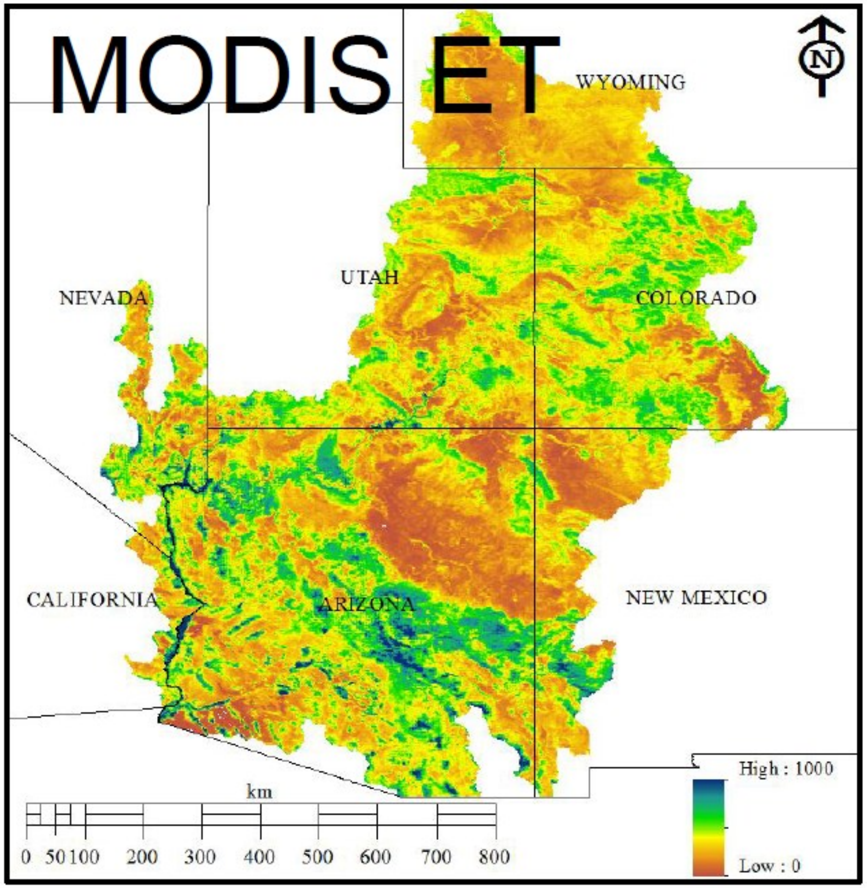
- use models you like
- numbers accepted by the community
- realize economies, while meeting accuracy standards

Consistent inputs to *ET* component of NWC to reduce uncertainty:

- USDA CDL or state GIS for crops;
- ET_{rc} from NOAA;
- consistently pre-processed Landsat imagery from USGS (consistent with requirements for an Essential Climate Variable)

