The Evaporative Demand Drought Index (EDDI):
Early warning, monitoring, and attribution of drought

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with

Darren Jackson[1,2], Dan McEvoy[3,4], Imtiaz Rangwala[2,5], Heather Yocum[2,5]

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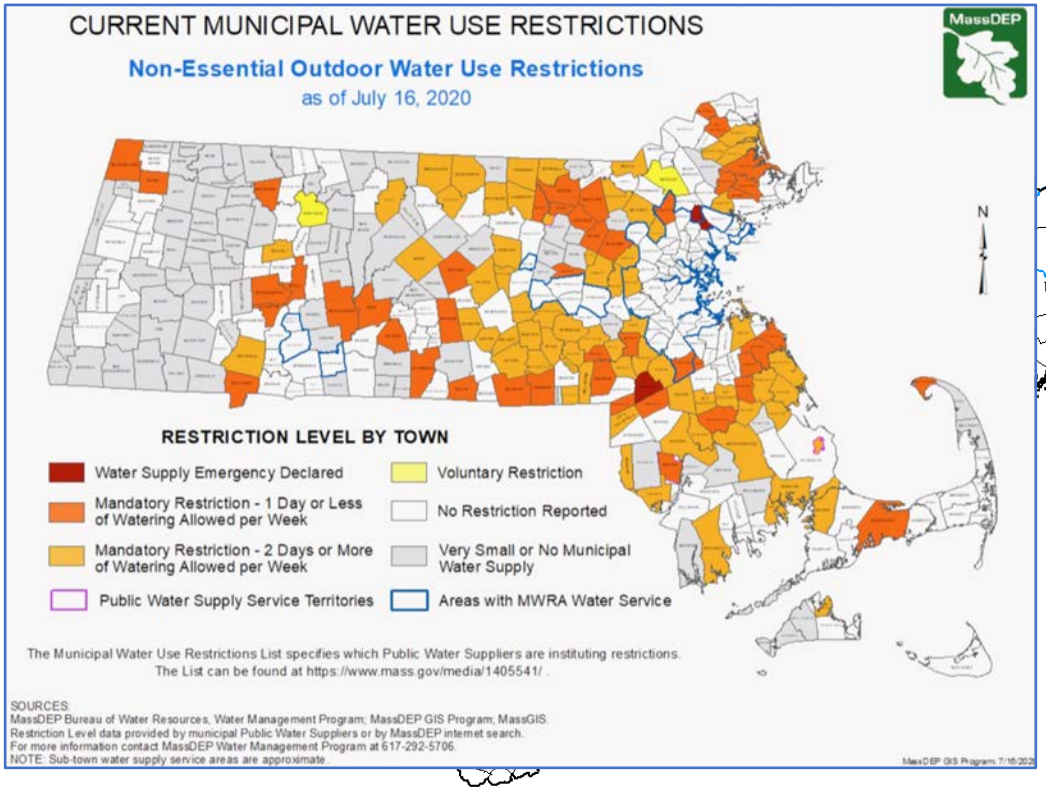
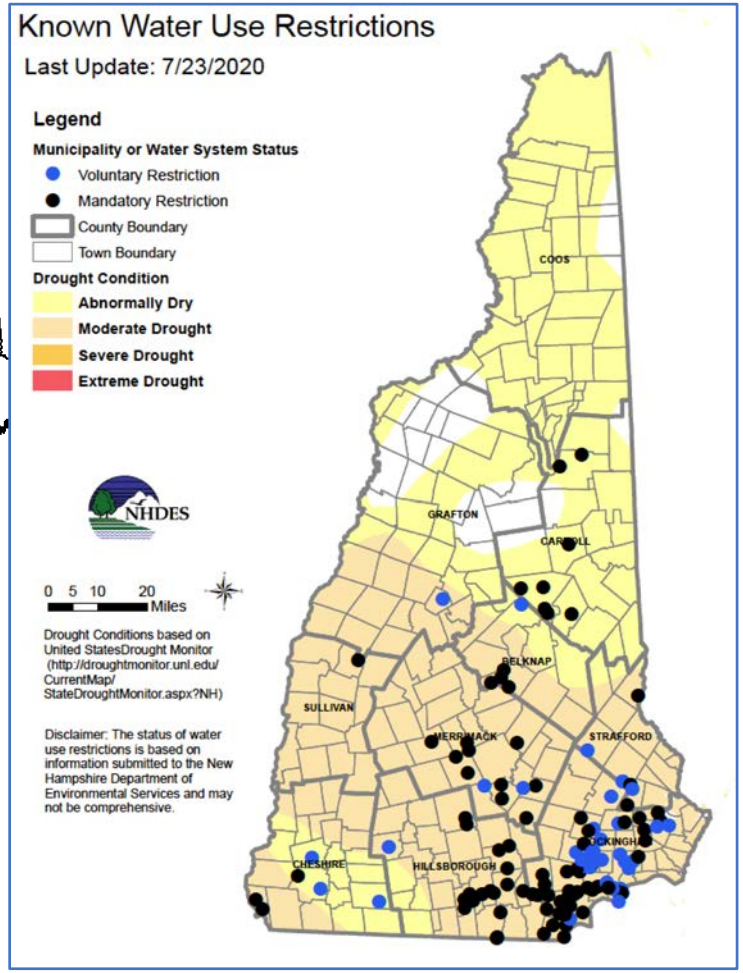
(2) University of Colorado-Cooperative Institute for Research in Environmental Sciences
(3) NOAA-Western Regional Climate Center
(4) Desert Research Institute
(5) USGS-North Central Climate Adaptation Science Center

NOAA Eastern Region Webinar, July 30, 2020


CURRENT MUNICIPAL WATER USE RESTRICTIONS
Non-Essential Outdoor Water Use Restrictions
as of July 16, 2020
MassDEP
N
RESTRICTION LEVEL BY TOWN
Water Supply Emergency Declared
Mandatory Restriction - 1 Day or Less of Watering Allowed per Week
Mandatory Restriction - 2 Days or More of Watering Allowed per Week
Public Water Supply Service Territories
Voluntary Restriction
No Restriction Reported
Very Small or No Municipal Water Supply
Areas with MWRA Water Service
The Municipal Water Use Restrictions List specifies which Public Water Suppliers are instituting restrictions.
The List can be found at https://www.mass.gov/media/1405541/ .
SOURCES:
MassDEP Bureau of Water Resources, Water Management Program; MassDEP GIS Program; MassGIS.
Restriction Level data provided by municipal Public Water Suppliers or by MassDEP internet search.
For more information contact MassDEP Water Management Program at 617-292-5706.
NOTE: Sub-town water supply service areas are approximate.


Known Water Use Restrictions
Last Update: 7/23/2020
Legend
Municipality or Water System Status
Voluntary Restriction
Mandatory Restriction
County Boundary
Town Boundary
Drought Condition
Abnormally Dry
Moderate Drought
Severe Drought
Extreme Drought
NHDES
0 5 10 20
Miles
Drought Conditions based on United StatesDrought Monitor (http://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?NH)
Disclaimer: The status of water use restrictions is based on information submitted to the New Hampshire Department of Environmental Services and may not be comprehensive.
COOS
GRAFTON
CARROLL
BELKNAP
SULLIVAN
MERRIMACK
STRAFFORD
ROCKINGHAM
CHESHIRE
HILLSBOROUGH

What is EDDI?

An EDDI month is 30 days, so this 1-month EDDI map is based on E_0 from June 26 - July 25.

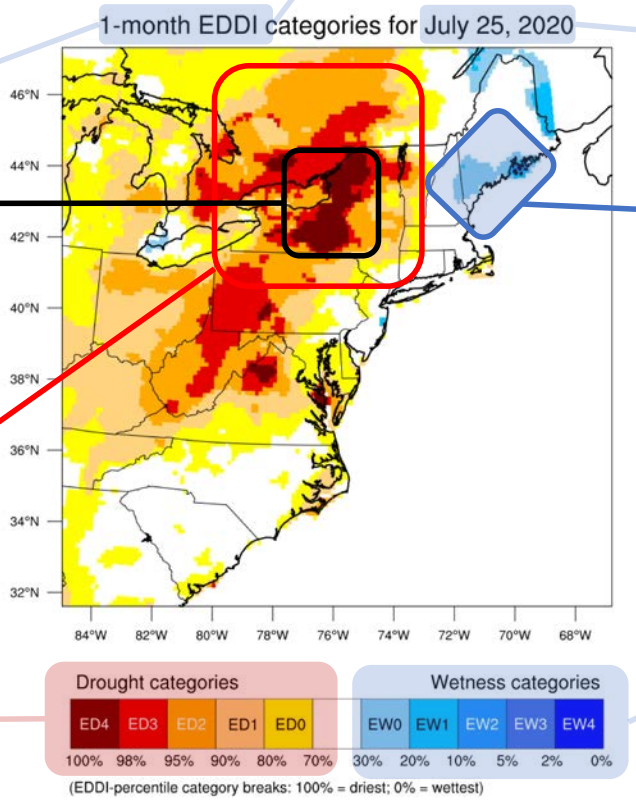
There are 24 time scales: 1-12 weeks, 1-12 months.

Lag of ~4 days, so this map was released on July 29.

ED4 in Upstate NY means that such dry conditions are expected only 2% of June 13 – July 12 periods.

E_0 is unusually low in southern Maine, indicating wetter-than-normal surface conditions and atmosphere.

E_0 is unusually high in the western NE DEWS region, indicating drier-than-normal surface conditions and atmosphere.



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.

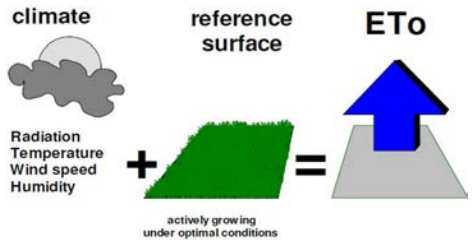
EDDI: the anomaly in evaporative demand at a specified timescale, for a given location, expressed as a percentile.

Background | *What is evaporative demand (E_0)?*

E_0 = evaporative demand
ET = actual evapotranspiration
ET_0 = reference ET

- E_0 is <u>not</u> evapotranspiration/evaporation
- E_0 is evaporation **given an unlimited moisture supply**:
  - **Reference *ET*, ET_0**
  - Potential *ET ("PET")*
  - Pan evaporation
- Good estimate
  - **physically based**
  - radiation-based
  - temperature-based
- E_0 is used for:
  - estimating crop water requirements
  - scheduling irrigation
  - driving *ET* estimates in LSMs and R/S fusion
  - monitoring drought

E_0 is the "thirst of the atmosphere"



Background | *Exploiting E_0 in a demand-side treatment of drought*

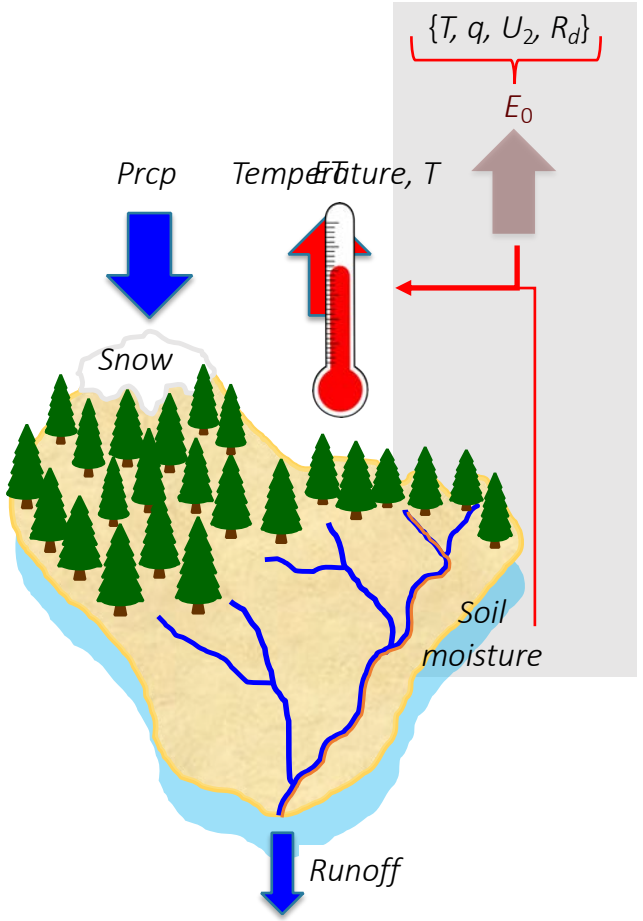
Drought = imbalance of supply to, and demand for, surface moisture

Water balance at land surface:

~ *f*(*Prcp*, *ET*)

where *ET* is more physically driven by:

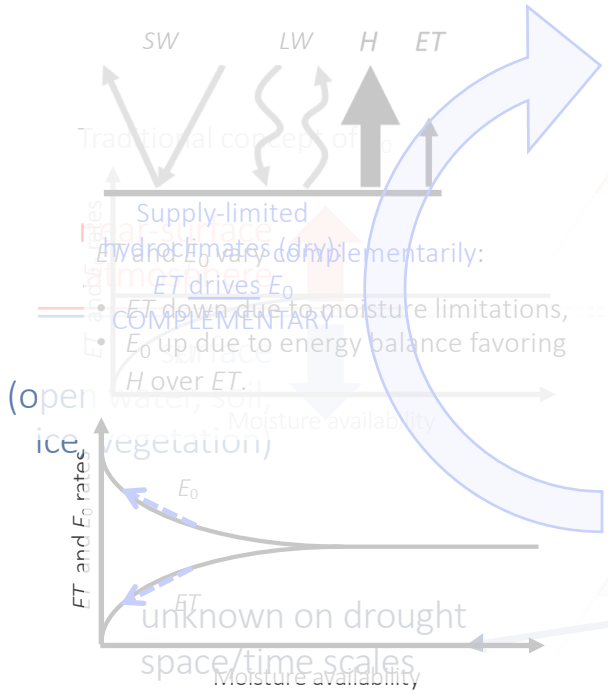
- surface moisture status,
- evaporative demand (E_0),
  - e.g., Penman-Monteith.



