Drought Monitoring and Early Warning

Our office (The Colorado Climate Center at Colorado State University(began systematic monthly climate and drought assessments in 1977 in response to a large and extreme Western US drought

That continued for many years, stimulated by the State's first "Drought Response Plan" in 1981 and several ensuing updates

Early deployment of a NIDIS pilot project in the Upper Colorado River Basin in the late 2000s lead to stakeholder surveys

- n

Traditional monthly climate and water supply updates a few days to weeks after the end of each month were found to be simply inadequate for drought early warning (e.g. 2002 experience))

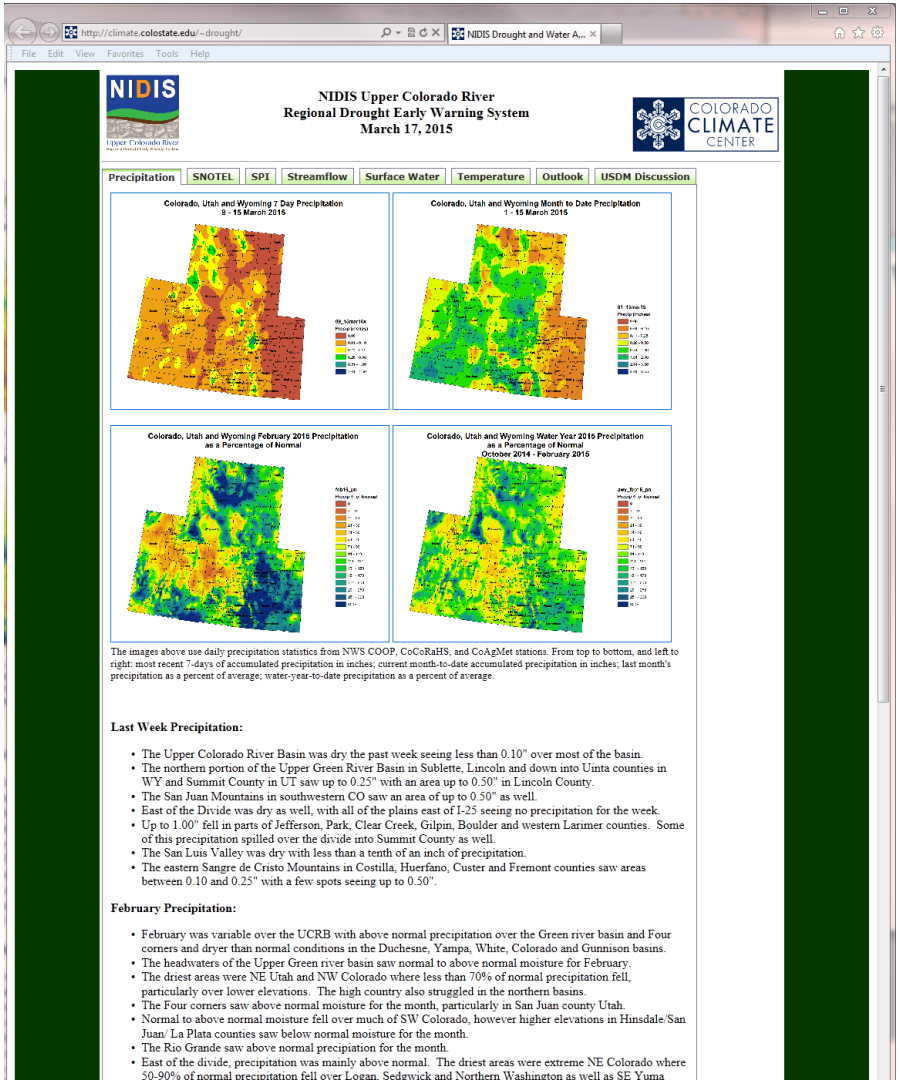
Colorado Climate Center has been conducting *Weekly* Drought Assessments for the UCRB since WY2010

NIDIS

Upper Colorado River

Regional Drought Early Warning System

Weekly Climate, Water & Drought Assessment



http://climate.colostate.edu/~drought/

NIDIS Drought and Water A...

File Edit View Favorites Tools Help

NIDIS Upper Colorado River

NIDIS Upper Colorado River
Regional Drought Early Warning System
March 17, 2015

COLORADO CLIMATE CENTER

Precipitation | SNOTEL | SPI | Streamflow | Surface Water | Temperature | Outlook | USDM Discussion

Colorado, Utah and Wyoming 7 Day Precipitation
8 - 15 March 2015

Colorado, Utah and Wyoming Month to Date Precipitation
1 - 15 March 2015

Colorado, Utah and Wyoming February 2015 Precipitation as a Percentage of Normal

Colorado, Utah and Wyoming Water Year 2015 Precipitation as a Percentage of Normal
October 2014 - February 2015

The images above use daily precipitation statistics from NWS COOP, CoCoRaHS, and CoAgMet stations. From top to bottom, and left to right: most recent 7-days of accumulated precipitation in inches; current month-to-date accumulated precipitation in inches; last month's precipitation as a percent of average; water-year-to-date precipitation as a percent of average.

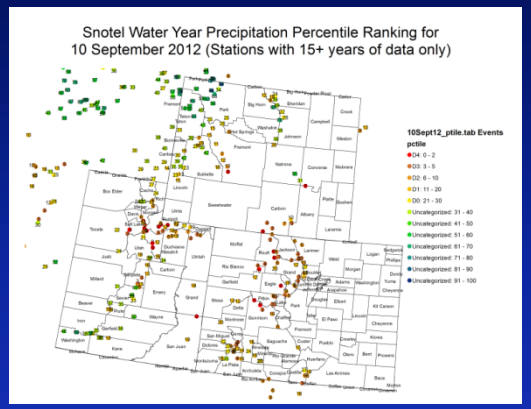
Last Week Precipitation:

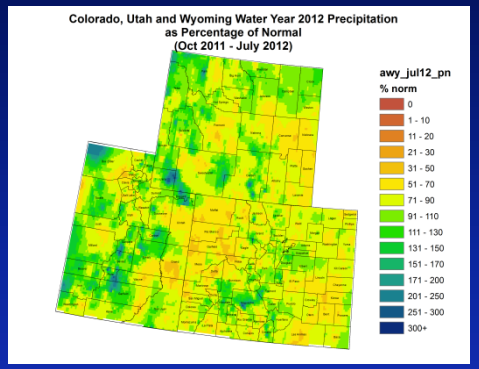
- The Upper Colorado River Basin was dry the past week seeing less than 0.10" over most of the basin.
- The northern portion of the Upper Green River Basin in Sublette, Lincoln and down into Uinta counties in WY and Summit County in UT saw up to 0.25" with an area up to 0.50" in Lincoln County.
- The San Juan Mountains in southwestern CO saw an area of up to 0.50" as well.
- East of the Divide was dry as well, with all of the plains east of I-25 seeing no precipitation for the week.
- Up to 1.00" fell in parts of Jefferson, Park, Clear Creek, Gilpin, Boulder and western Larimer counties. Some of this precipitation spilled over the divide into Summit County as well.
- The San Luis Valley was dry with less than a tenth of an inch of precipitation.
- The eastern Sangre de Cristo Mountains in Costilla, Huerfano, Custer and Fremont counties saw areas between 0.10 and 0.25" with a few spots seeing up to 0.50".

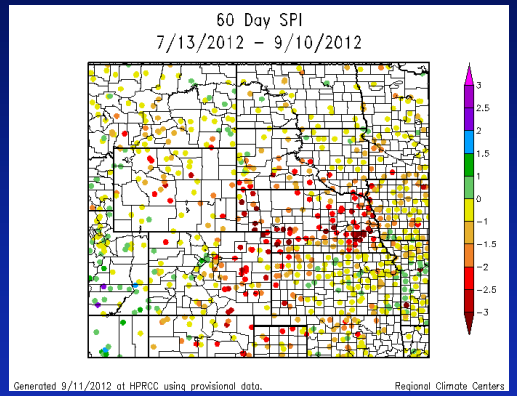
February Precipitation:

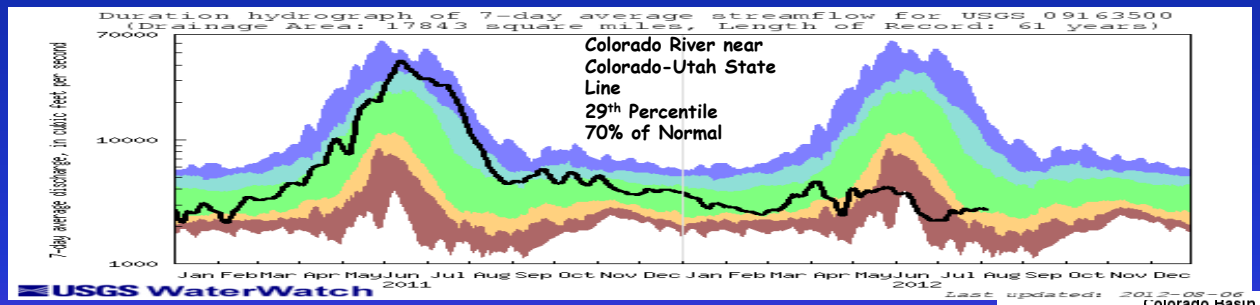
- February was variable over the UCRB with above normal precipitation over the Green river basin and Four corners and dryer than normal conditions in the Duchesne, Yampa, White, Colorado and Gunnison basins.
- The headwaters of the Upper Green river basin saw normal to above normal moisture for February.
- The driest areas were NE Utah and NW Colorado where less than 70% of normal precipitation fell, particularly over lower elevations. The high country also struggled in the northern basins.
- The Four corners saw above normal moisture for the month, particularly in San Juan county Utah.
- Normal to above normal moisture fell over much of SW Colorado, however higher elevations in Hinsdale/San Juan/ La Plata counties saw below normal moisture for the month.
- The Rio Grande saw above normal precipiation for the month.
- East of the divide, precipitation was mainly above normal. The driest areas were extreme NE Colorado where 50-90% of normal precipitation fell over Logan, Sedgwick and Northern Washington as well as SE Yuma