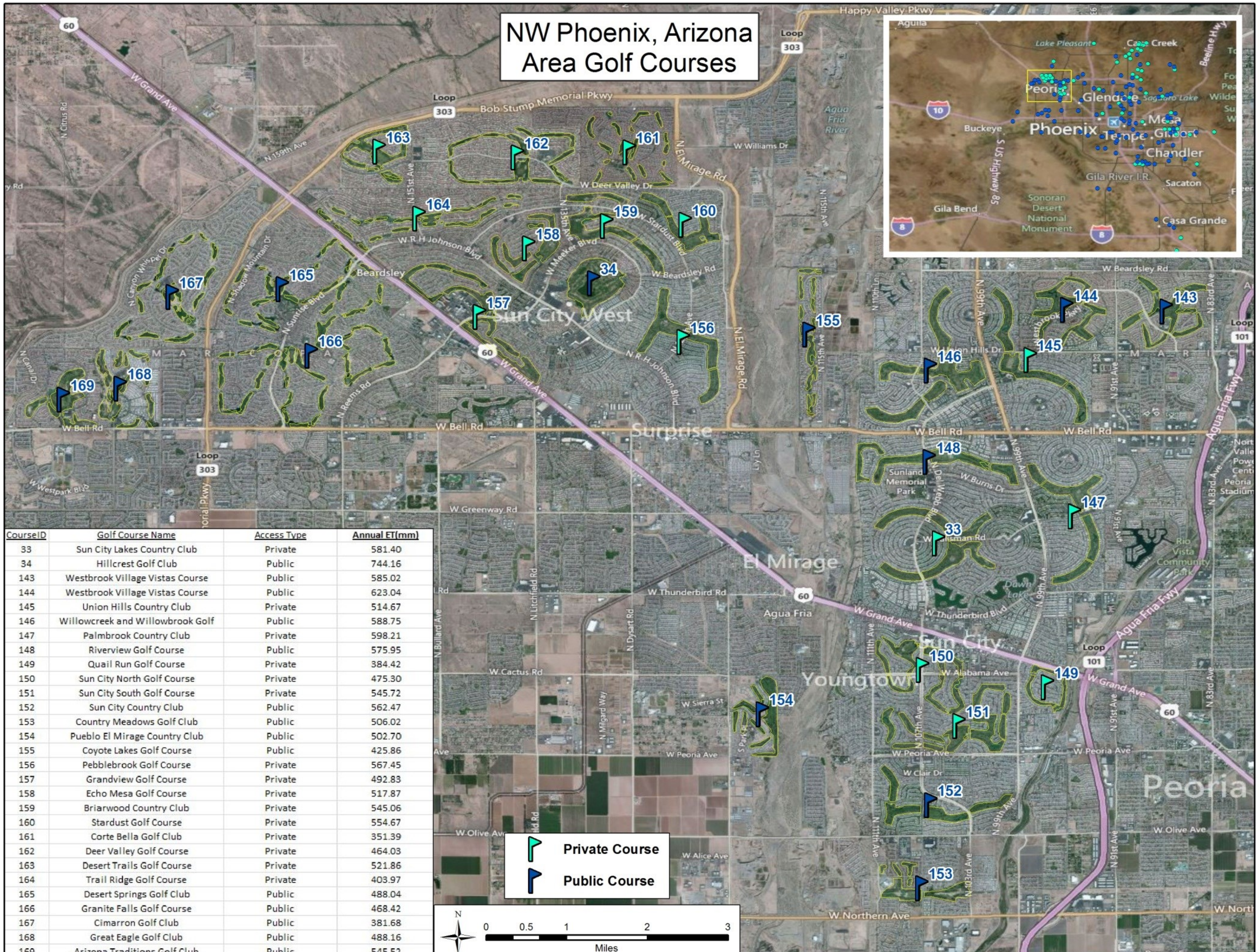
Comparison of annual *ET*: Colorado River basin, 2010





1st-ever full basin Landsat-scale annual *ET*

Estimation of “crop” water-use: Golf courses in NW Phoenix, AZ



CourseID	Golf Course Name	Access Type	Annual ET(mm)
33	Sun City Lakes Country Club	Private	581.40
34	Hillcrest Golf Club	Public	744.16
143	Westbrook Village Vistas Course	Public	585.02
144	Westbrook Village Vistas Course	Public	623.04
145	Union Hills Country Club	Private	514.67
146	Willowcreek and Willowbrook Golf	Public	588.75
147	Palmbrook Country Club	Private	598.21
148	Riverview Golf Course	Public	575.95
149	Quail Run Golf Course	Private	384.42
150	Sun City North Golf Course	Private	475.30
151	Sun City South Golf Course	Private	545.72
152	Sun City Country Club	Public	562.47
153	Country Meadows Golf Club	Public	506.02
154	Pueblo El Mirage Country Club	Public	502.70
155	Coyote Lakes Golf Course	Public	425.86
156	Pebblebrook Golf Course	Private	567.45
157	Grandview Golf Course	Private	492.83
158	Echo Mesa Golf Course	Private	517.87
159	Briarwood Country Club	Private	545.06
160	Stardust Golf Course	Private	554.67
161	Corte Bella Golf Club	Private	351.39
162	Deer Valley Golf Course	Private	464.03
163	Desert Trails Golf Course	Private	521.86
164	Trail Ridge Golf Course	Private	403.97
165	Desert Springs Golf Club	Public	488.04
166	Granite Falls Golf Course	Public	468.42
167	Cimarron Golf Club	Public	381.68
168	Great Eagle Golf Club	Public	488.16
169	Arizona Traditions Golf Club	Public	545.52