T = air temperature
q = specific humidity
U_2 = wind speed
R_d = solar radiation

Background | E_0 / ET constraints and interactions

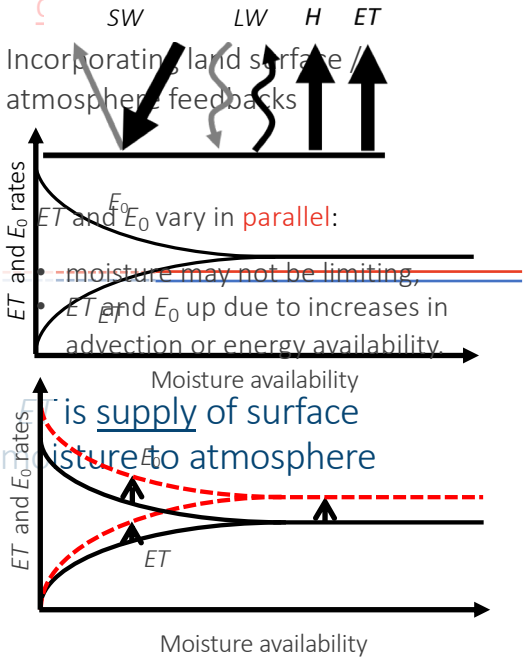
Ongoing drought - water limited



unknown on drought space/time scales

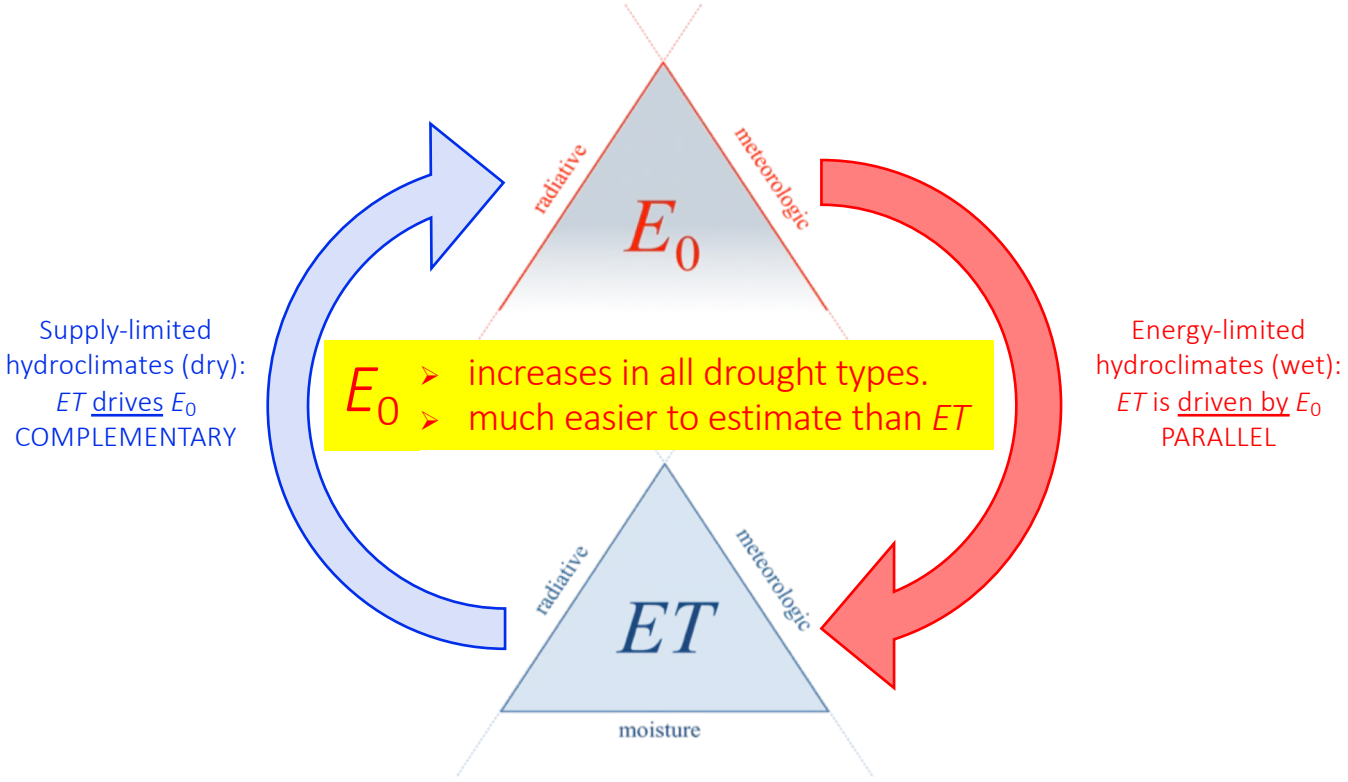
Flash drought - energy driven

E_0 is atmospheric



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

Background | *E_0 / ET constraints and interactions*



Background | E_0 *and drought*

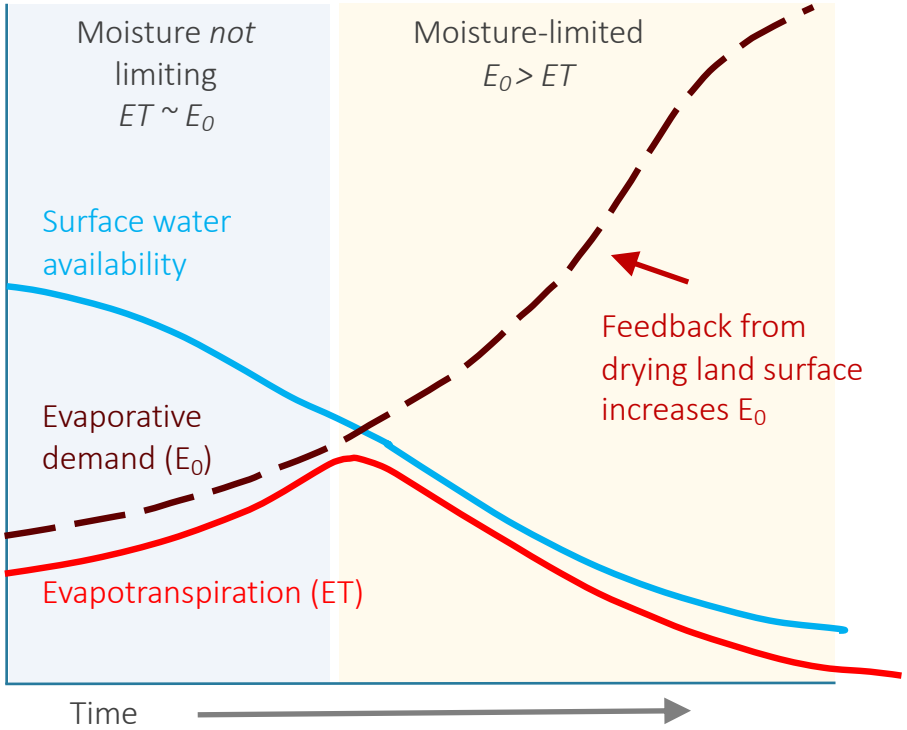
(Lukas et al., WWA 2017)

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

Evaporative demand rises in all forms of drought.



Background | *Estimating E_0 from reference ET*

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

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

Reference crop specified:

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

Drivers from NLDAS-2:

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

Reanalysis specifications:

- daily, Jan 1, 1979 – present
- latency ~ 5 days
- 0.125° lat x lon, CONUS+ (to 53°N)

Mean daily E_0 (mm), 1981-2010

Exploiting E_0 | *Evaporative Demand Drought Index (EDDI)*

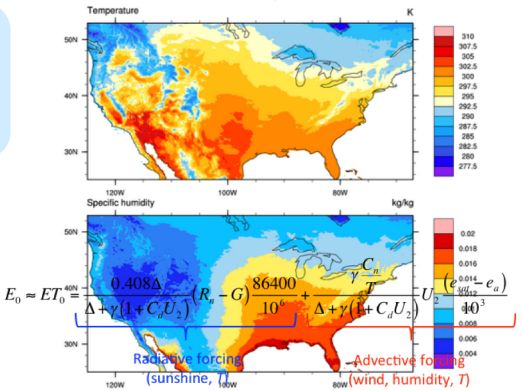
(*Hobbins et al.*, JHM 2016;
McEvoy et al., JHM 2016)

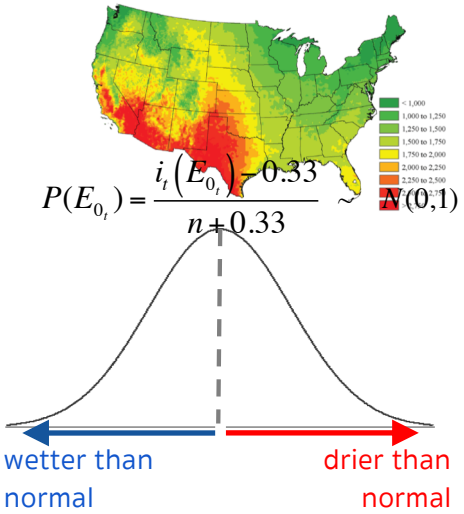
Meteorological Inputs
temperature, humidity, wind speed, solar radiation
NLDAS-2, 12-km gridded, daily

Reference Evapotranspiration calculation
Penman-Monteith FAO56

Temporal aggregation &
rank-based non-parametric standardization
wrt 39-year climatology of ET_0

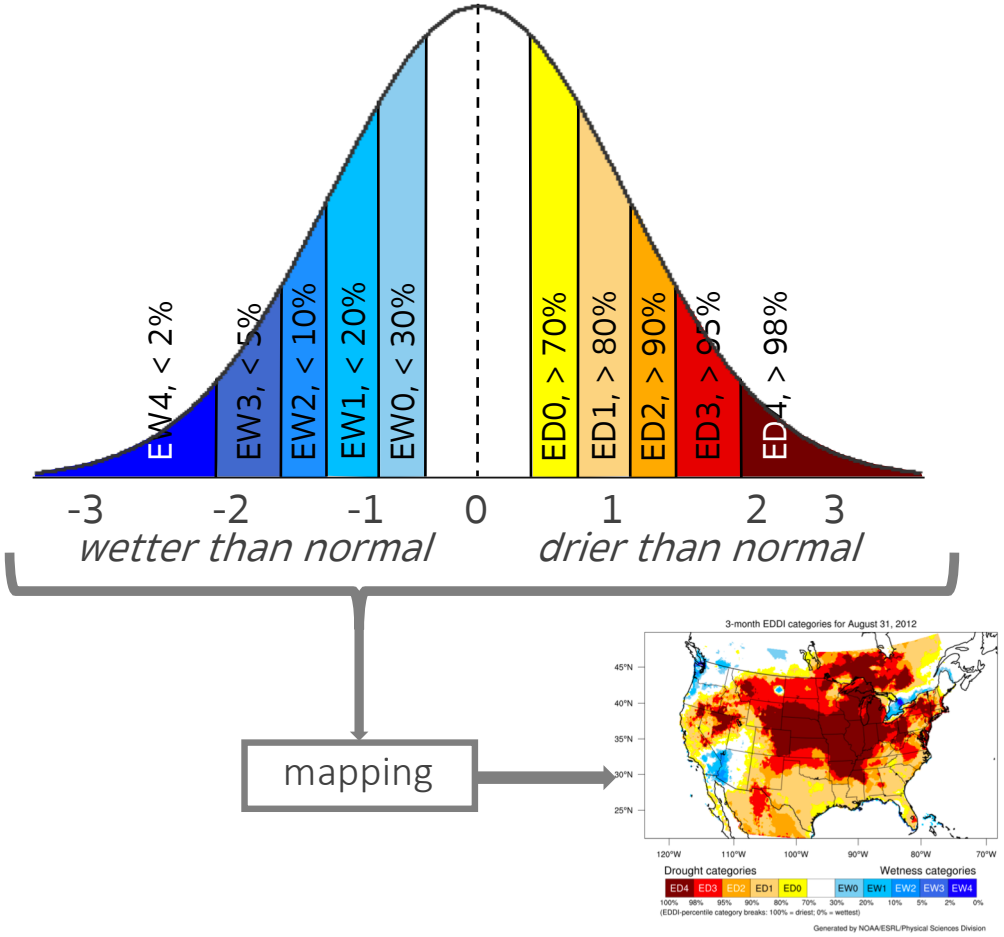
EDDI





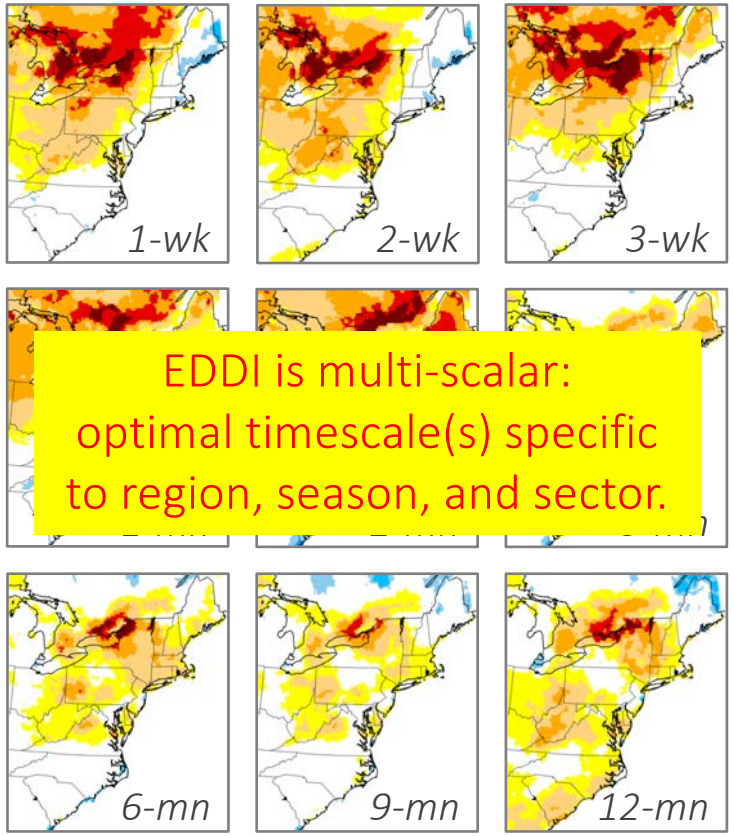
Exploiting E_0 | *Evaporative Demand Drought Index (EDDI)*

(*Hobbins et al.*, JHM 2016;
McEvoy et al., JHM 2016)



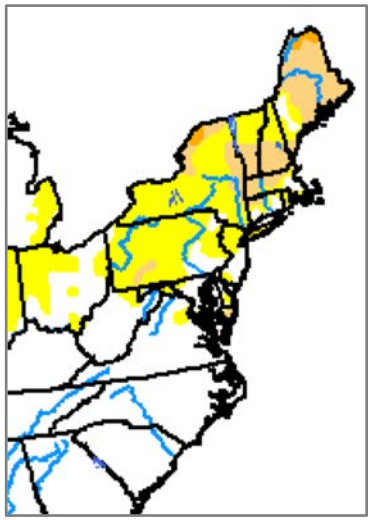
EDDI | *A multi-scalar drought estimator*

EDDI, July 7, 2020



EDDI is multi-scalar:
optimal timescale(s) specific
to region, season, and sector.

US Drought Monitor, July 7, 2020



Intensity:
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

EDDI | *Cross-sectoral monitoring*

EDDI is NOT a measure of
METEOROLOGICAL DROUGHT
(or precipitation deficit)

AGRICULTURAL DROUGHT
- soil moisture
- grazing health
- ET

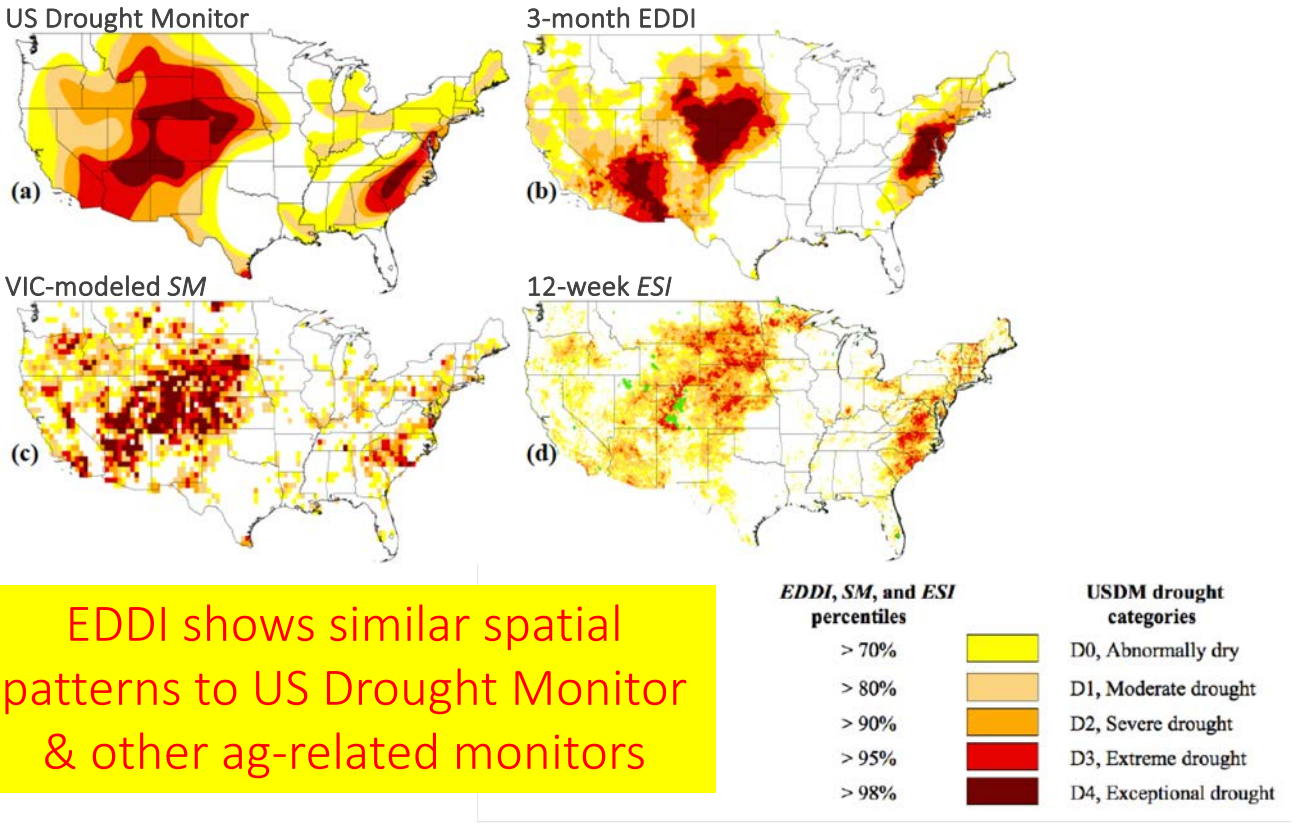
FIRE-RISK MONITORING
- weather
- fuel loads