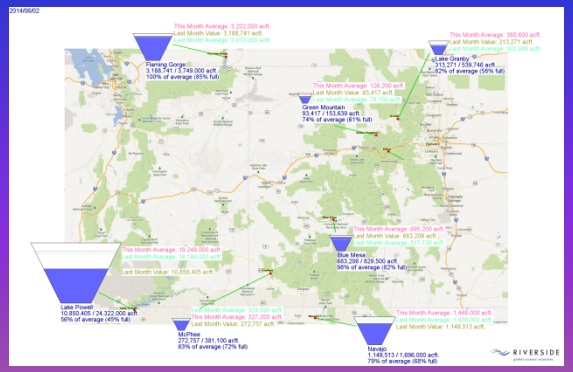
We put current hydrometeorological conditions into perspective for diverse users

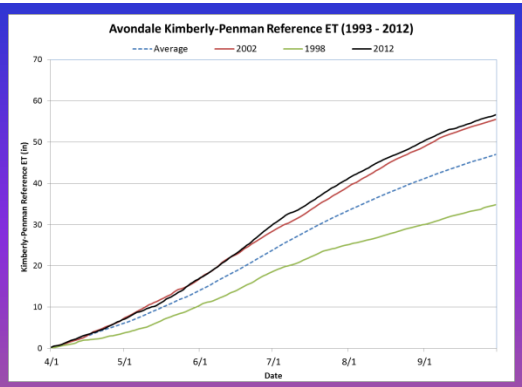


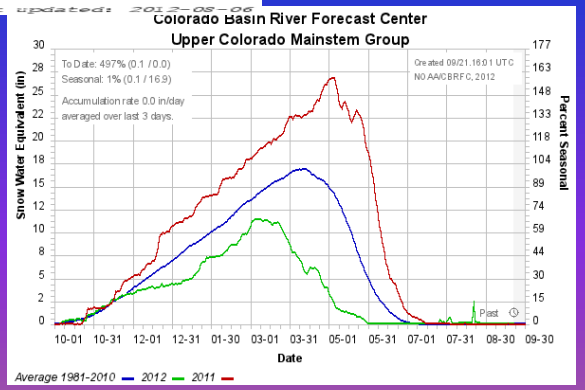








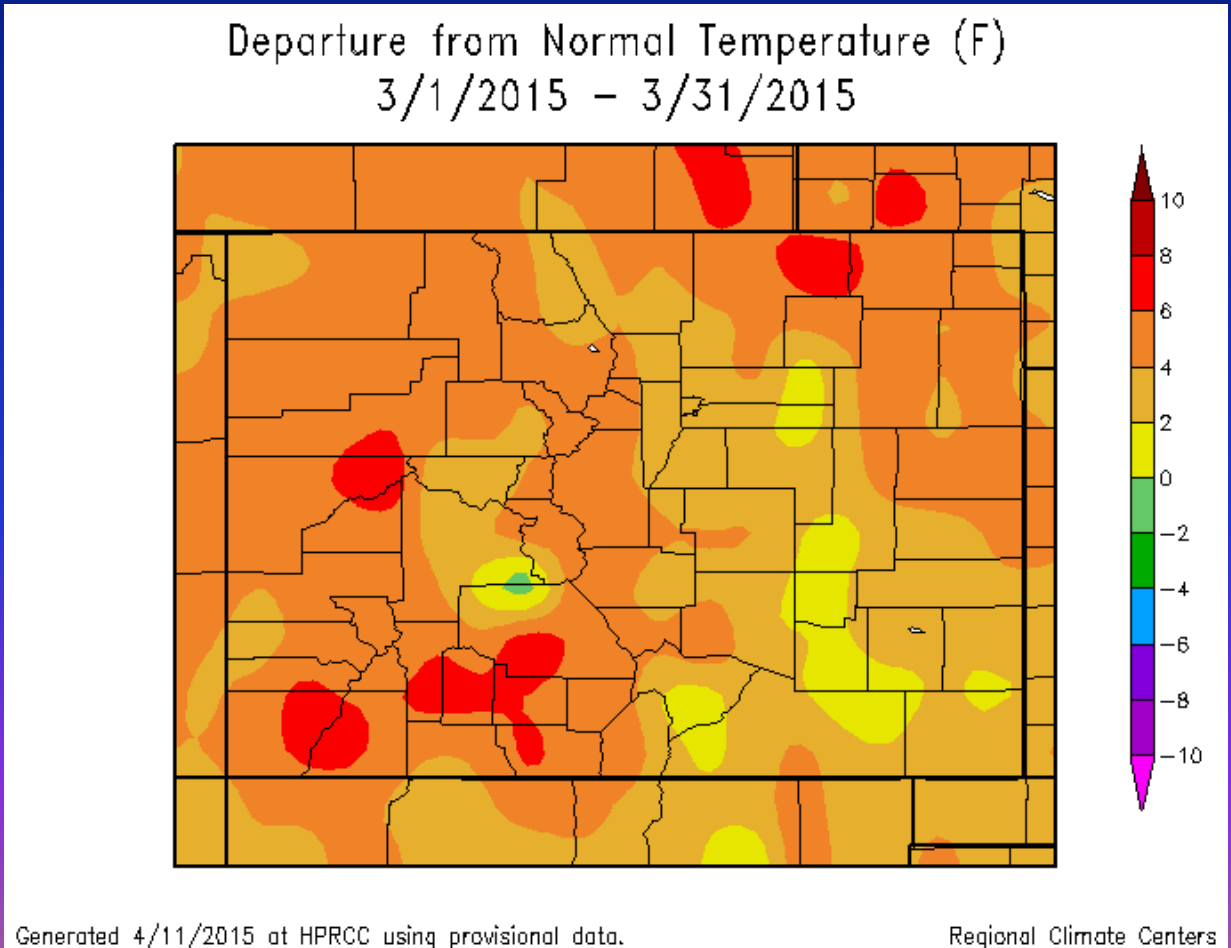




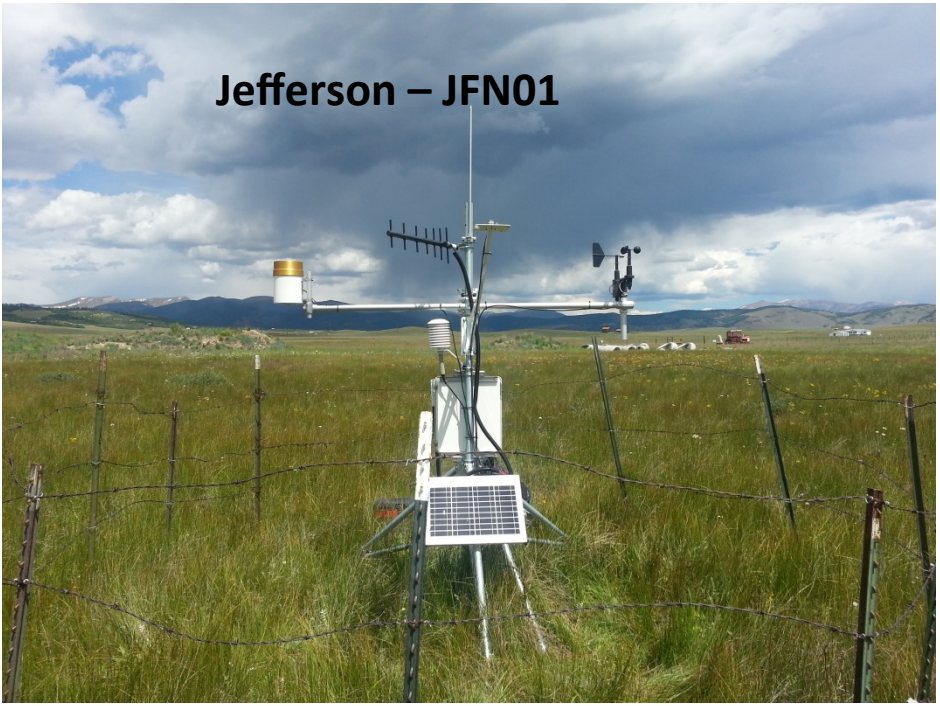
We've been doing drought monitoring for a long time -- but

Early on, we found that we were overemphasizing water supply monitoring and underemphasizing water demand monitoring

Temperature anomalies are a useful but insufficient surrogate for water demand anomalies