The dangers of T-based parameterizations of E_0

Regional long-term trends and the Palmer Drought Severity Index (PDSI)

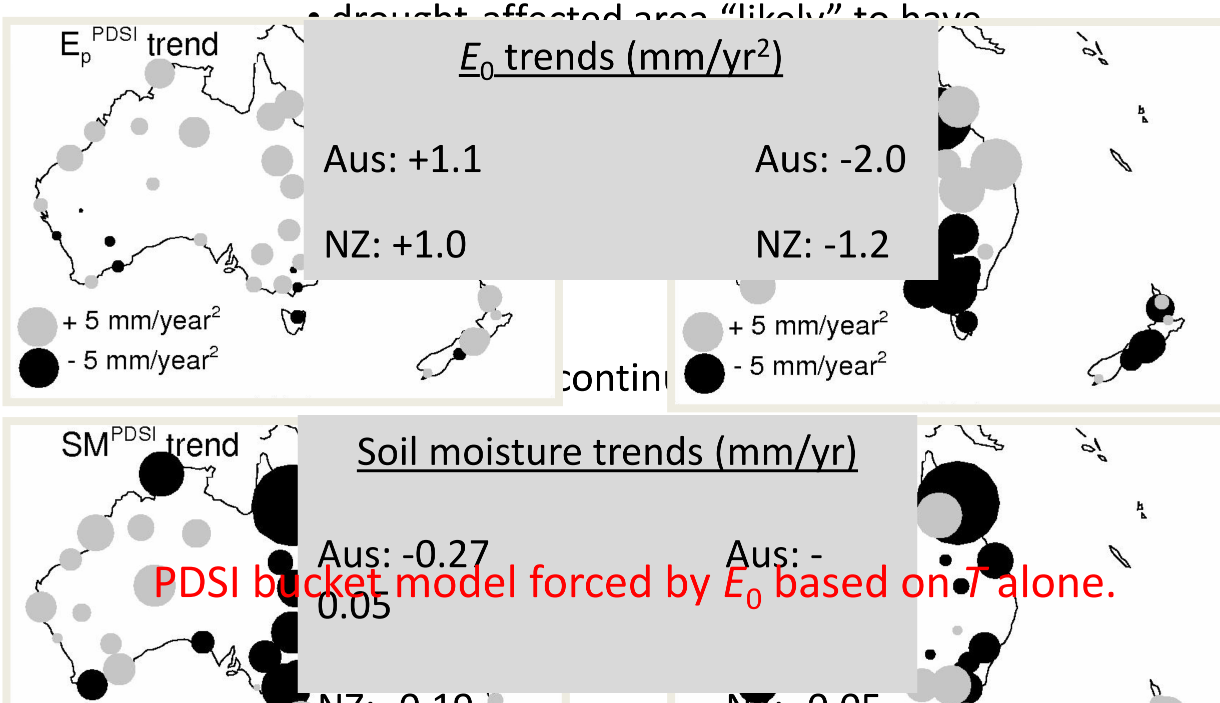
IPCC AR4 conclusions:

E_0^{PDSI}-forced trends | E_0^{Pan}-forced trends

• drought-affected area “likely” to have

E_0 trends

Soil moisture trends



<u>E_0 trends (mm/yr^2)</u>

Aus: +1.1	Aus: -2.0
NZ: +1.0	NZ: -1.2

<u>Soil moisture trends (mm/yr)</u>

Aus: -0.27	Aus: -0.05
NZ: -0.19	NZ: -0.05

PDSI bucket model forced by E_0 based on T alone.

No significant relation between SM^{Pan} and SM^{PDSI}

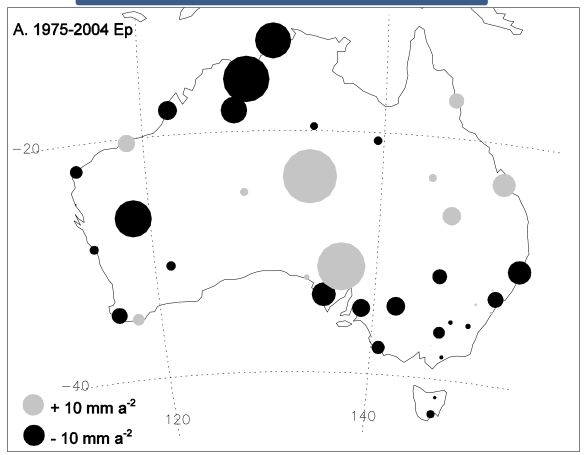
7 sites show opposite SM-trends: 5 in SW WA, NSW and Vic.