ECOLOGICAL DROUGHT

EDDI | *Agricultural drought*

VIC = Variable Infiltration Capacity model
ESI = Evaporative Stress Index

Western US, July 31, 2002

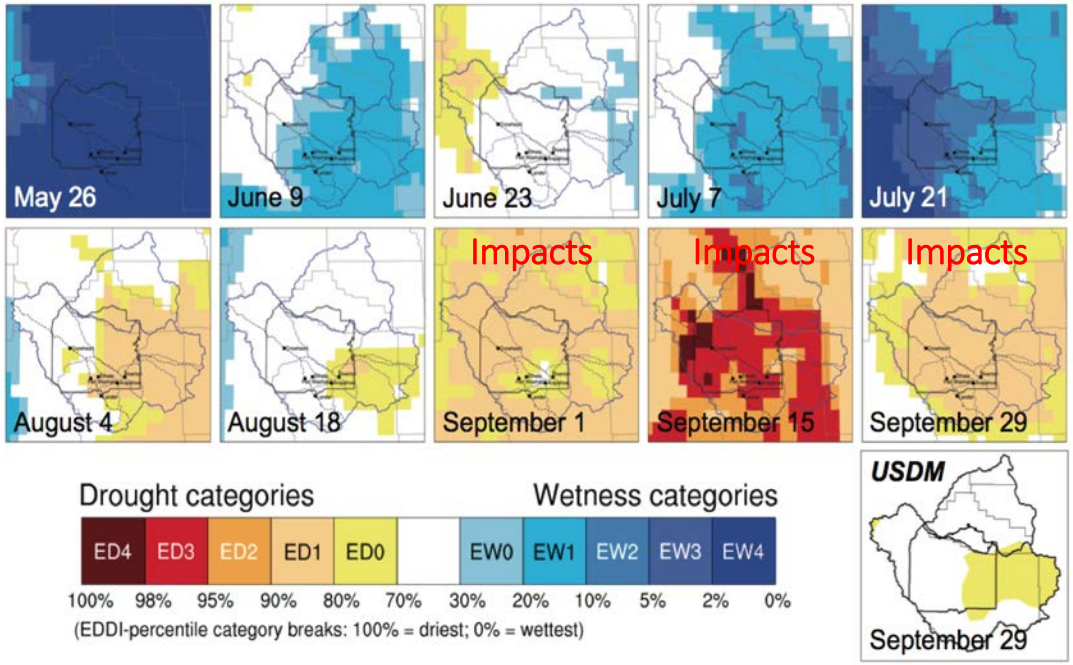


EDDI shows similar spatial patterns to US Drought Monitor & other ag-related monitors

EDDI | *Early warning of flash drought*

Wind River Indian Reservation, WY: 2015

2-week EDDI at 2-week intervals through growing season

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E&E NEWS
CLIMATE

A Wyoming Reservation Shows the New Face of Drought

A climate-driven warping of the water cycle is forcing a re-think of water management practices

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

ELSEVIER

Anatomy of an interrupted irrigation season: Micro-drought at the Wind River Indian Reservation

Shannon M. McNeeley[a,*], Candida F. Dewes[a,b,c], Crystal J. Stiles[d], Tyler A. Beeton[a], Imtiaz Rangwala[a,b,c], Michael T. Hobbins[b,c], Cody L. Knutson[e]

McNeeley et al., *Climate Risk Management*, 2018

EDDI | *Early warning of flash drought*

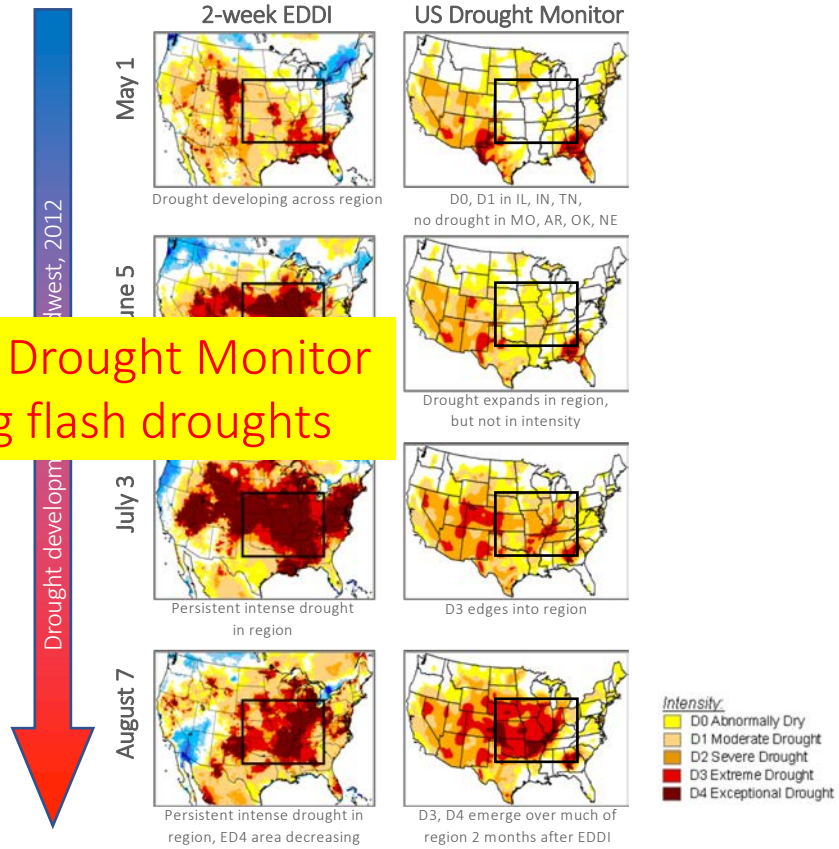
Midwest US: 2012

EDDI captured severe drought conditions ~2 months before the US Drought Monitor

EDDI leads US Drought Monitor in identifying flash droughts

Q: Had we been looking at E_0 would this have been a flash drought in Otkin's intensification-rate rubric?

Better warning ⇨ fewer flash droughts?

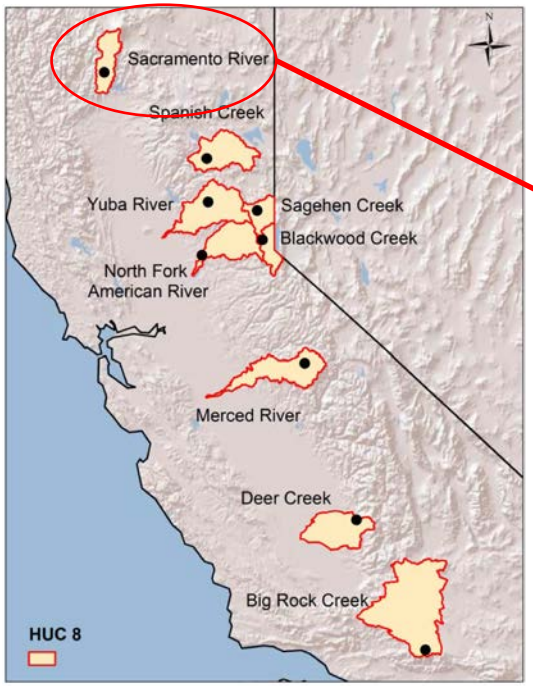


Hobbins et al., *CRC Press*, 2017

EDDI | *Early warning of hydrological drought*

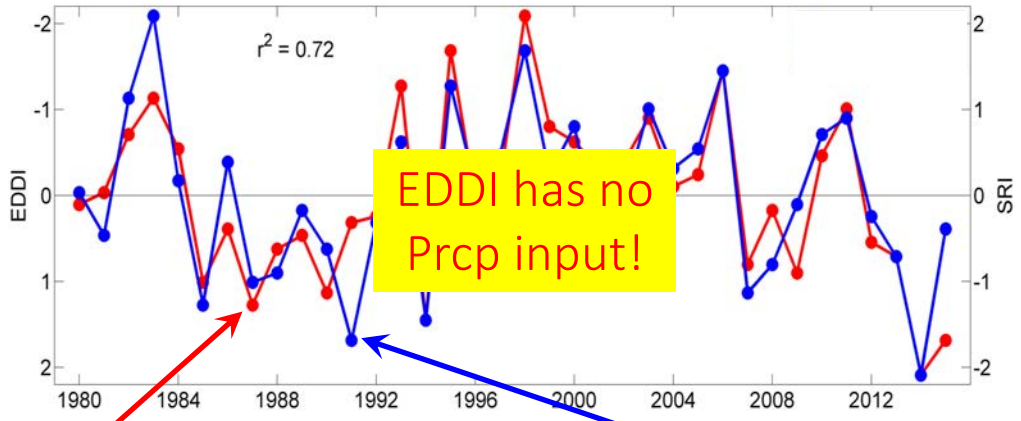
SRI = Standardized Runoff Index

EDDI and streamflow in nine snowmelt-dominated basins



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

Sacramento River Basin, CA



EDDI has no Prcp input!

6-month EDDI (Nov-Apr)

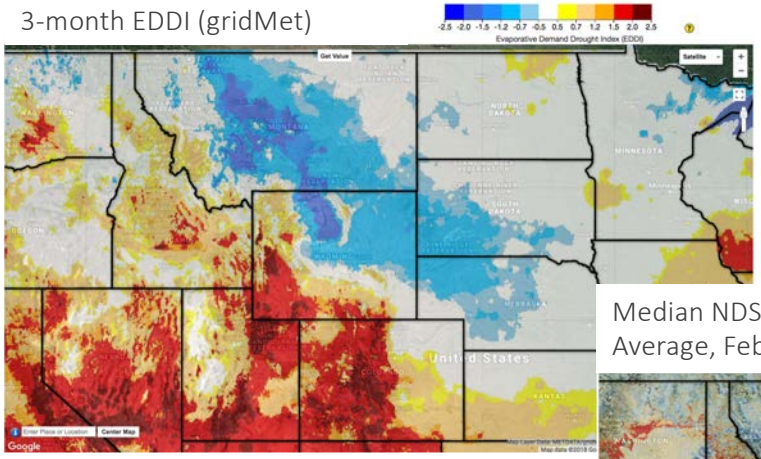
12-month SRI (Oct-Sep)

DRI Desert Research Institute

EDDI | *Snow and snow drought*

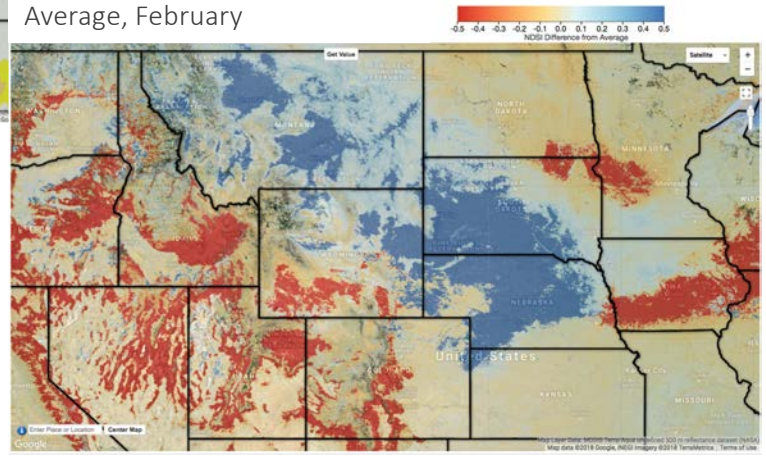
Northern Great Plains: December, 2017 – February, 2018

3-month EDDI (gridMet)



- Useful for evaluating snow and snow drought
- Snow drought can occur due to low *Prcp*, or average *Prcp* but rain vs. snow

Median NDSI Difference from Average, February

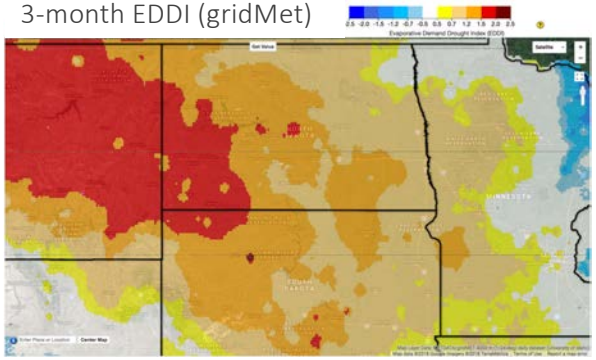


EDDI | *Complementing remote sensing*

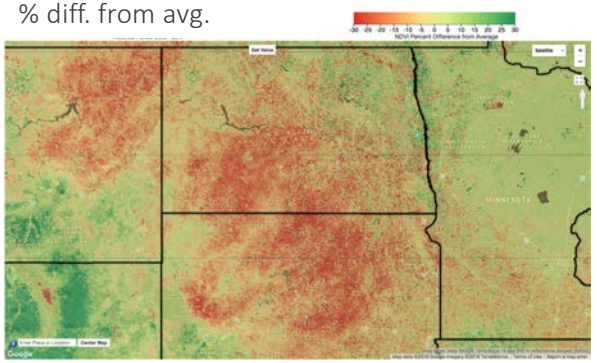
Understanding remote sensing anomalies of land surface temperature, vegetation, and ET

Northern Great Plains: May – July, 2017

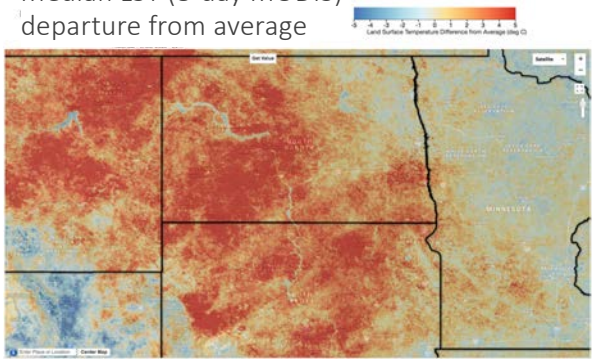
3-month EDDI (gridMet)



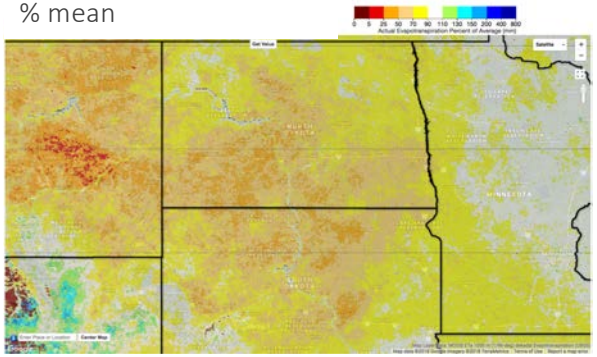
Median NDVI (16-day MODIS)
% diff. from avg.