Point data from our ag weather network have been helpful

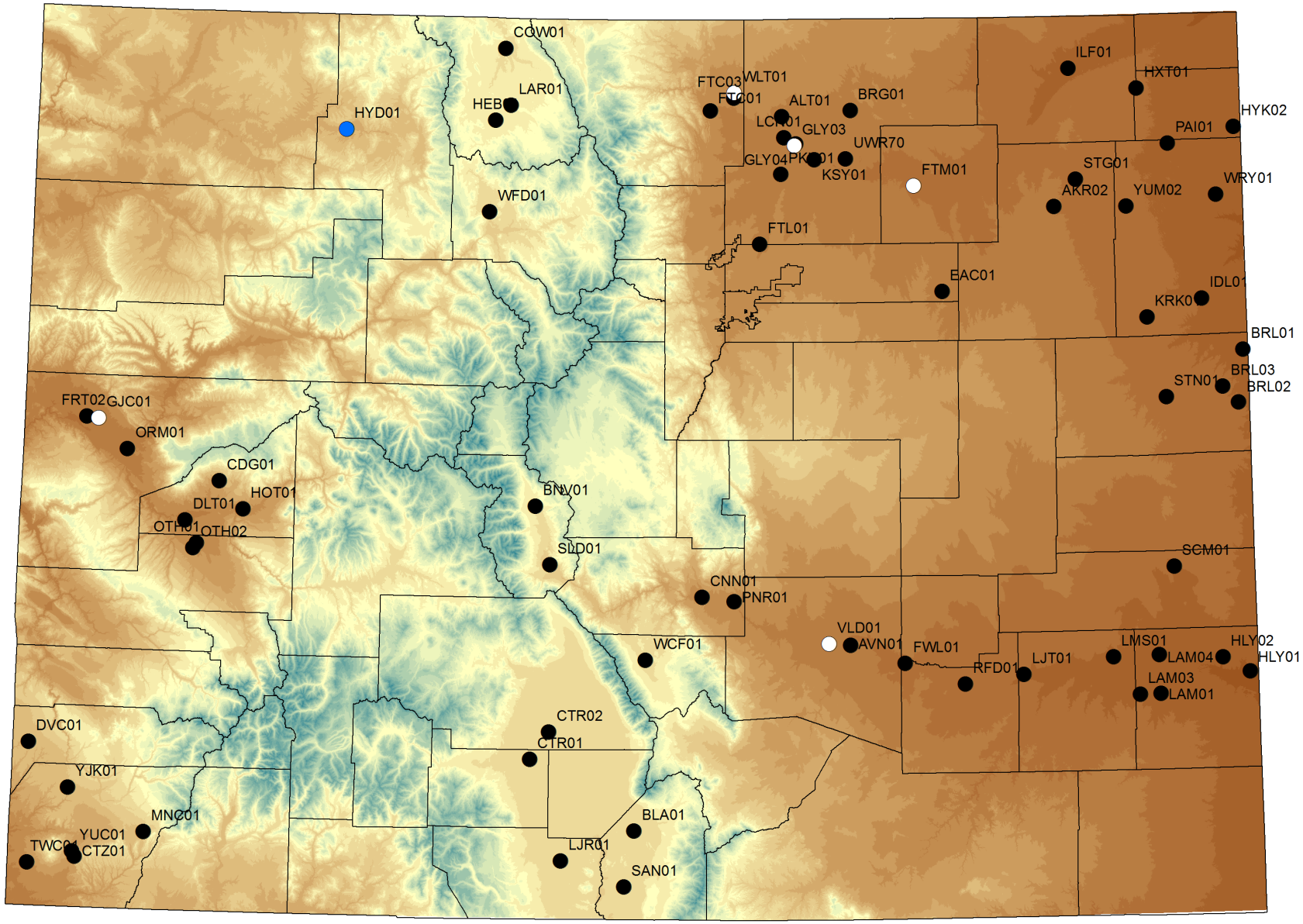


Removed

New/Proposed

Current Active

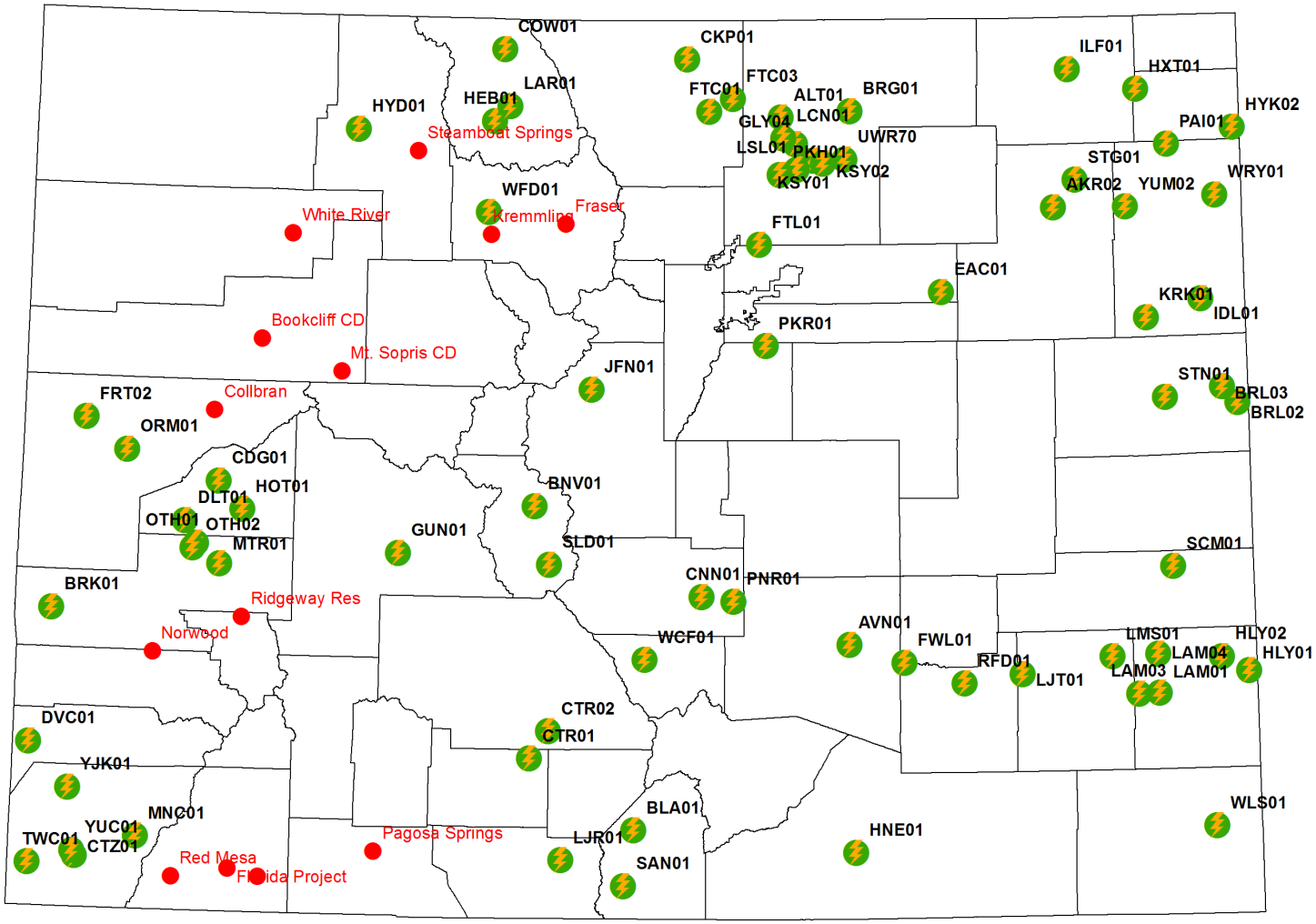
October 2011 CoAgMet Network Status



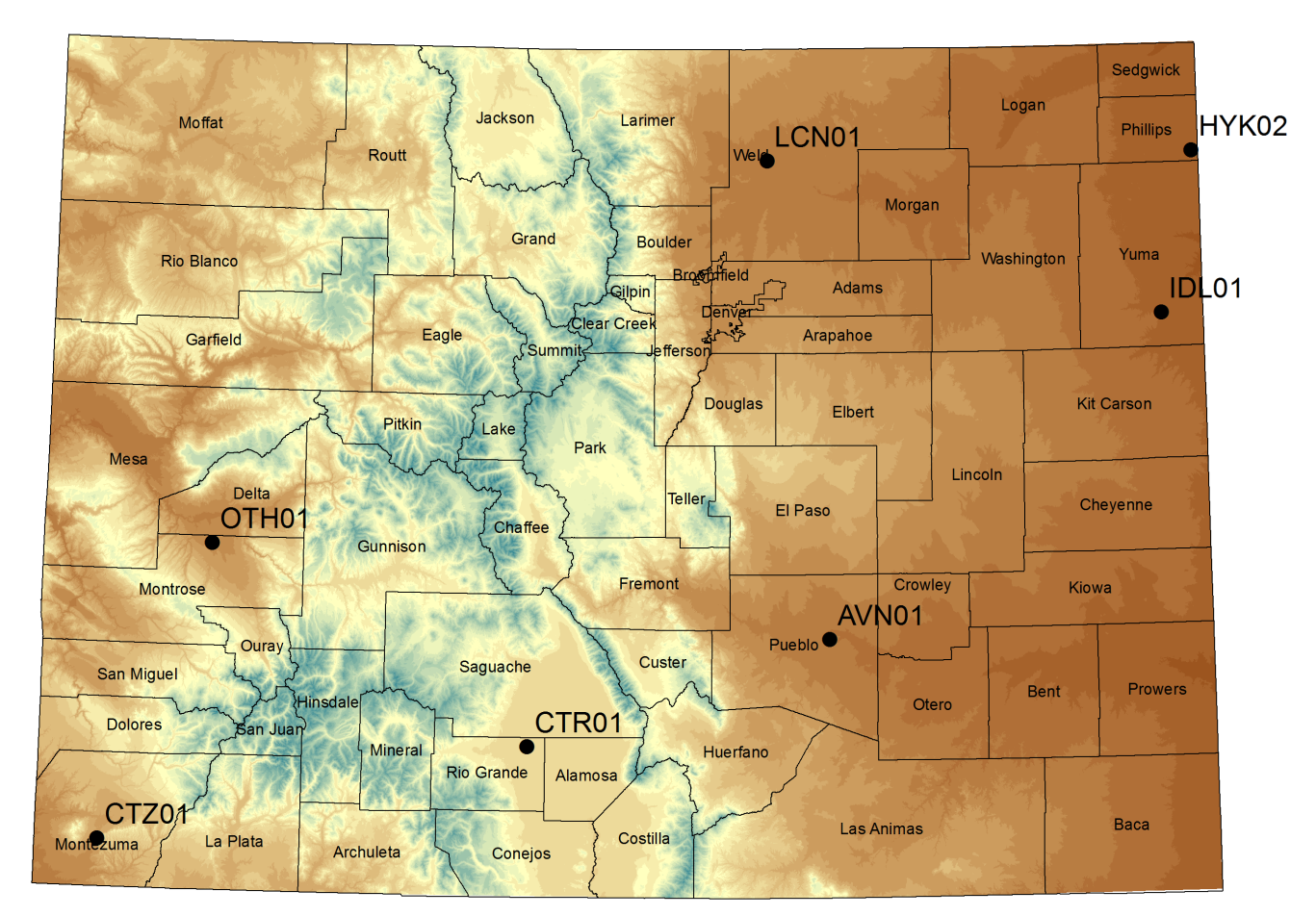
Planned/Proposed

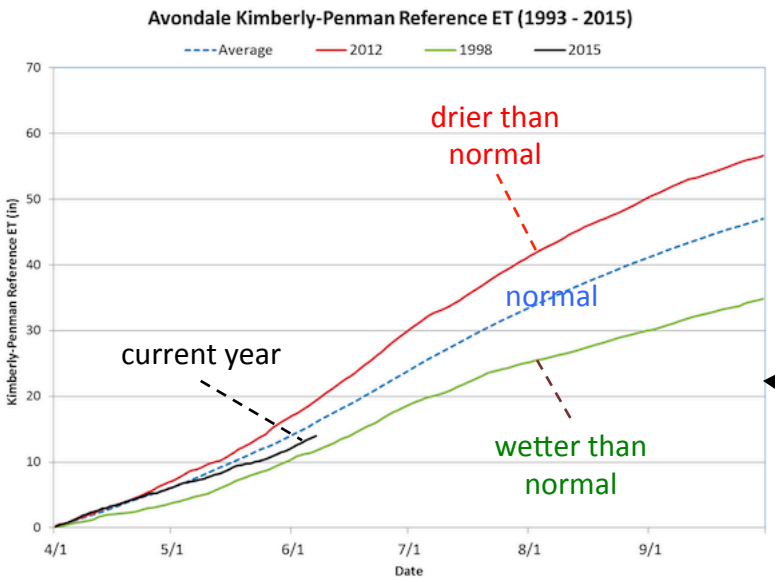
Active

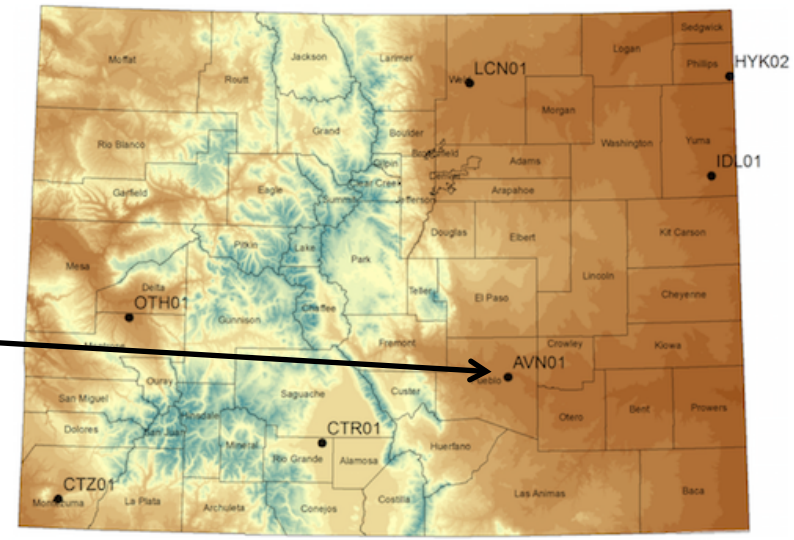
CoAgMet Active and Proposed 2015



We've used a subset of our best long-term ag weather stations to compute cumulative growing season reference and crop ET