Hobbins at el., GRL, 2008

The dangers of T-based parameterizations of E_0

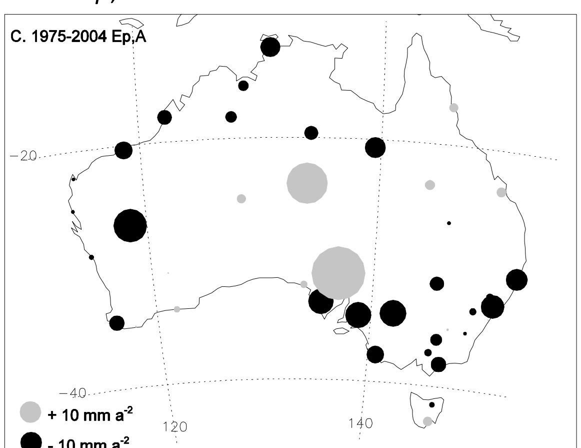
Decomposing observed E_0-trend forcings

$\boxed{dE_p/dt = -2.0 \text{ mm/yr}^2}$?

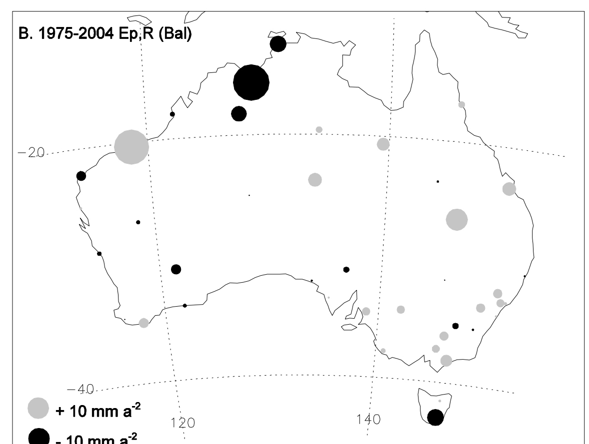


$$E_{pan} \sim E_p = E_{p,Advective} + E_{p,Radiative}$$

$dE_{p,\text{Advective}}/dt = -2.6 \text{ mm/yr}^2$



$dE_{p,\text{Radiative}}/dt = +0.6 \text{ mm/yr}^2$

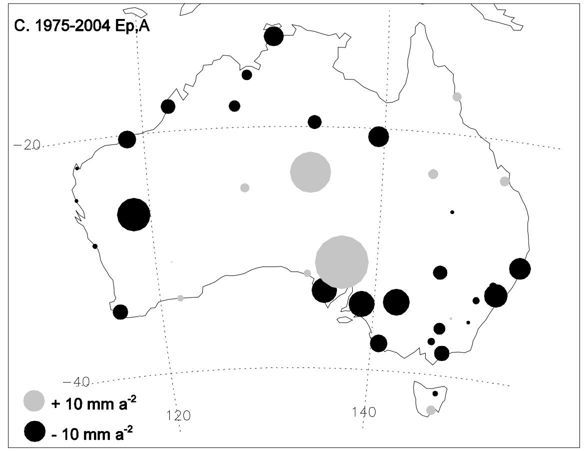


Roderick et al., GRL, 2007

The dangers of T-based parameterizations of E_0

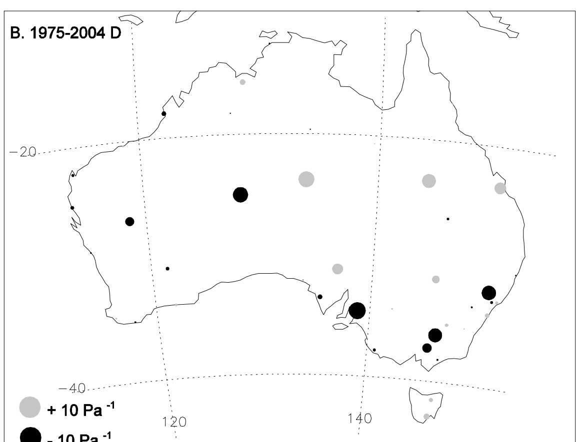
Decomposing observed E_0-trend forcings

$dE_{p,\mathrm{Advective}}/dt$ = -2.6 mm/yr^2