Median LST (8-day MODIS)
departure from average

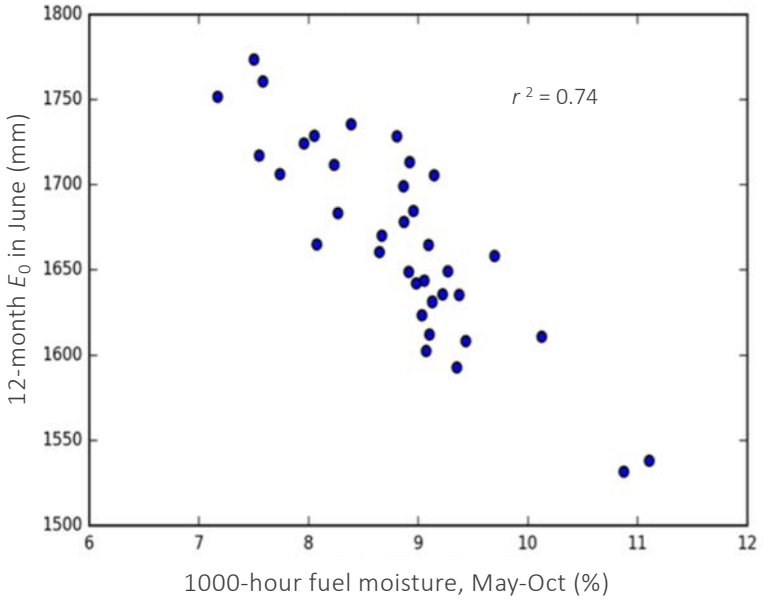


3-month *ET* (SSEBop)
% mean



EDDI | *Wildfire-risk monitoring*

E_0 - fuel moisture relationship across S. California GACC



Q: Can EDDI provide early warning of wildfire risk?

climate

MDPI

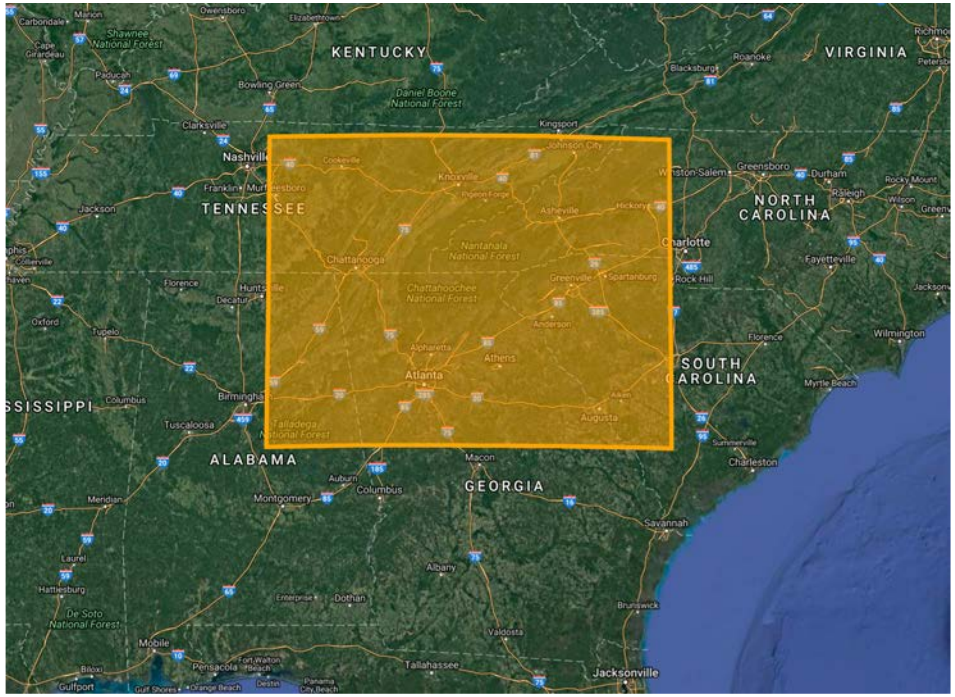
Article

Establishing Relationships between Drought Indices and Wildfire Danger Outputs: A Test Case for the California-Nevada Drought Early Warning System

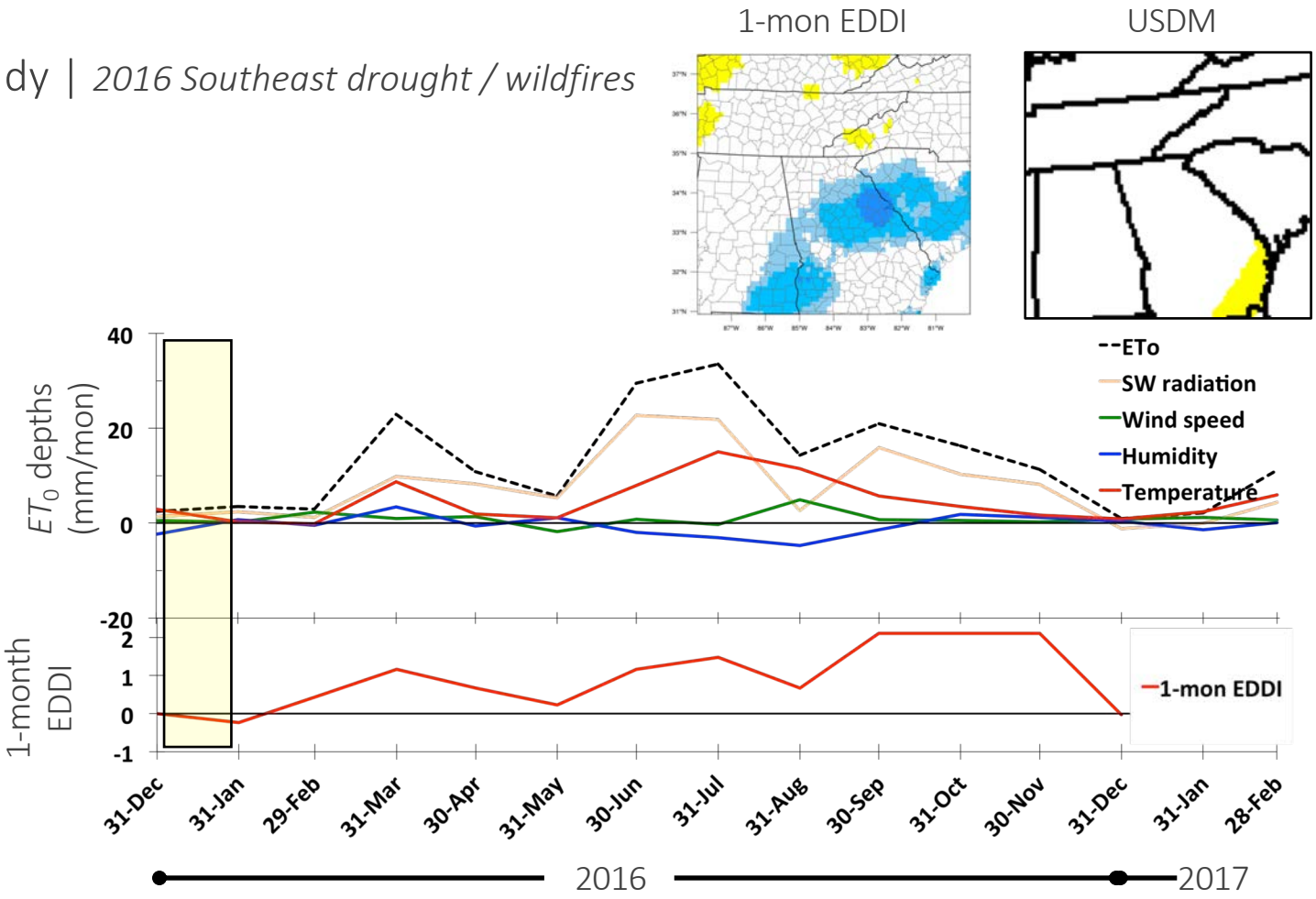
Daniel J. McEvoy [1,2,*], Mike Hobbins [3,4], Timothy J. Brown [1,2], Kristin VanderMolen [1,2], Tamara Wall [1,2], Justin L. Huntington [2,5] and Mark Svoboda [6]

GACC = Geographic Area Coordination Center

Case study | *2016 Southeast drought and wildfires*



Case study | *2016 Southeast drought / wildfires*



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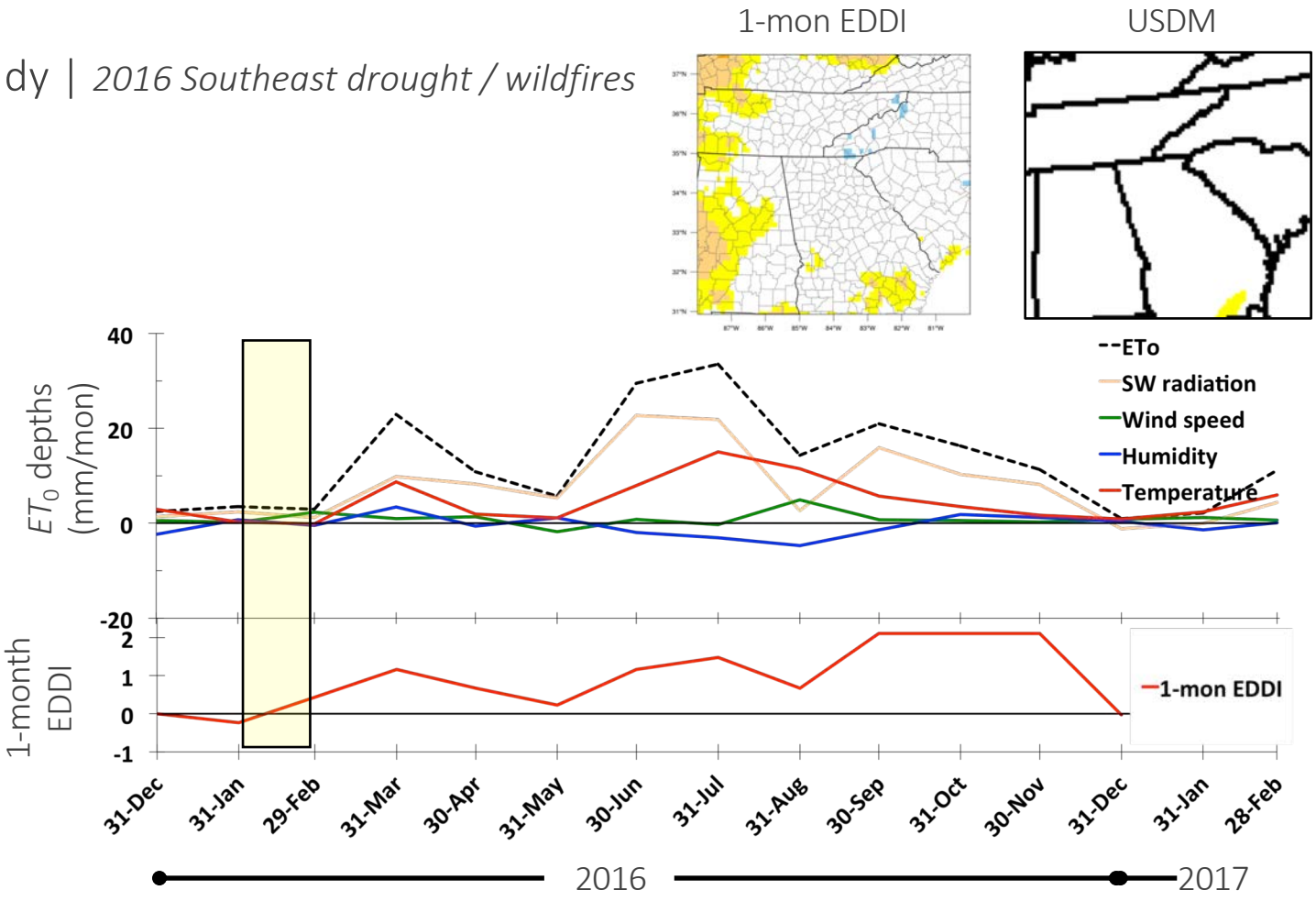

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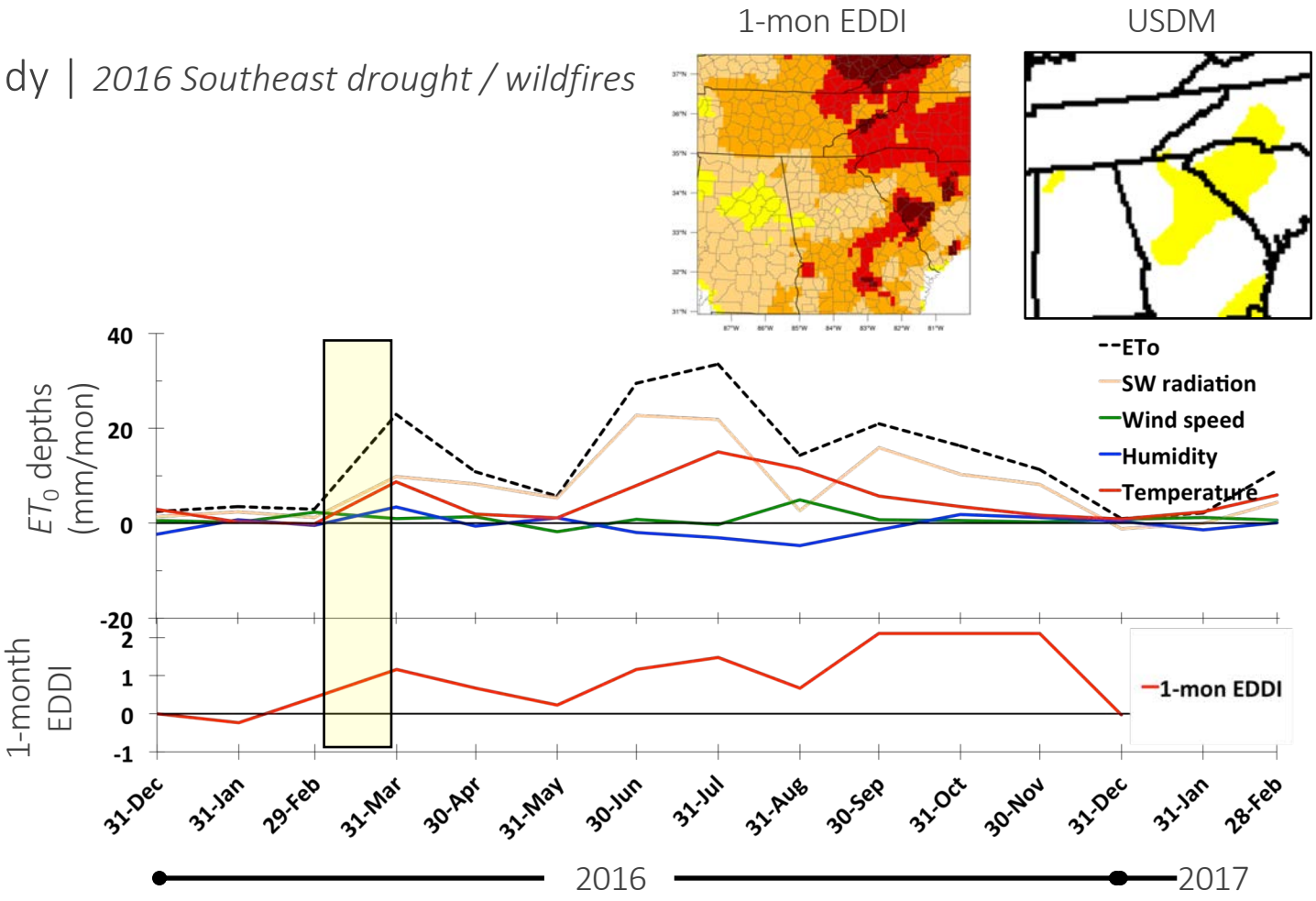
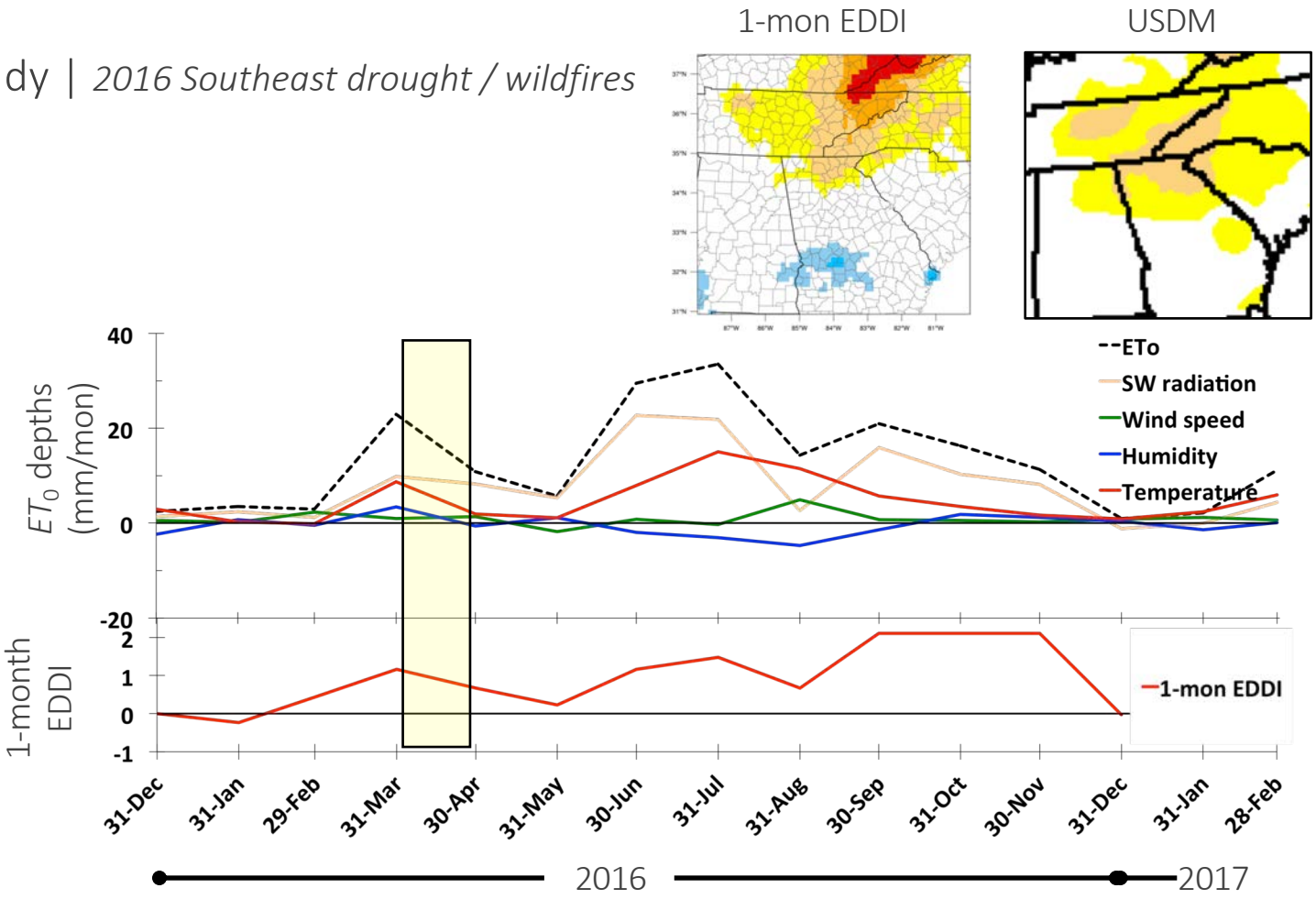