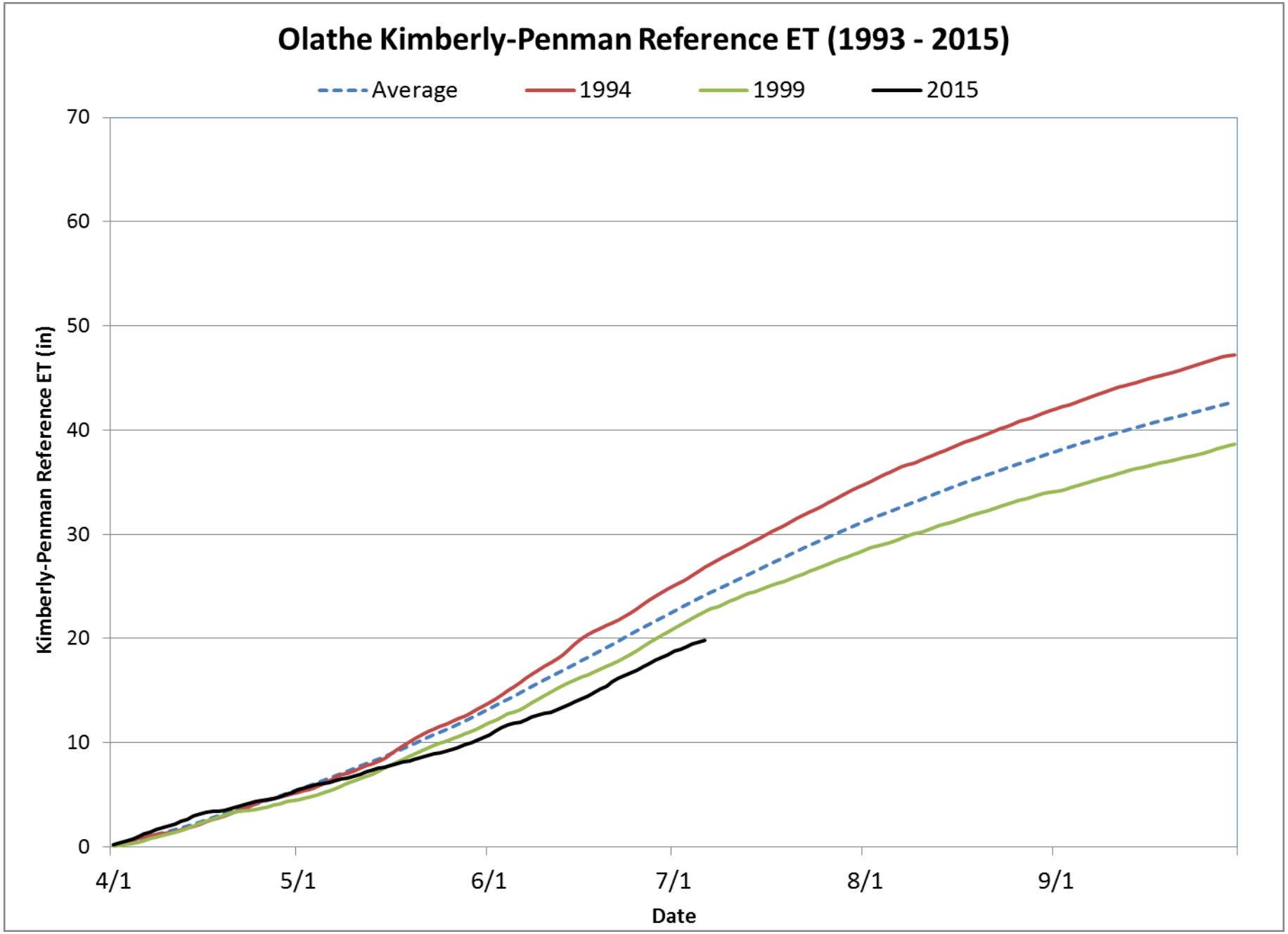


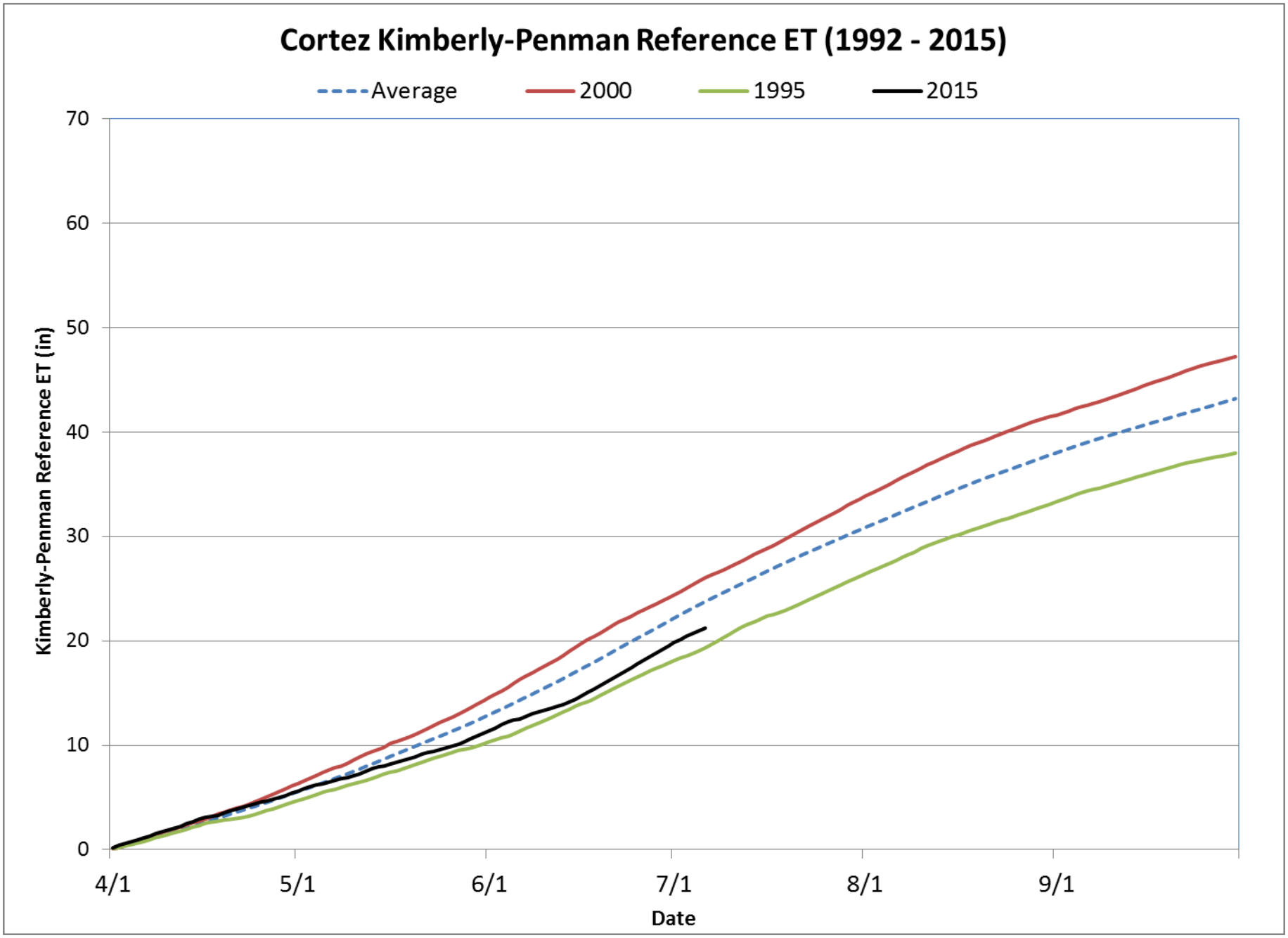


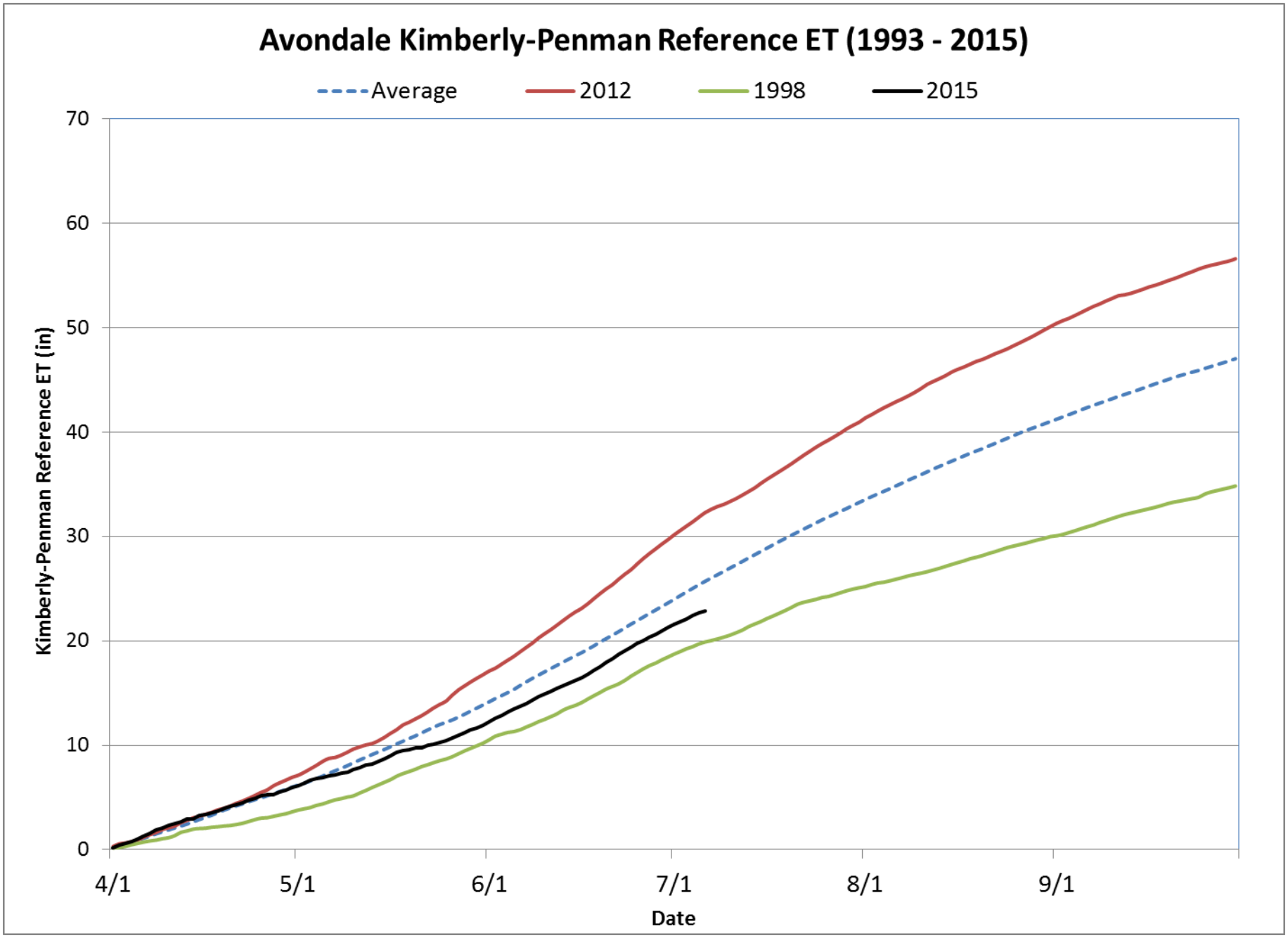


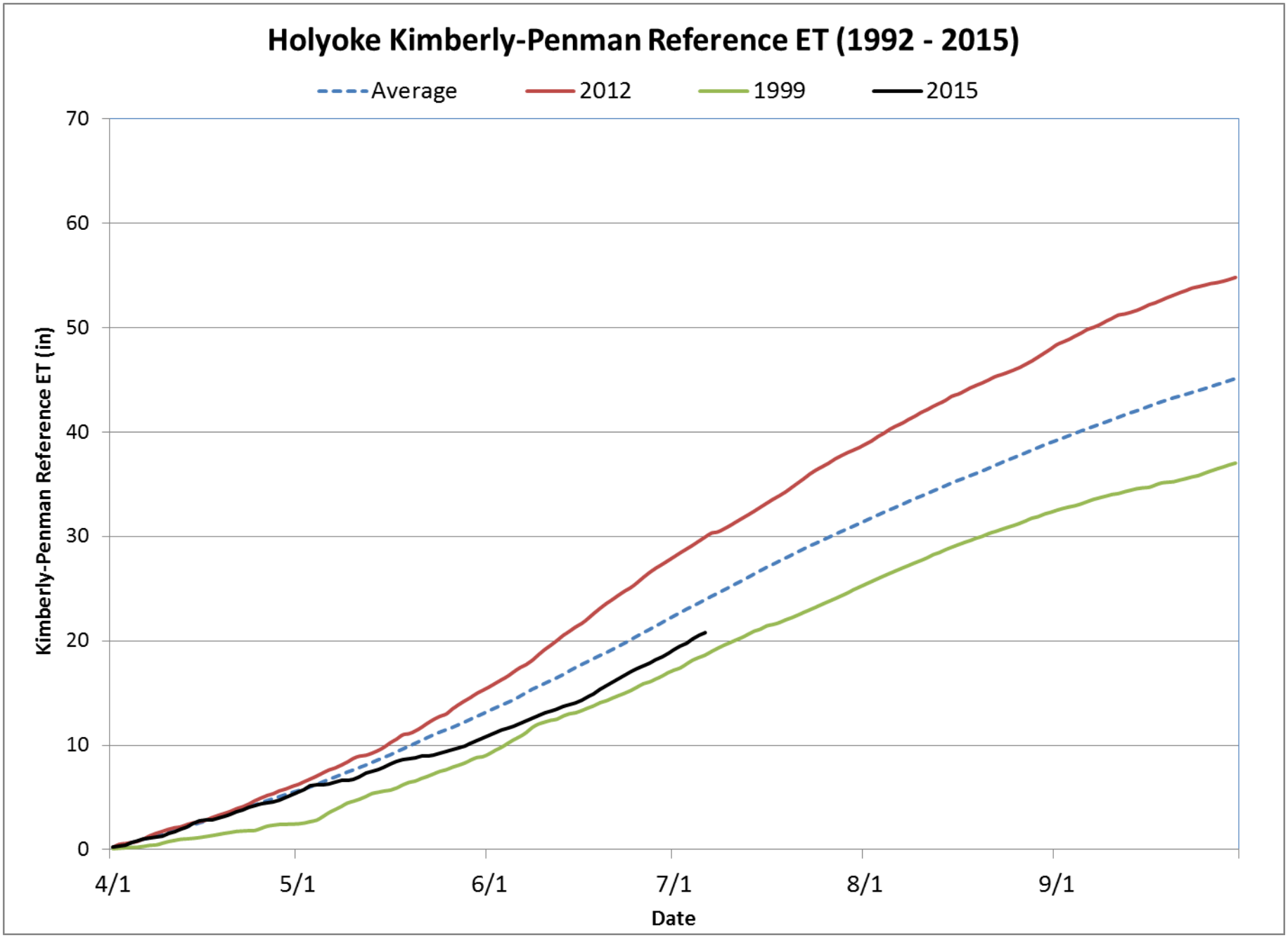
- 7 stations in Colorado