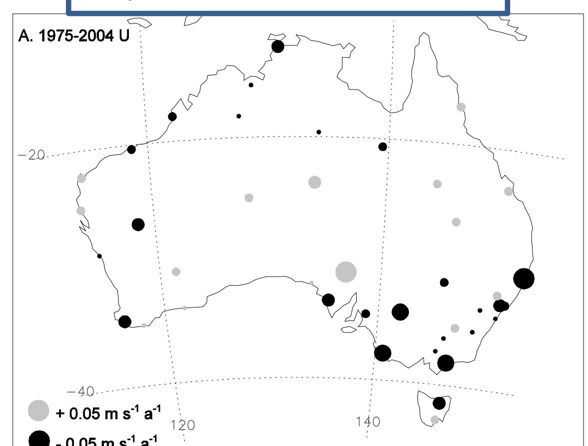
$dVPD/dt$ = -0.2 Pa/yr

$dE_{p,VPD}/dt$ = 0.0 mm/yr^2



dU_2/dt = -0.01 m/sec/yr

$\boxed{dE_{p,U2}/dt = -2.7 \text{ mm/yr}^2}$



Roderick et al., GRL, 2007

The dangers of T-based parameterizations of E_0

Global long-term trends and the PDSI

PDSI trends E_0 trends

Little change in drought over the past 60 years

Differences in E_0 trends:

- global dimming
- stilling (decreasing U_z)
- *VPD* changes

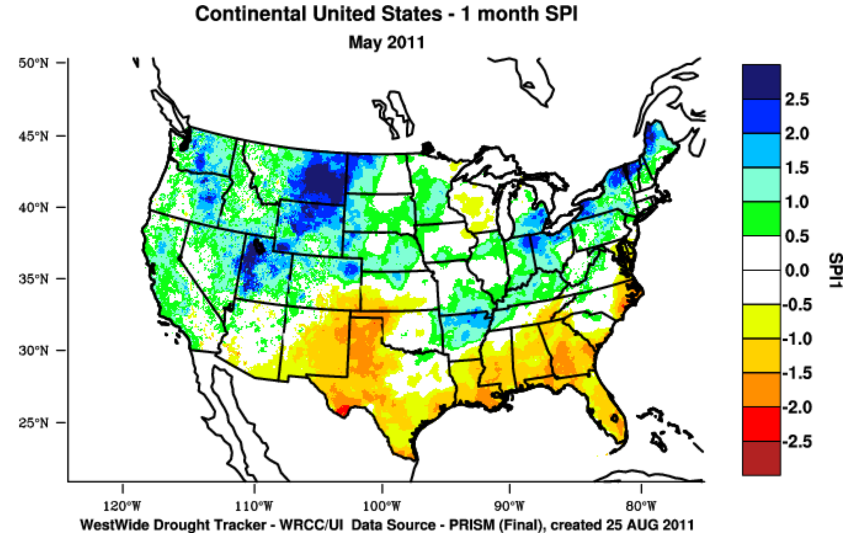
Differences in signs of PDSI trends

Widespread significant trends in E_0 and PDSI difference

Sheffield et al., Nature, 2012

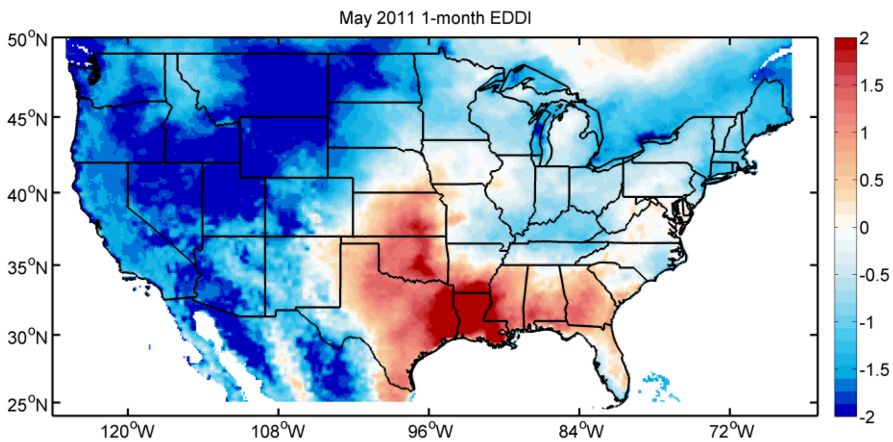
Evaporative Demand Drought Index, EDDI:

2011 drought: EDDI *vs.* Standardized Precipitation Index



1-month SPI: May

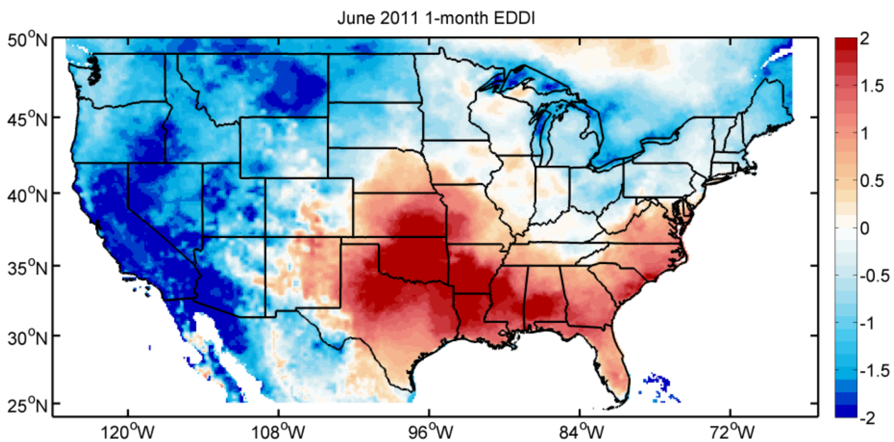
1-month EDDI: May

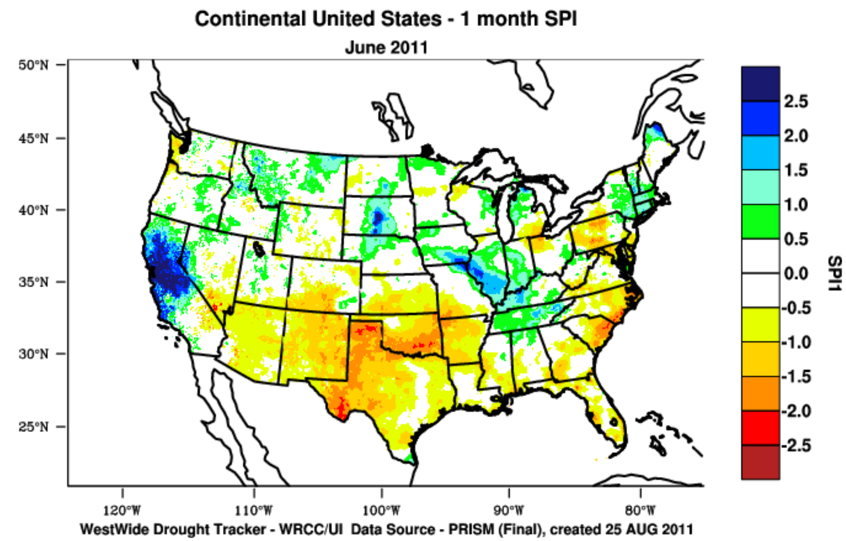


Evaporative Demand Drought Index, EDDI:

2011 drought: EDDI *vs.* Standardized Precipitation Index

1-month EDDI: June

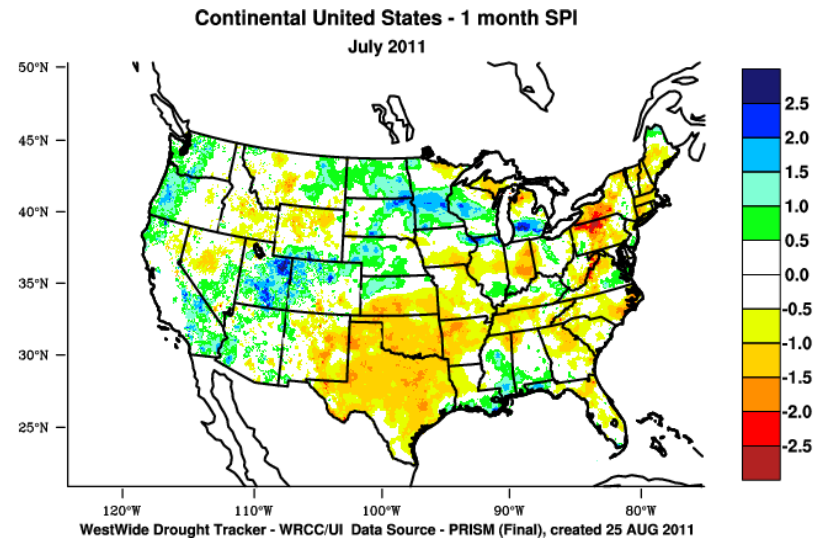




1-month SPI: June

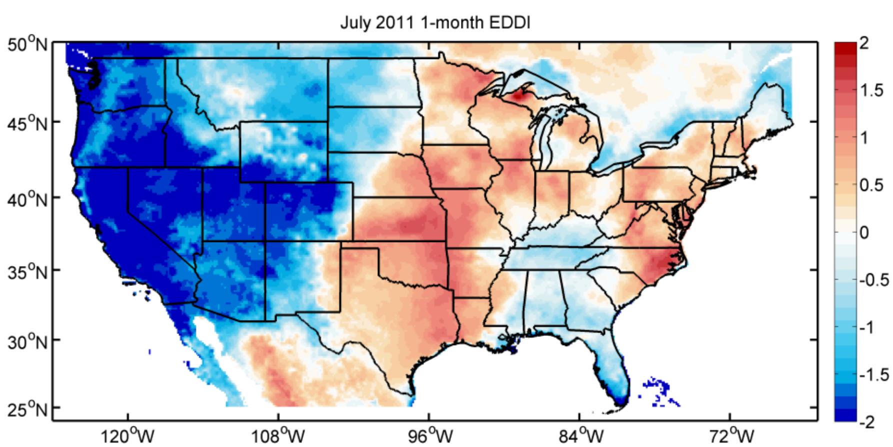
Evaporative Demand Drought Index, EDDI:

2011 drought: EDDI *vs.* Standardized Precipitation Index



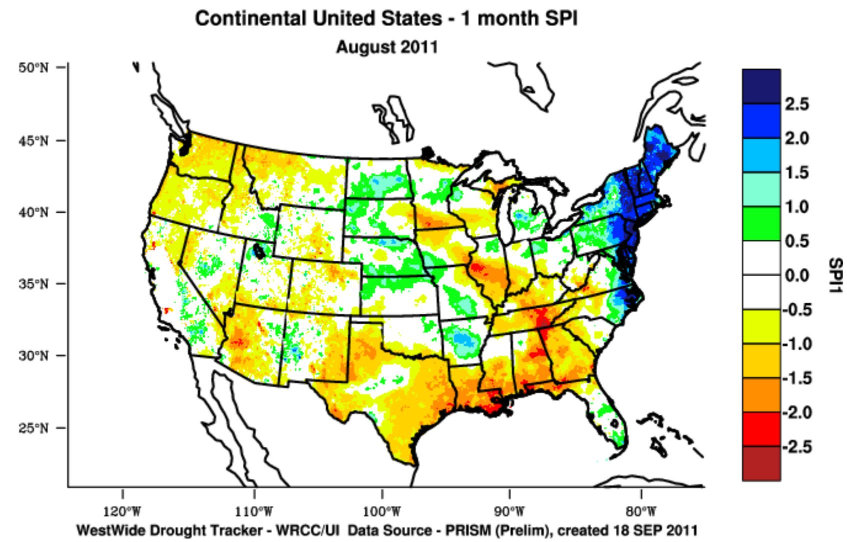
1-month SPI: July

1-month EDDI: July



Evaporative Demand Drought Index, EDDI:

2011 drought: EDDI *vs.* Standardized Precipitation Index



1-month SPI: August

1-month EDDI: August