Case study | *2016 Southeast drought / wildfires*



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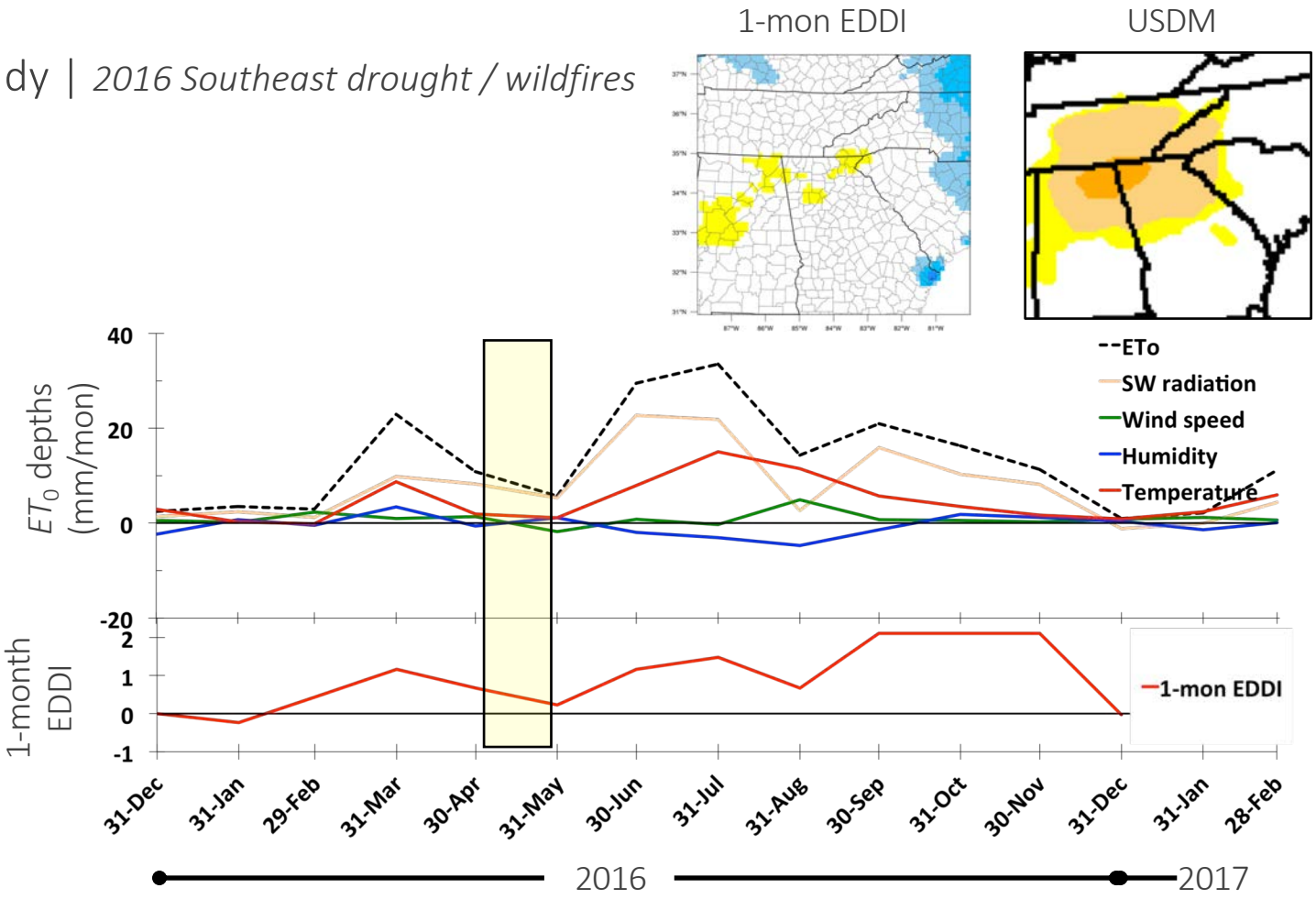
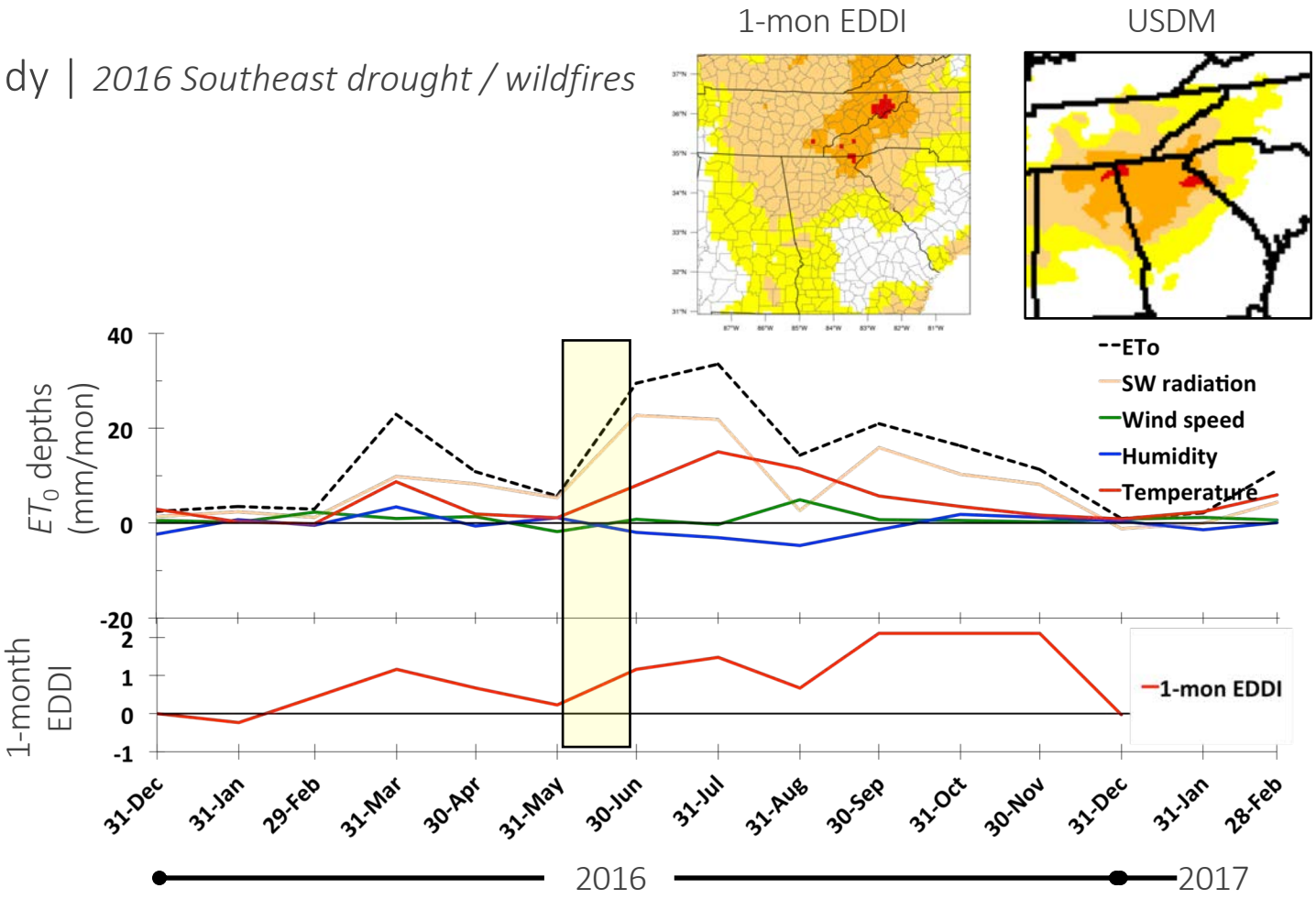
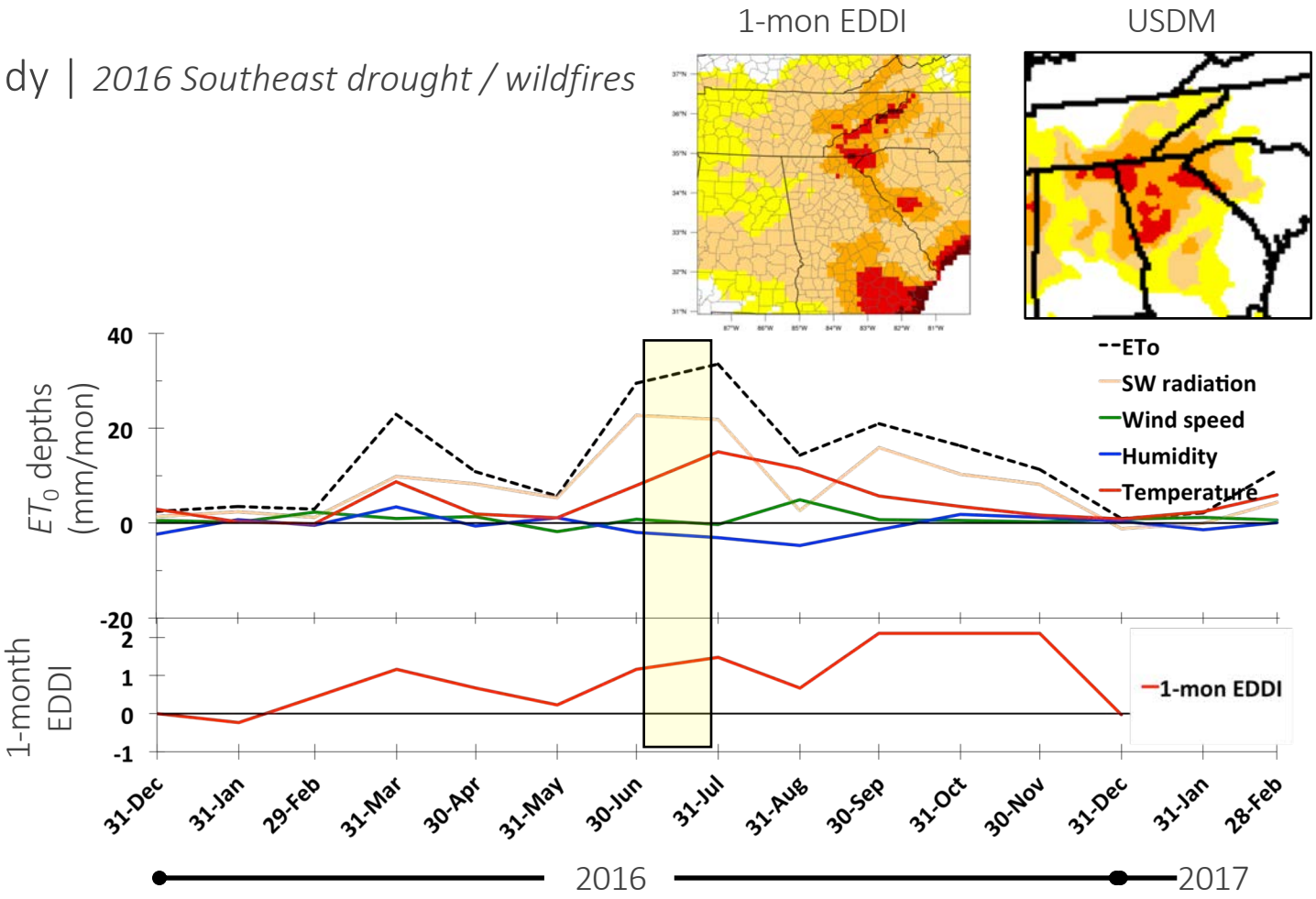


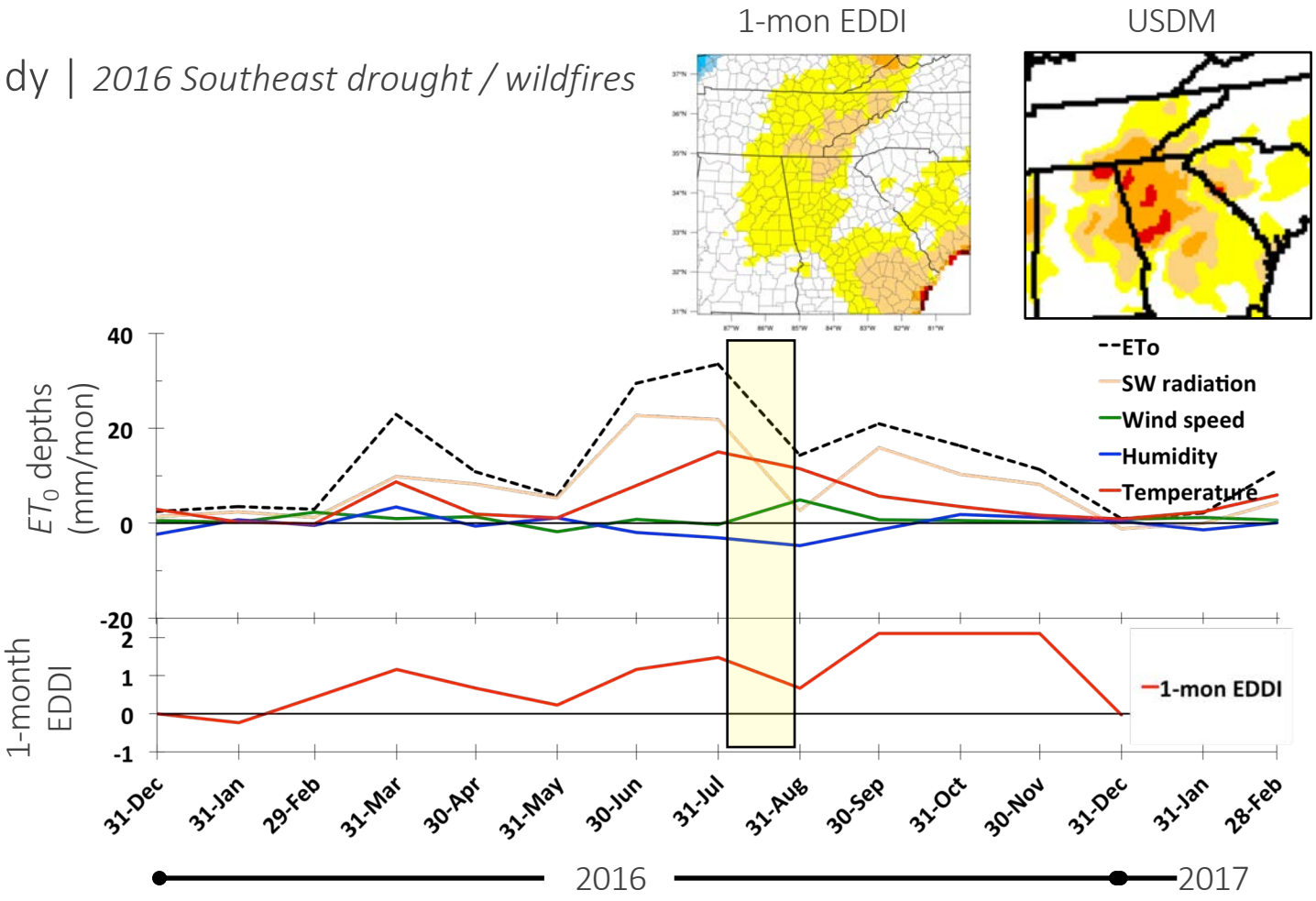
Case study | *2016 Southeast drought / wildfires*