- Reference *ET* (ET_0) from Kimberley-Penman formulation
- Current year plotted against bounds / mean of 1993-2015

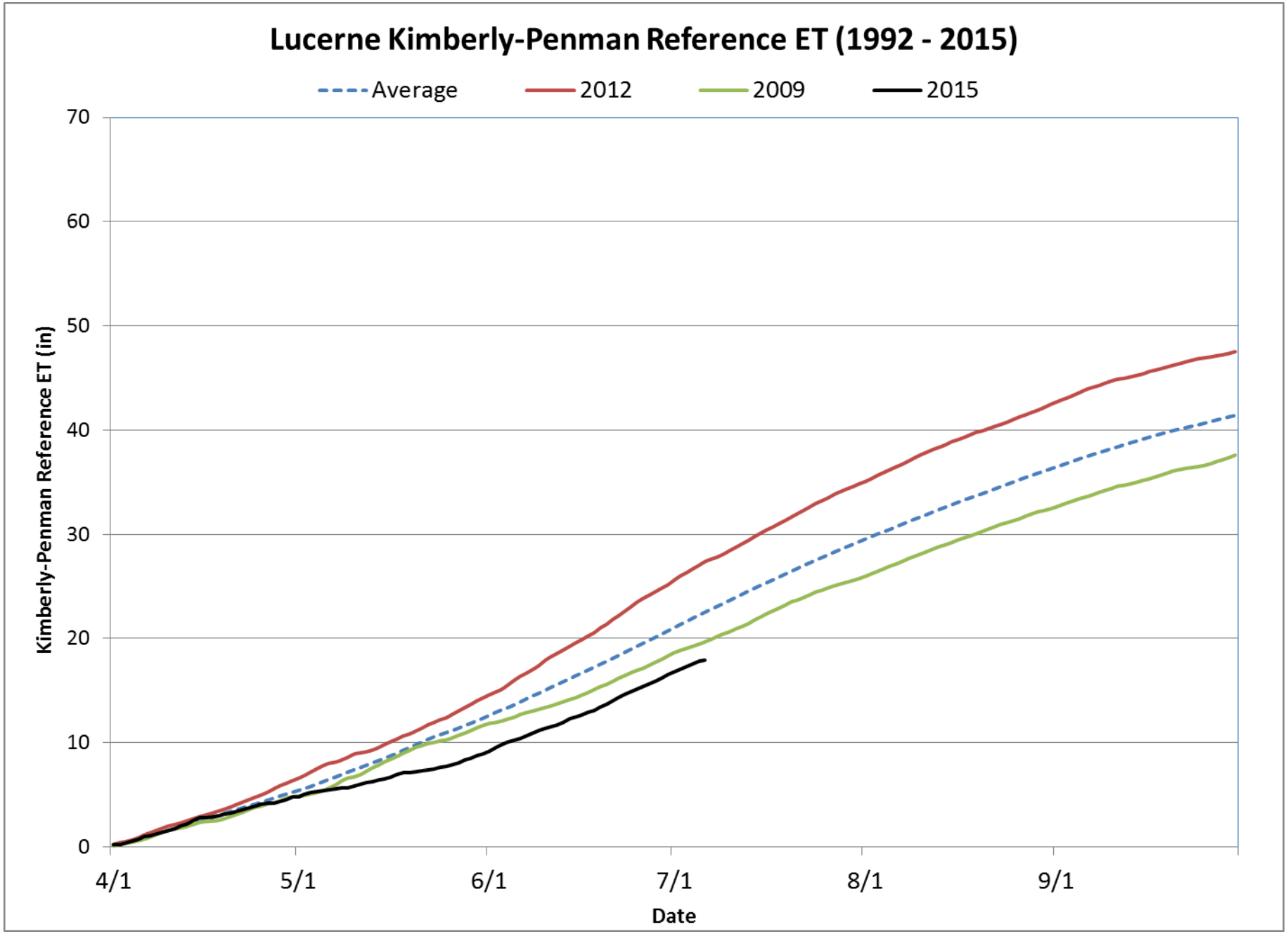
NIDIS
Upper Colorado River
Regional Drought Early Warning System