Case study | *2016 Southeast drought / wildfires*



Case study | *2016 Southeast drought / wildfires*



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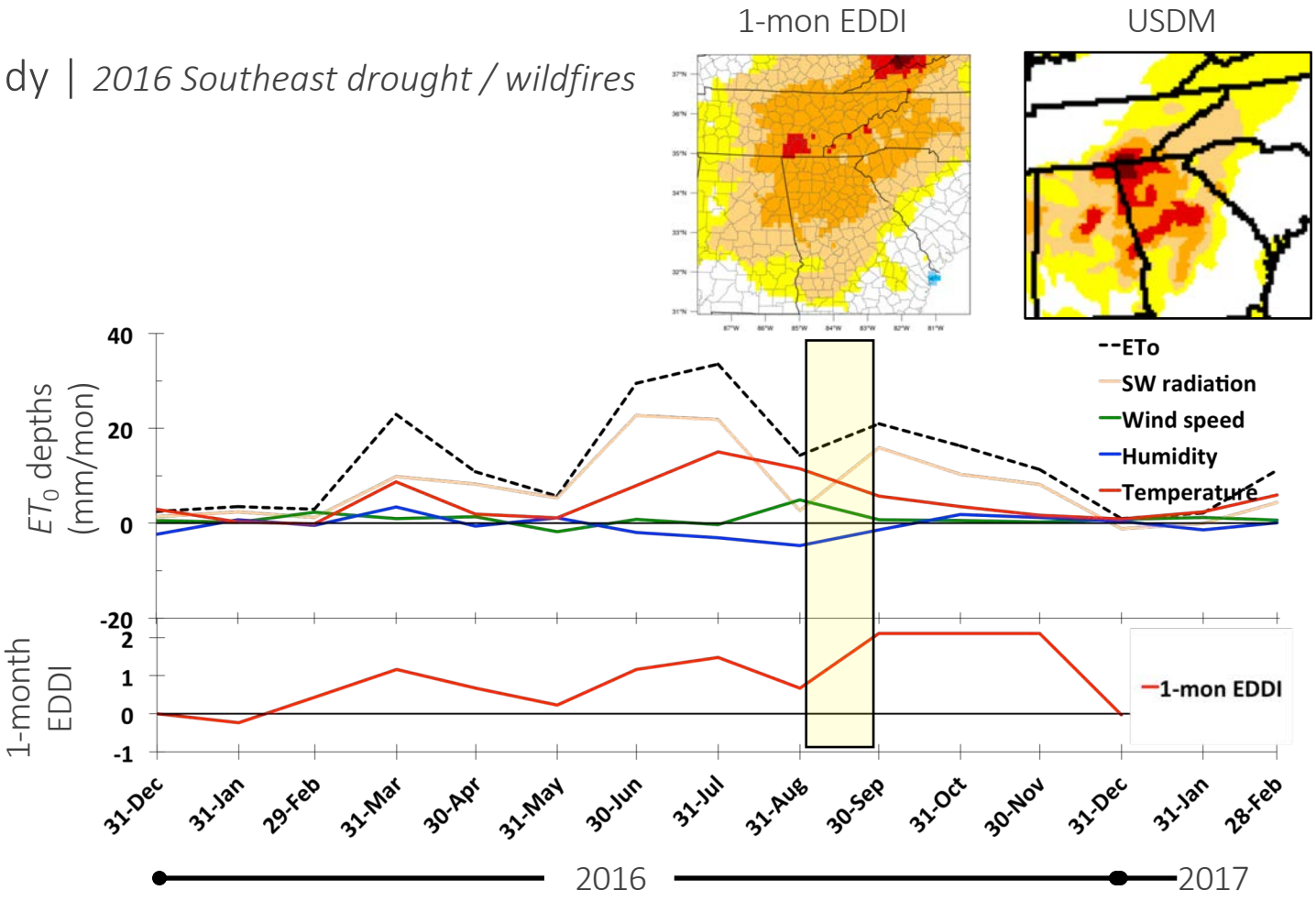

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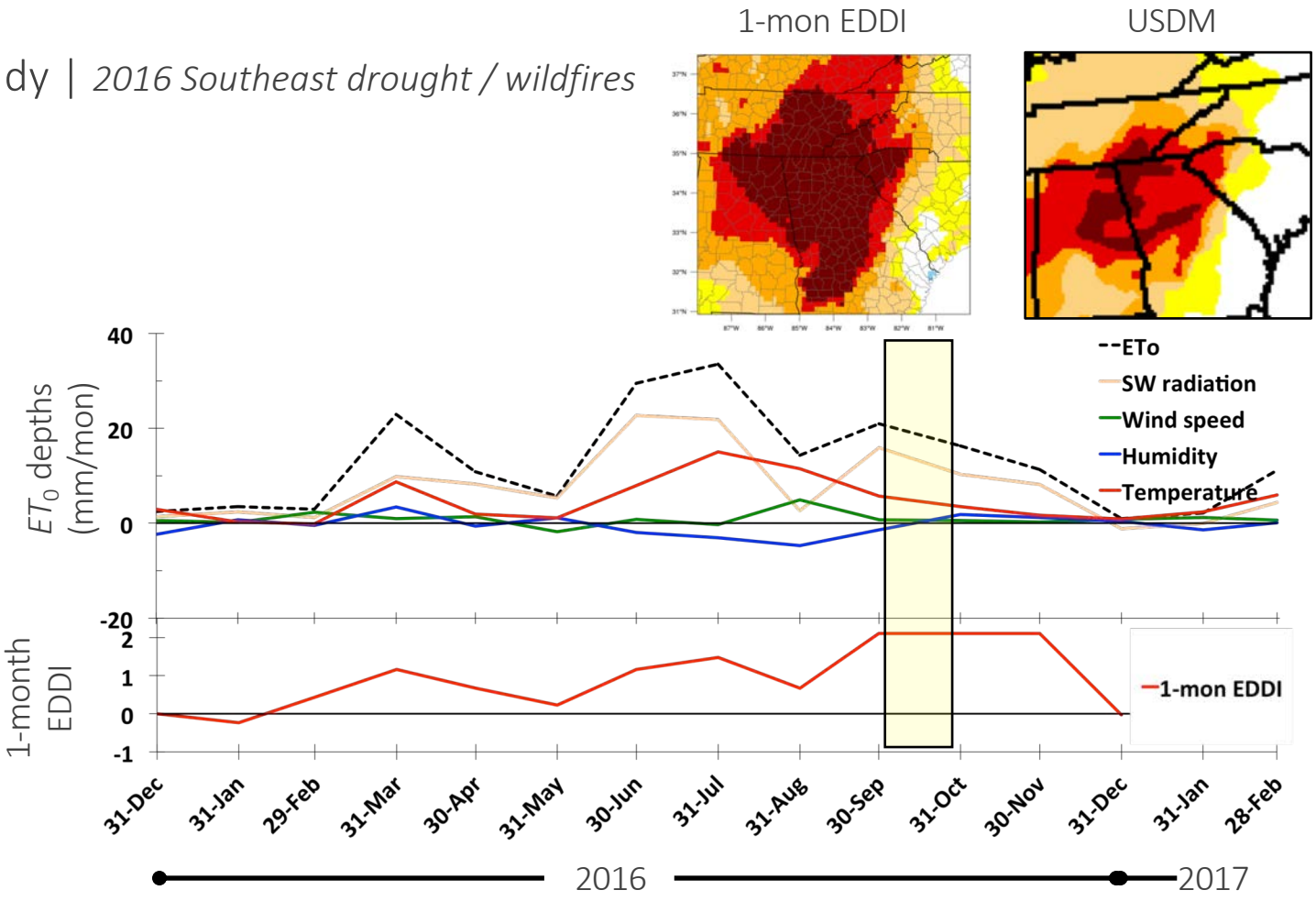

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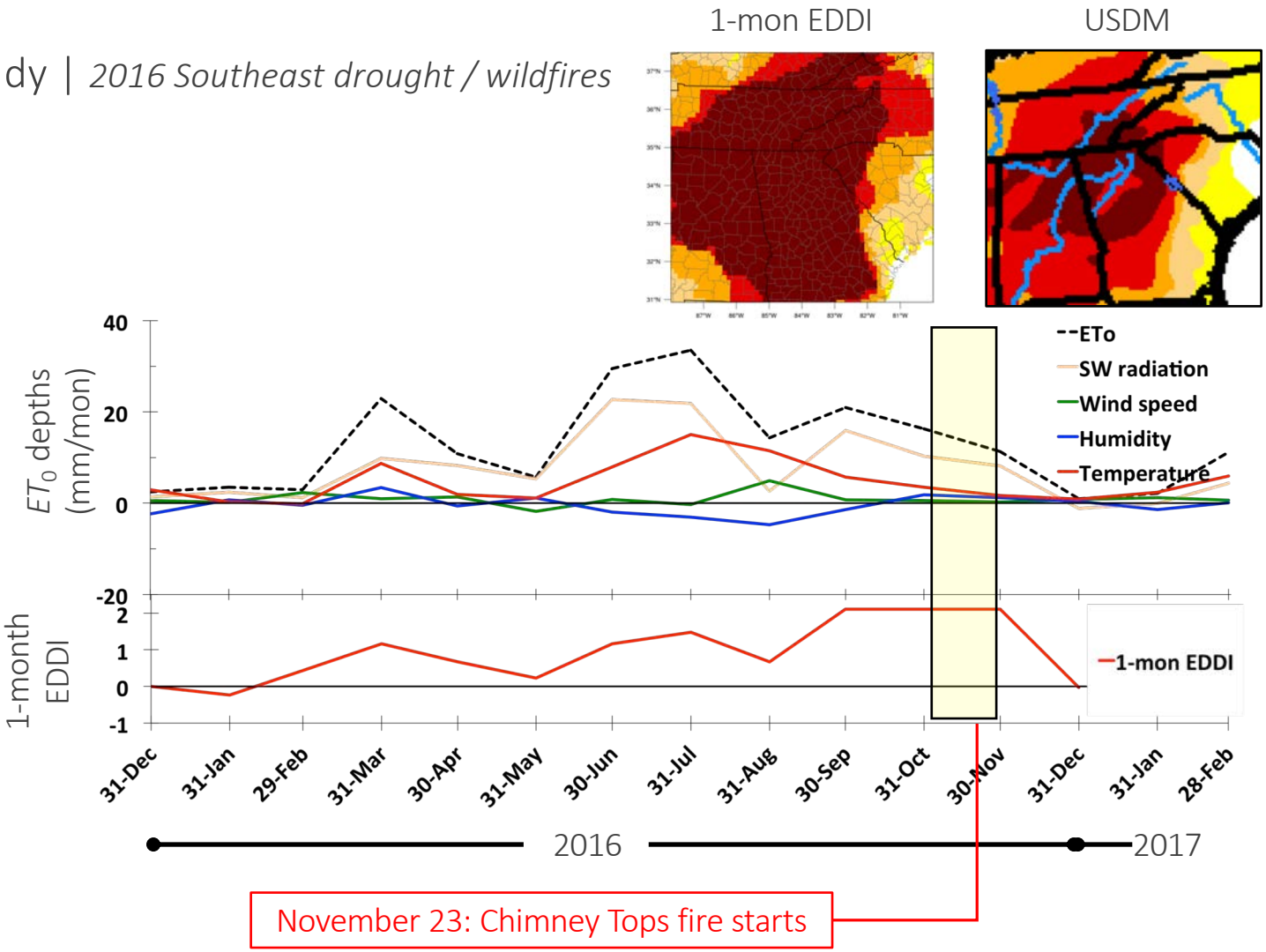

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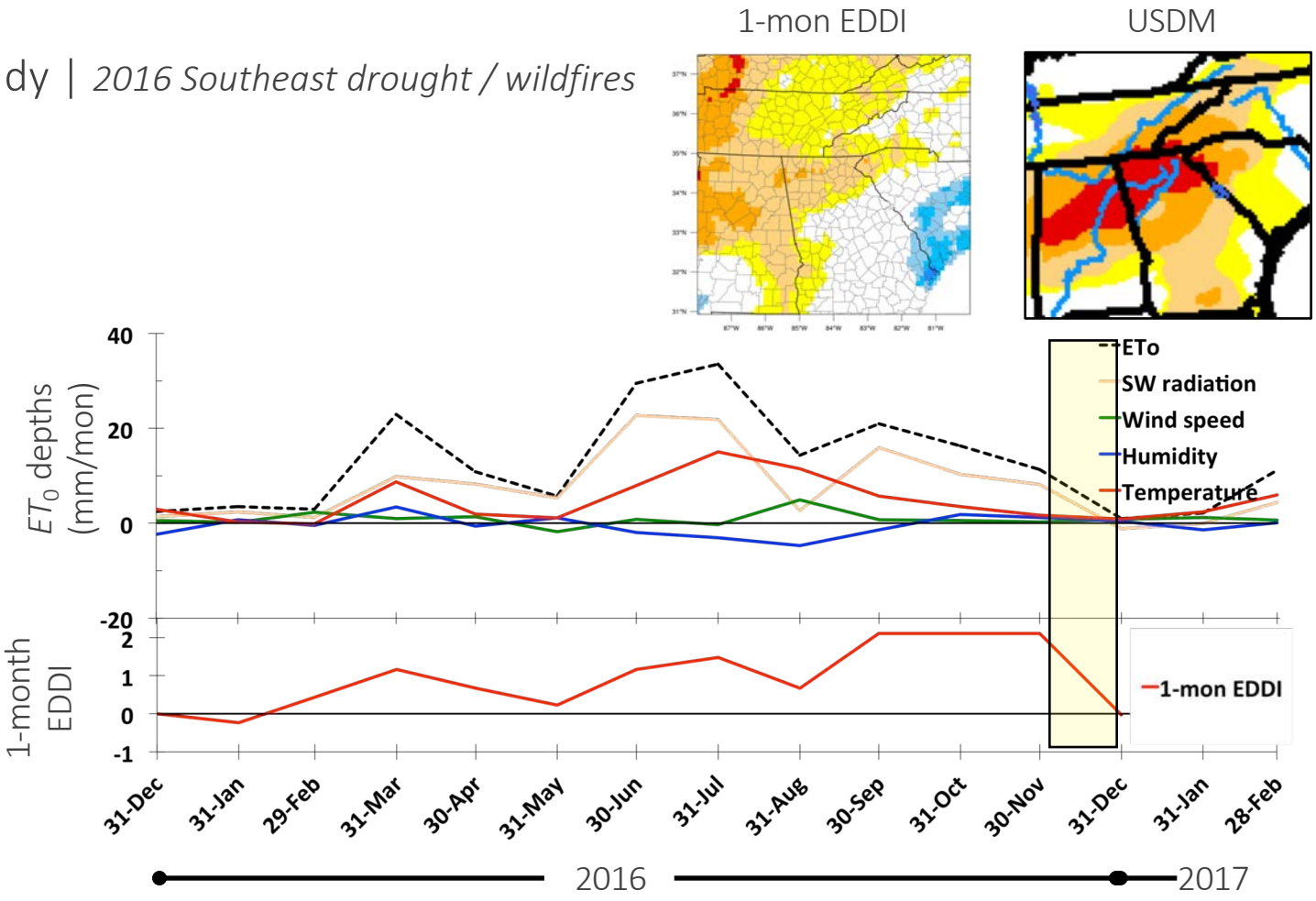
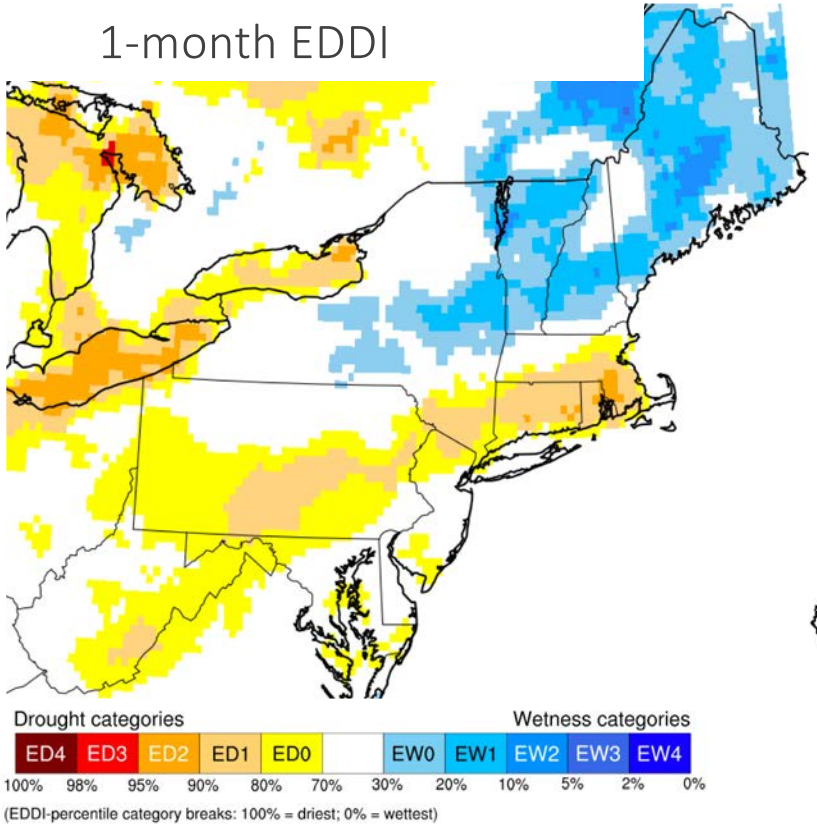