Olathe Kimberly-Penman Reference ET (1993 - 2015)
Average
1994
1999
2015
70
60
50
40
30
20
10
0
Kimberly-Penman Reference ET (in)
4/1
5/1
6/1
7/1
8/1
9/1
Date


Cortez Kimberly-Penman Reference ET (1992 - 2015)
Average
2000
1995
2015
70
60
50
40
30
20
10
0
Kimberly-Penman Reference ET (in)
4/1
5/1
6/1
7/1
8/1
9/1
Date


Avondale Kimberly-Penman Reference ET (1993 - 2015)
Average
2012
1998
2015
70
60
50
40
30
20
10
0
Kimberly-Penman Reference ET (in)
4/1
5/1
6/1
7/1
8/1
9/1
Date


Holyoke Kimberly-Penman Reference ET (1992 - 2015)
Average
2012
1999
2015
70
60
50
40
30
20
10
0
Kimberly-Penman Reference ET (in)
4/1
5/1
6/1
7/1
8/1
9/1
Date


Lucerne Kimberly-Penman Reference ET (1992 - 2015)
Average
2012
2009
2015
70
60
50
40
30
20
10
0
Kimberly-Penman Reference ET (in)
4/1
5/1
6/1
7/1
8/1
9/1
Date

Along comes EDDI – the Evaporative Demand Drought Index

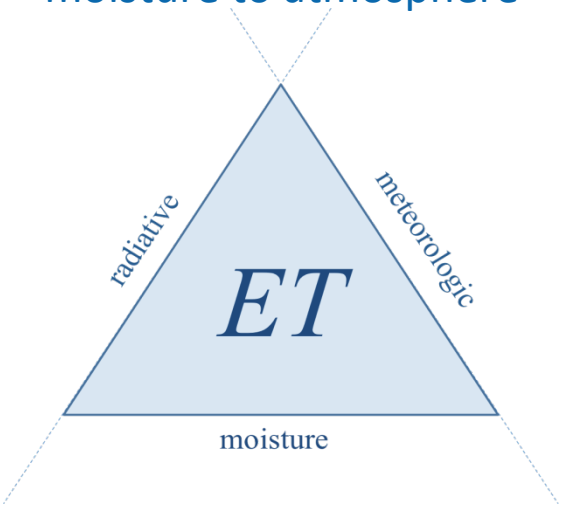
An opportunity to apply a new tool from a familiar source (i.e. We've know Mike Hobbins for a long time) and filling the need for a spatially continuous gridded product

The Evaporative Demand Drought Index, *EDDI*

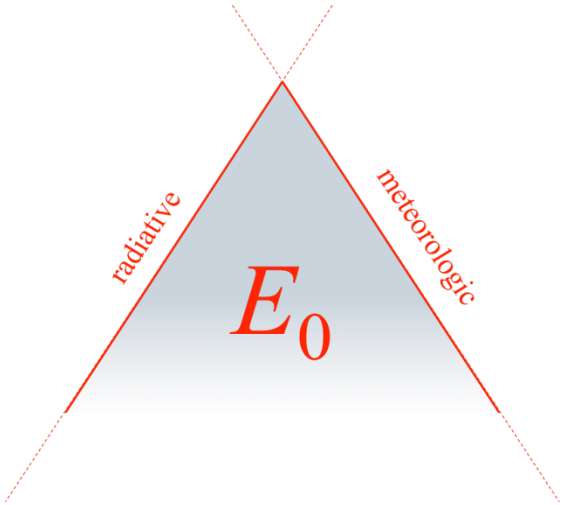
Background

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

ET is supply of surface moisture to atmosphere



E_0 is atmospheric demand for *ET*



- Reference *ET*, ET_0

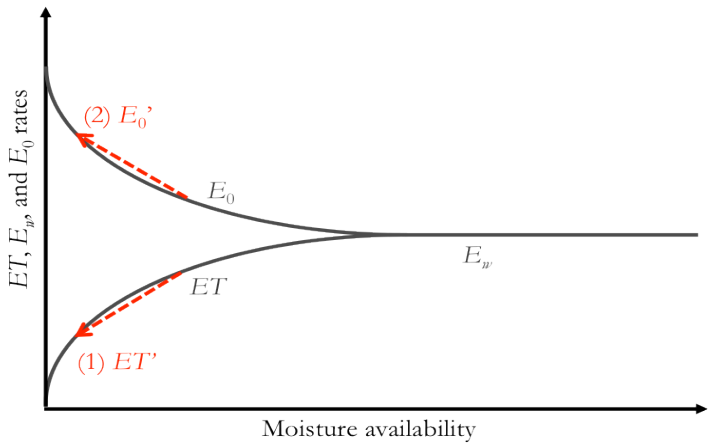
The Evaporative Demand Drought Index, *EDDI*

Background

Sustained drought - water limited

ET and E_0 vary in complementary directions:

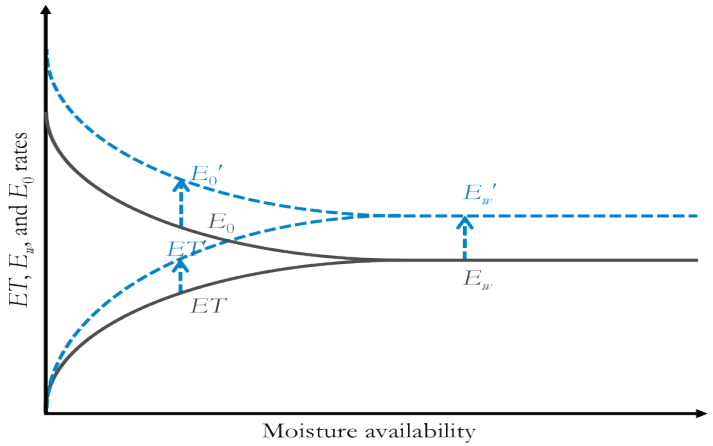
- *ET* decreases due to moisture limitations,
- E_0 increases due to energy balance favoring sensible heat over *ET*.



Flash drought - energy driven

ET and E_0 vary in a parallel direction:

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



Take home: in either drought type, E_0 increases.

Evaporative Demand Drought Index, *EDDI*:
Evaporative demand estimate

E_0 from reanalysis of ASCE Standardized Reference ET:

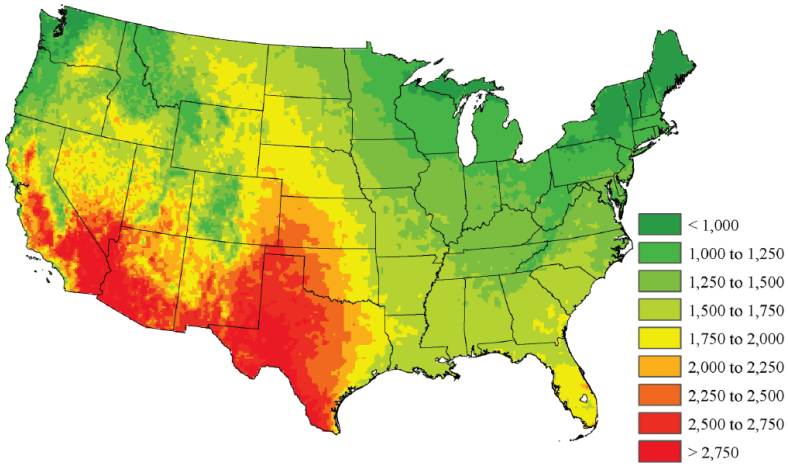
$$ET_0 = \underbrace{\frac{0.408\Delta}{\Delta+\gamma\left(1+C_d U_2\right)}\left(R_n + L_n - G\right)\frac{86400}{10^6}}_{\text{Radiative forcing}} + \underbrace{\frac{\gamma\frac{C_n}{T}}{\Delta+\gamma\left(1+C_d U_2\right)}U_2\frac{\left(e_{sat}-e_a\right)}{10^3}}_{\text{Advective forcing}}$$

Drivers from NLDAS:

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

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

- biases not crucial if they're systematic, consistent



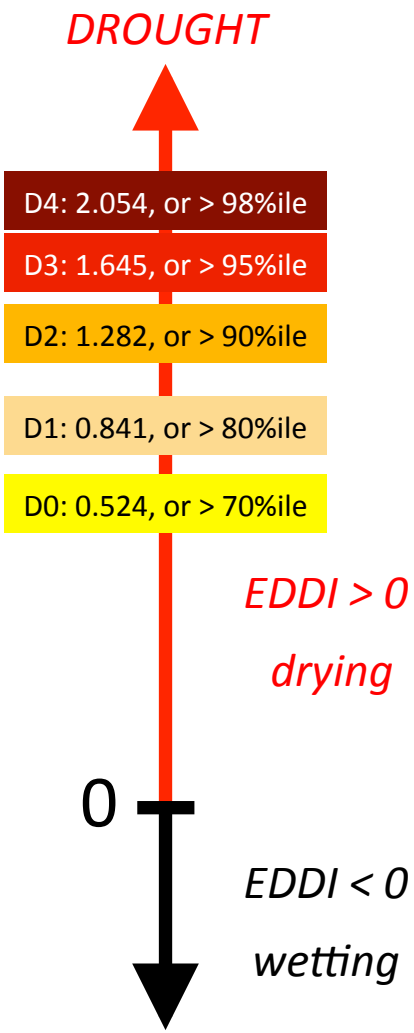
Mean annual ET_0 (mm), 1981-2010.

Evaporative Demand Drought Index, *EDDI*

EDDI formulated as Z-score

- Standardized anomalies of ET_0 accumulated across a window $\{i{:}j\}$ ranging from 1 day to >12 months.
- Climatology ($\overline{ET_0}$) is Jan 1, 1981, to Dec 31, 2010.

$$EDDI_{\{i:j\}} = \frac{\sum_i^j (ET_0 - \overline{ET_0})}{\sigma_{\overline{ET_0}_{\{i:j\}}}}$$

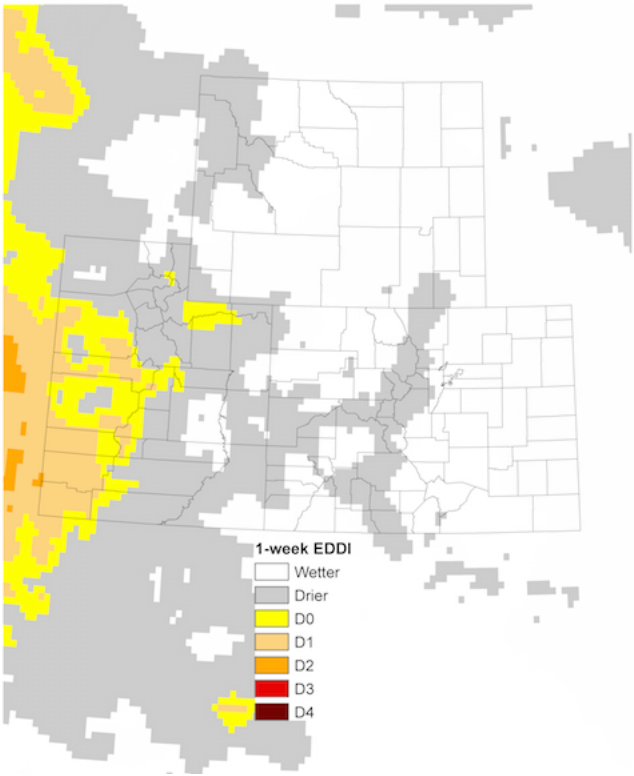


Current conditions for evaporative demand

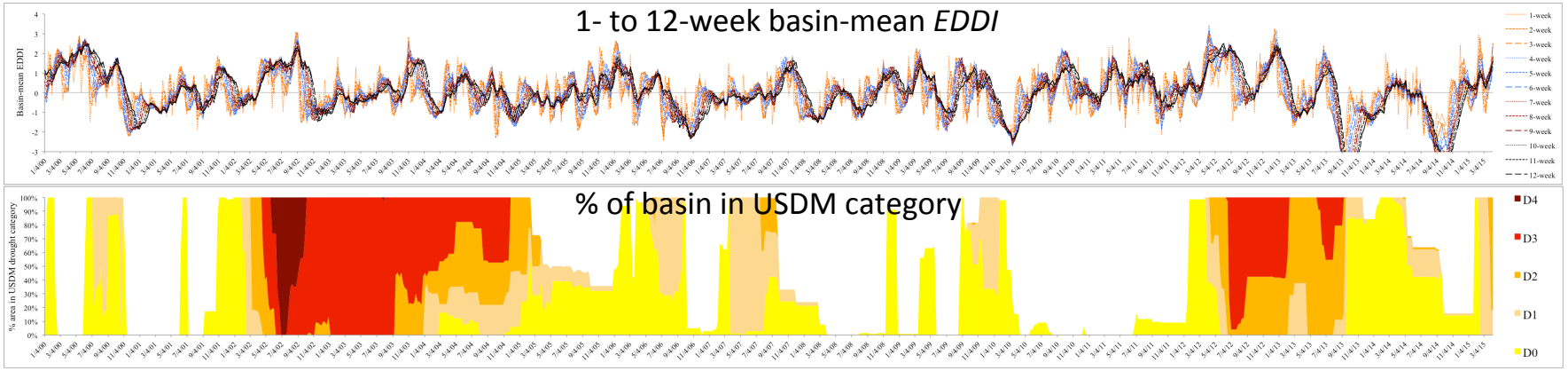
EDDI as of June 3, 2015

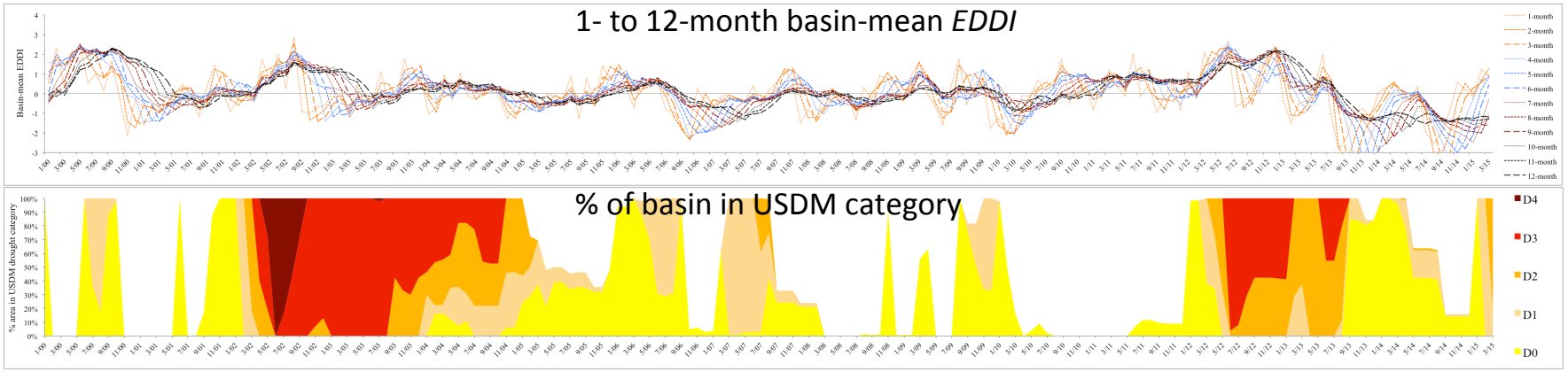
< 50 %ile	Wetter
> 50 %ile	Drier
> 70 %ile	D0
> 80 %ile	D1
> 90 %ile	D2
> 95 %ile	D3
> 98 %ile	D4

1-week *EDDI*



EDDI is multi-scalar:
Upper Colorado at Dolores



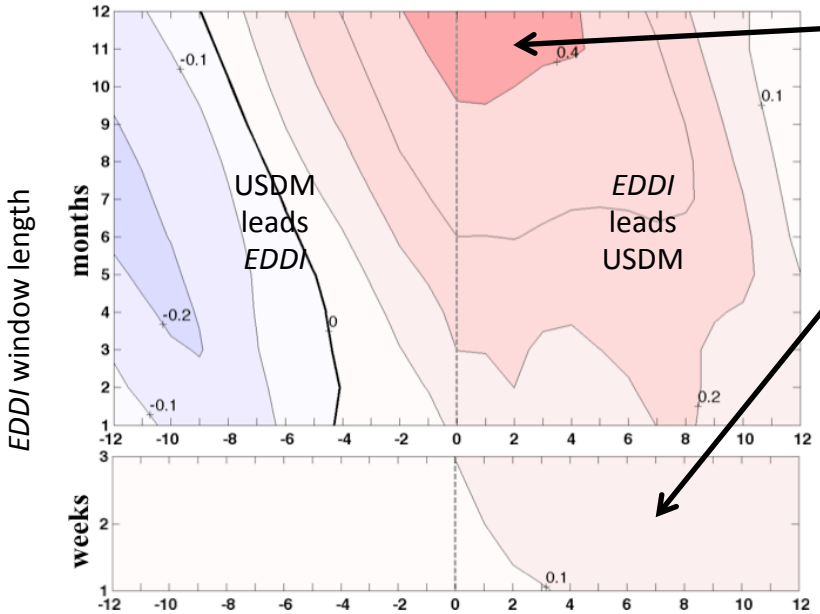


- Signals of different drying dynamics evident at different time-scales.
- *EDDI* signal precedes USDM at many time-scales.

EDDI as a leading indicator:

EDDI vs. USDM correlation across lead times and windows

Upper Colorado River near Cisco, UT



Lag of *EDDI* wrt USDM: months (top) and weeks (bottom).

Correlation between EDDI and USDM at various lead (and lag) times for Upper Colorado river basin above Cisco, UT.

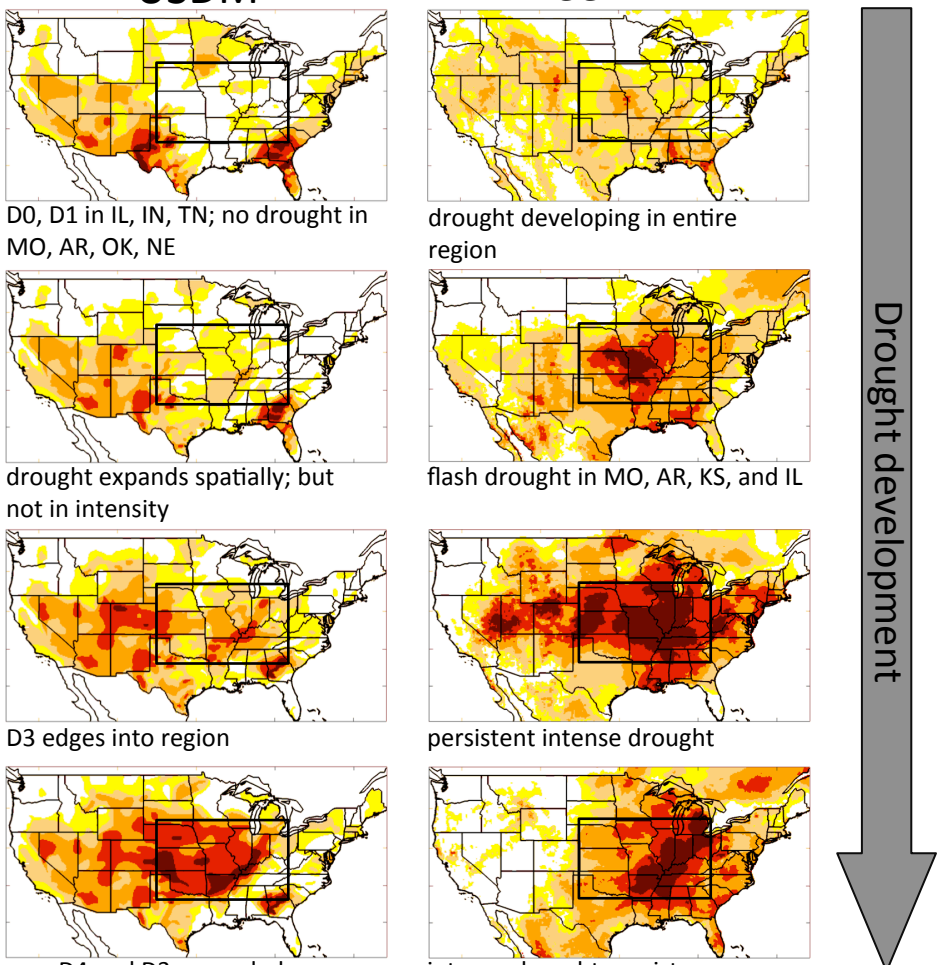
- 10- to 12-month optimal aggregation period yields a lead-time over the USDM of ~4 months
- little correlation at shorter 1- to 3-weekly aggregation periods.
- may be due to scale and hydroclimatology of the basin, as significant inter-seasonal storage occurs as snowpack. Dry anomalies in snow accumulation:
  - reflected quickly in *EDDI* signal,
  - not in USDM until following irrigation season.

What *EDDI* can tell us:

Flash-drought detection and early warning

Midwest flash drought, 2012

USDM (L) vs. 2-week *EDDI* (R) at 5-week intervals during drought onset.



D0, D1 in IL, IN, TN; no drought in MO, AR, OK, NE

drought developing in entire region

drought expands spatially; but not in intensity

flash drought in MO, AR, KS, and IL

D3 edges into region

persistent intense drought

new D4 and D3 expanded over much of region; drought introduced into NY, PA, and VA, 2 months after *EDDI*

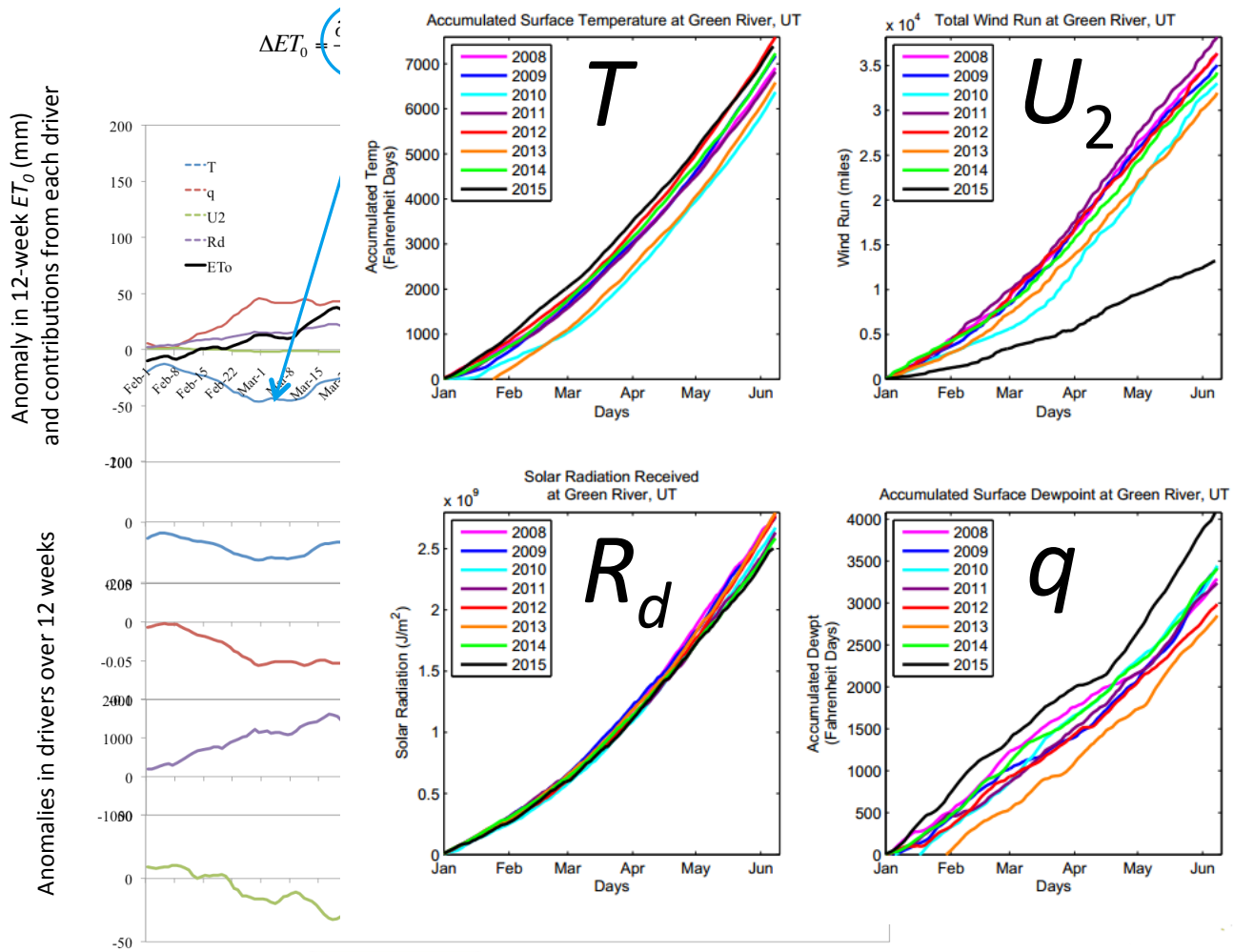
intense drought persists; note little drought in western US

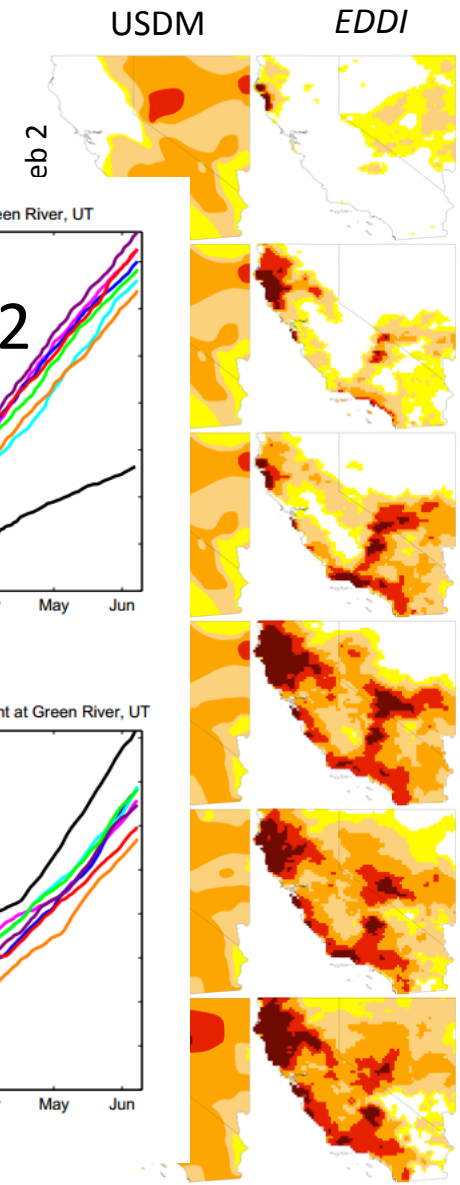
What *EDDI* can tell us:

Decomposition of drought evaporative forcing

$$\Delta ET_0 = f\{T, R_d, q, U_2\}$$

i.e., ET_0 is a function of four meteorological drivers, which vary during, and cause, drought.





Top: time-series of 12-week anomalies in ET_0 (ΔET_0) and contributions to ΔET_0 from each driver; bottom: 12-week anomalies in each driver.

A rapid drought intensification, 2013, mapped by (left) USDM and (right) 12-week EDDI.

Uses of *EDDI*:

Various applications of *EDDI* and ET_0 reanalysis

- stand-alone, leading indicator of drought in USDM.
- ET_0 reanalysis to provide a physically based data-stream to replace temperature-based E_0 currently used in PDSI.
- fire forecasting: USFS Southern Research Station currently using *EDDI* in seasonal forecasting of:
    - # large fires (> 5000 acres)
    - suppression costs on US lands

Summary

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

- easy to compute, physically rational:
  - responds to drying and wetting,
  - responds to both sustained and flash droughts.
- permits decomposition of evaporative drought drivers.
- permits near real-time drought monitoring / early warning.
- consistent with USDM:
- multi-scalar:
  - different drying dynamics evident at different time-scales,
  - short-term *EDDI* (e.g., < 12-week) can serve as a drought early warning signal, especially in agricultural areas,
  - long-term *EDDI* (e.g., 6-month) better for water-limited hydrologic drought monitoring.
- aggregation window may be calibrated for:
  - early warning cf. other monitors,
  - regionally specific hydroclimate and sector demands.

We're still in process of familiarization and implementation

-- using internally

-- now built into our infrastructure

-- Mike has introduced EDDI to UCRB stakeholders in a recent webinar

-- We're rolling with it now!