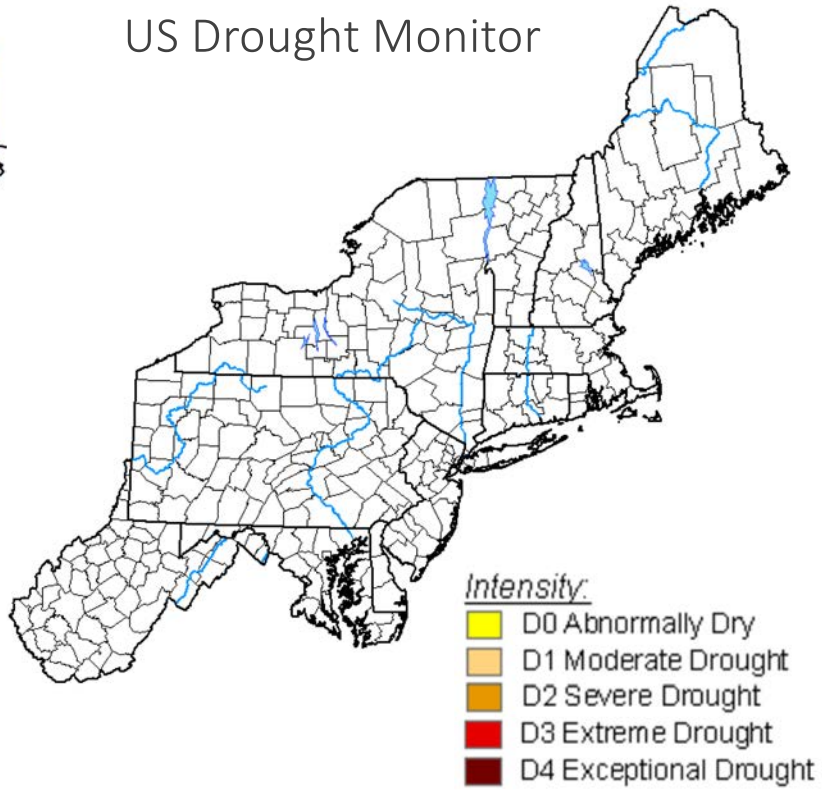
Case study |*Current Northeast drought*

February 25

1-month EDDI



US Drought Monitor

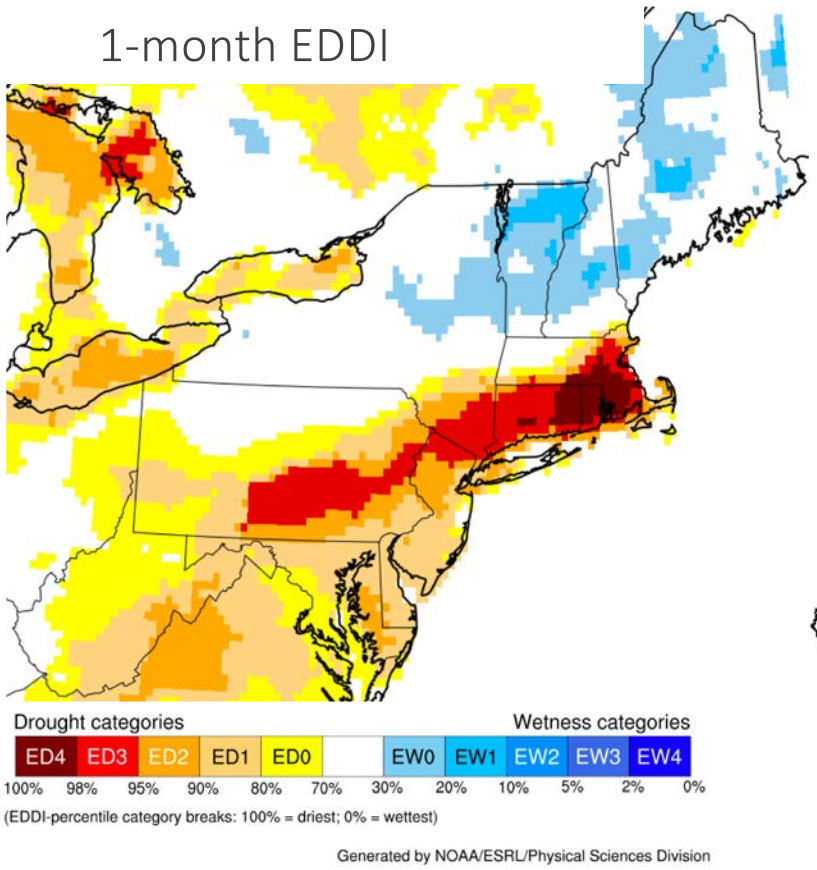


...ought in NE

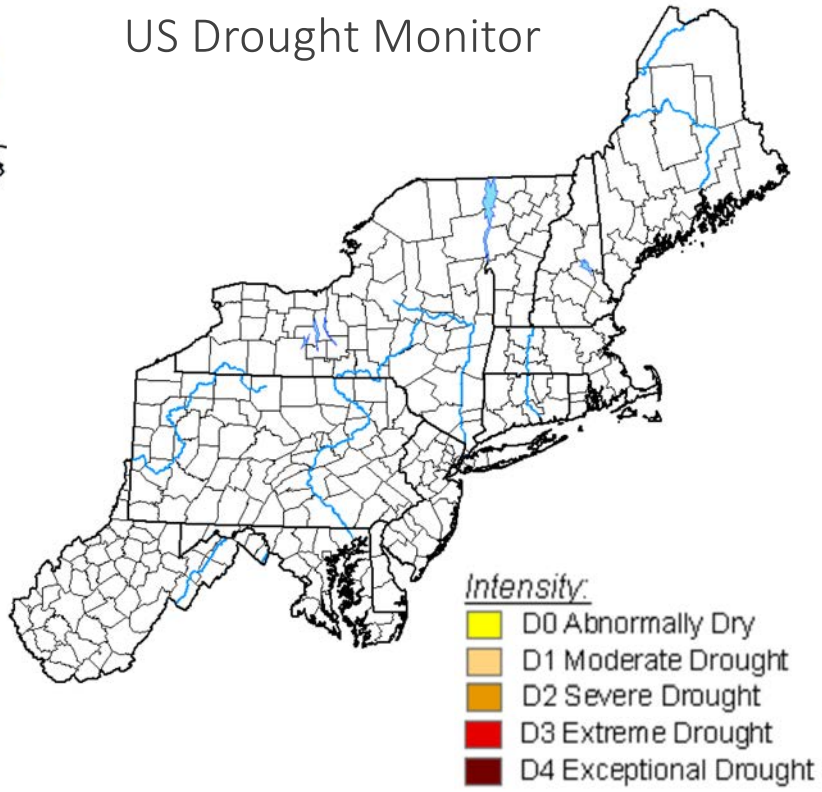
Case study |*Current Northeast drought*

March 3

1-month EDDI



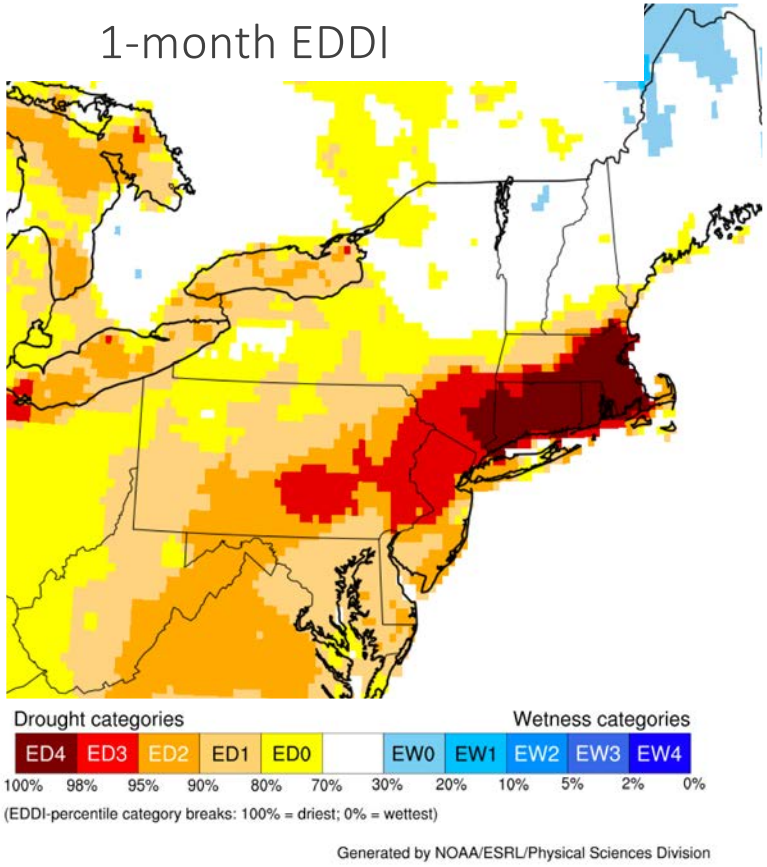
US Drought Monitor



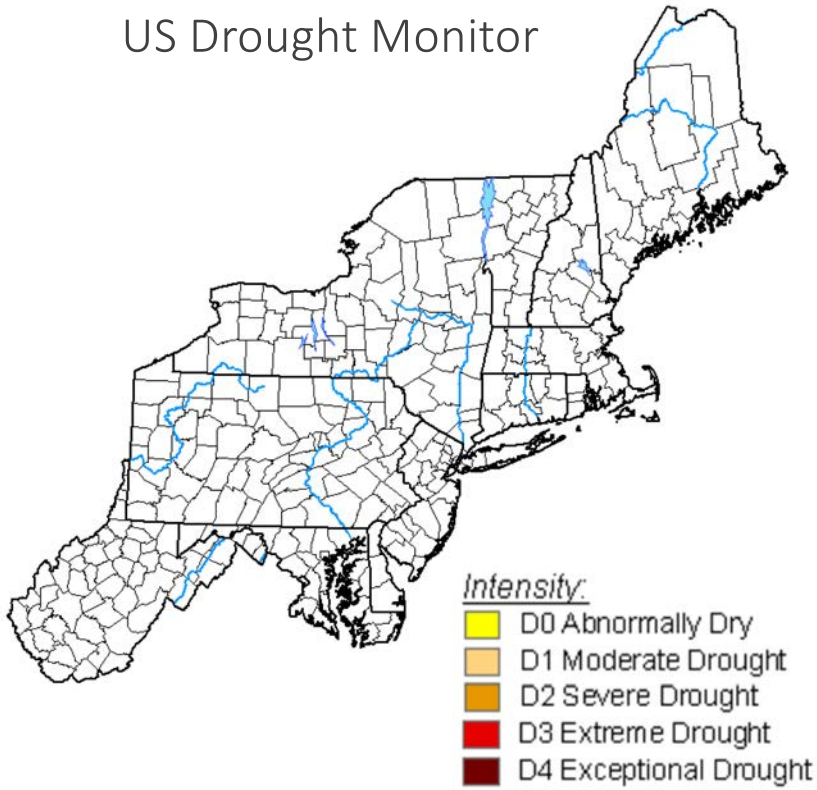
Case study |*Current Northeast drought*

March 10

1-month EDDI



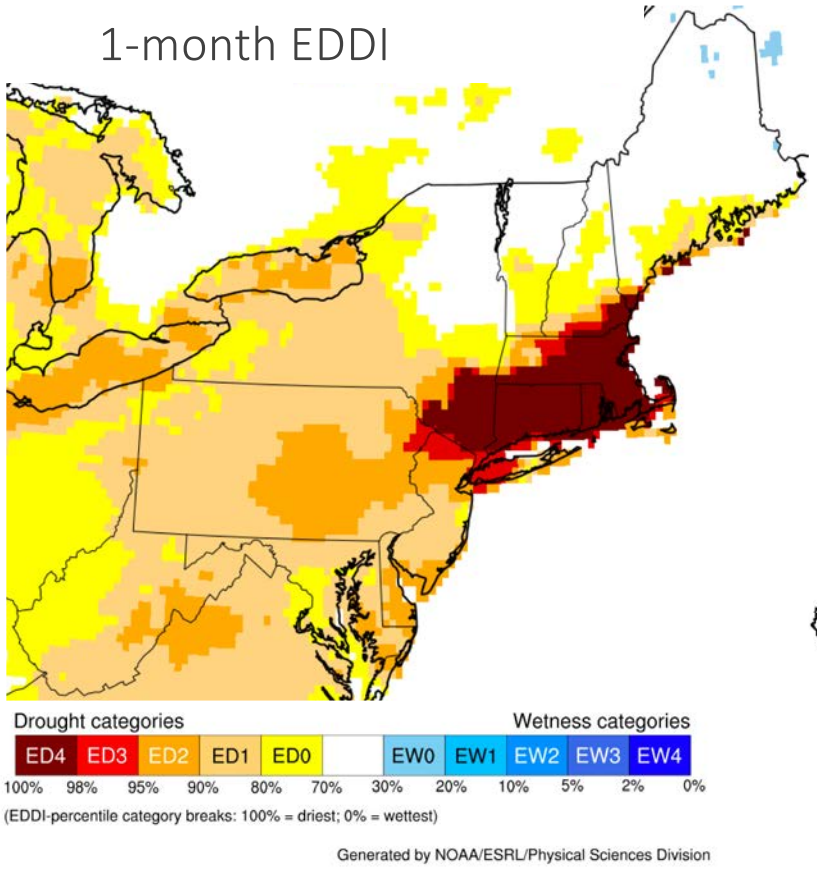
US Drought Monitor



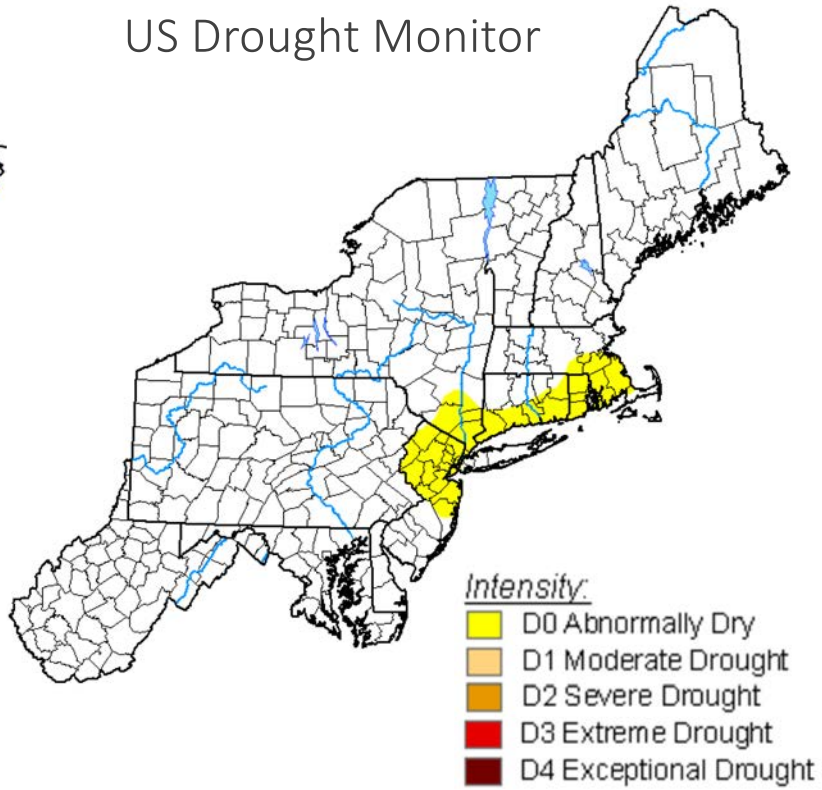
Case study |*Current Northeast drought*

March 17

1-month EDDI



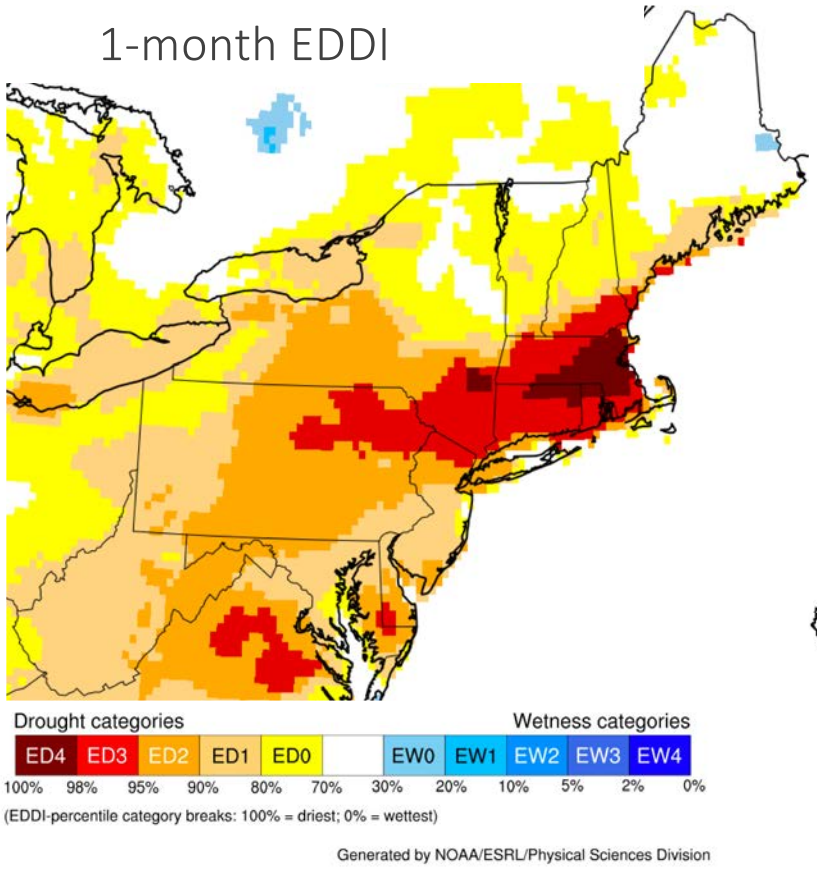
US Drought Monitor



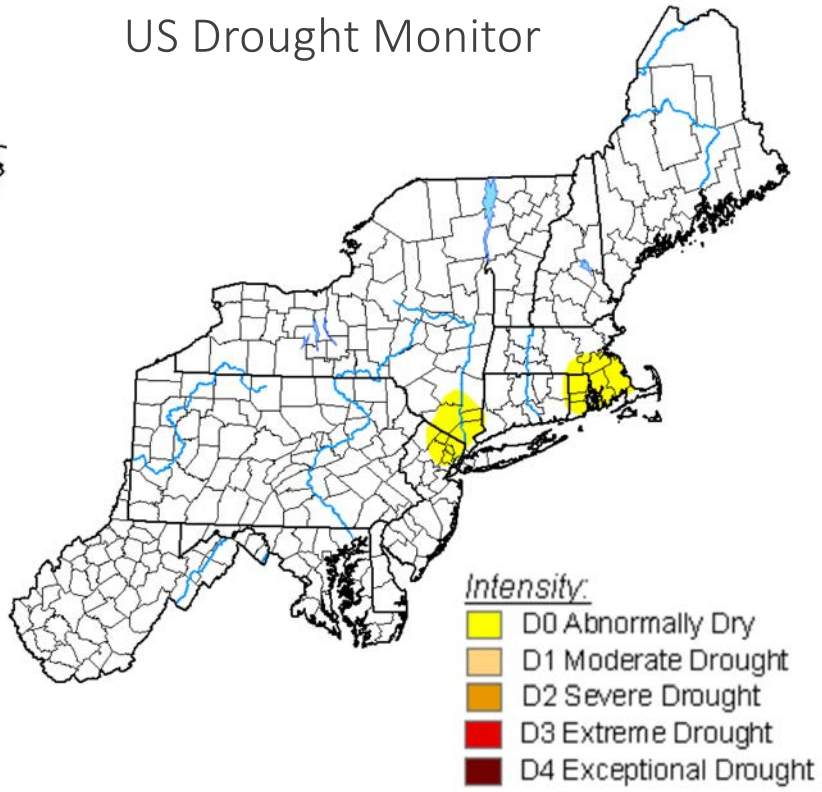
Case study |*Current Northeast drought*

March 24

1-month EDDI



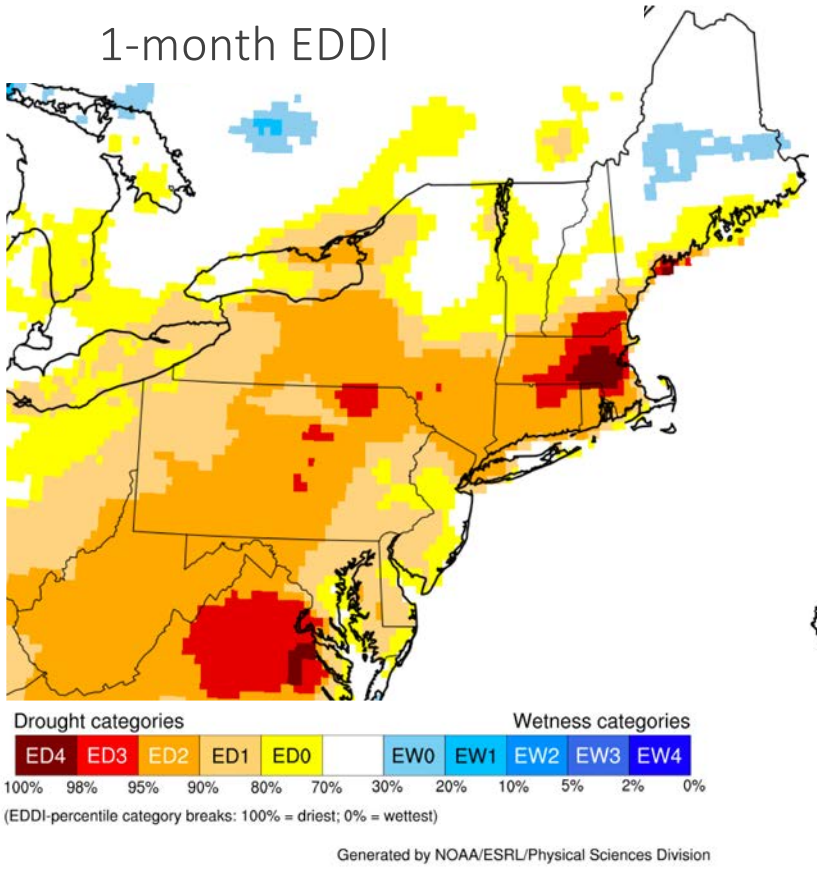
US Drought Monitor



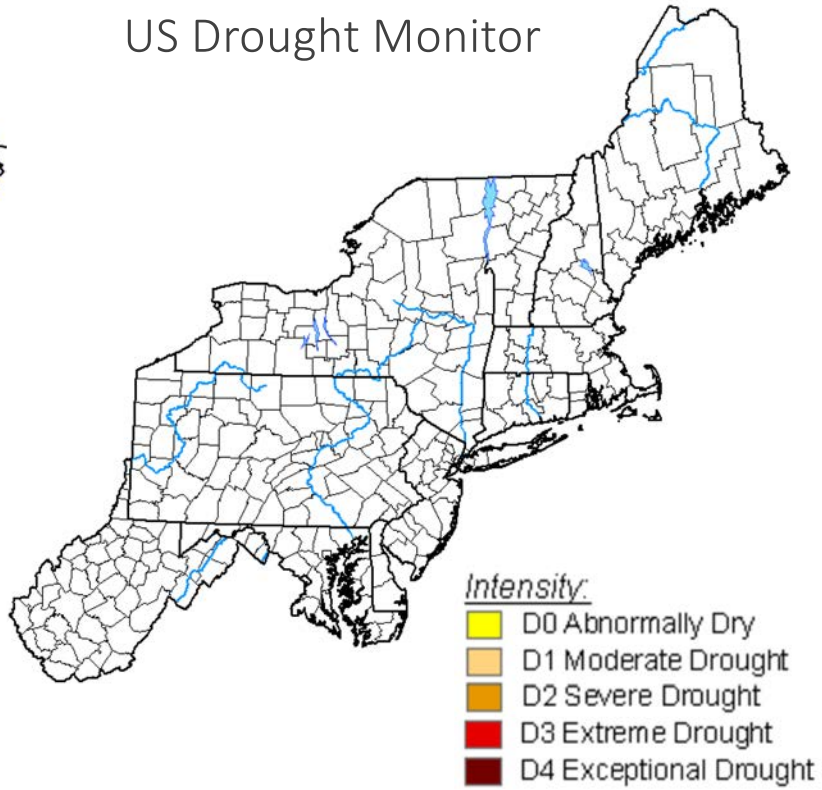
Case study |*Current Northeast drought*

March 31

1-month EDDI



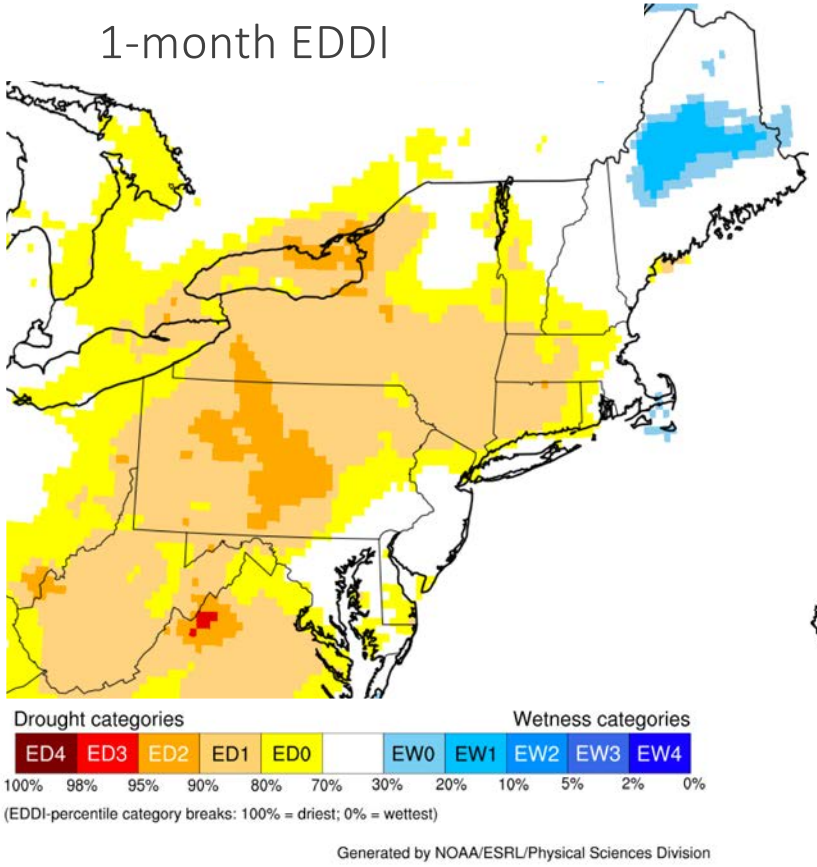
US Drought Monitor



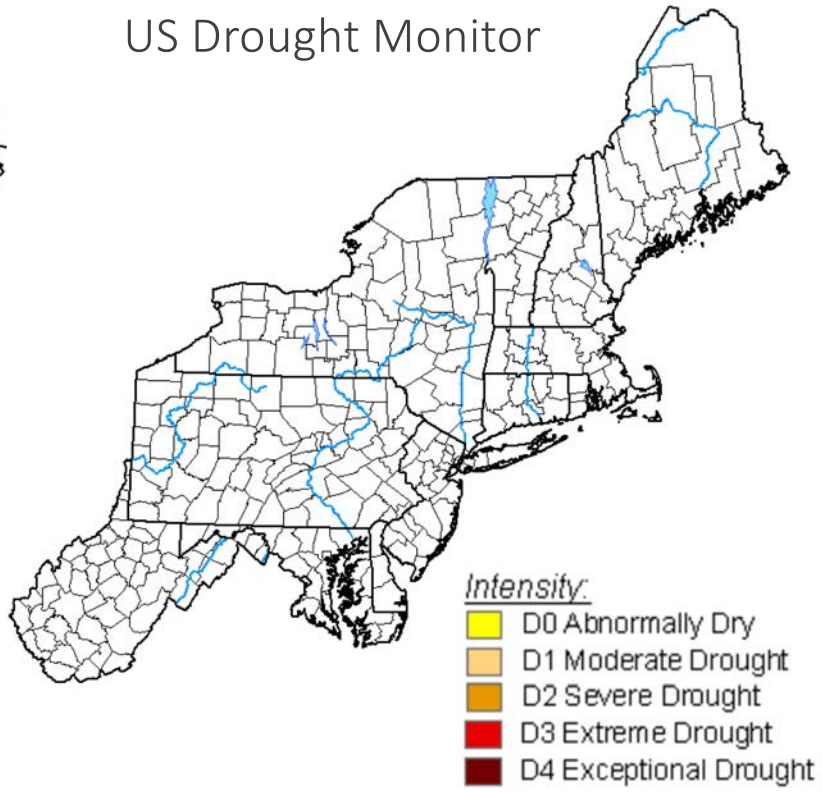
Case study |*Current Northeast drought*

April 7

1-month EDDI



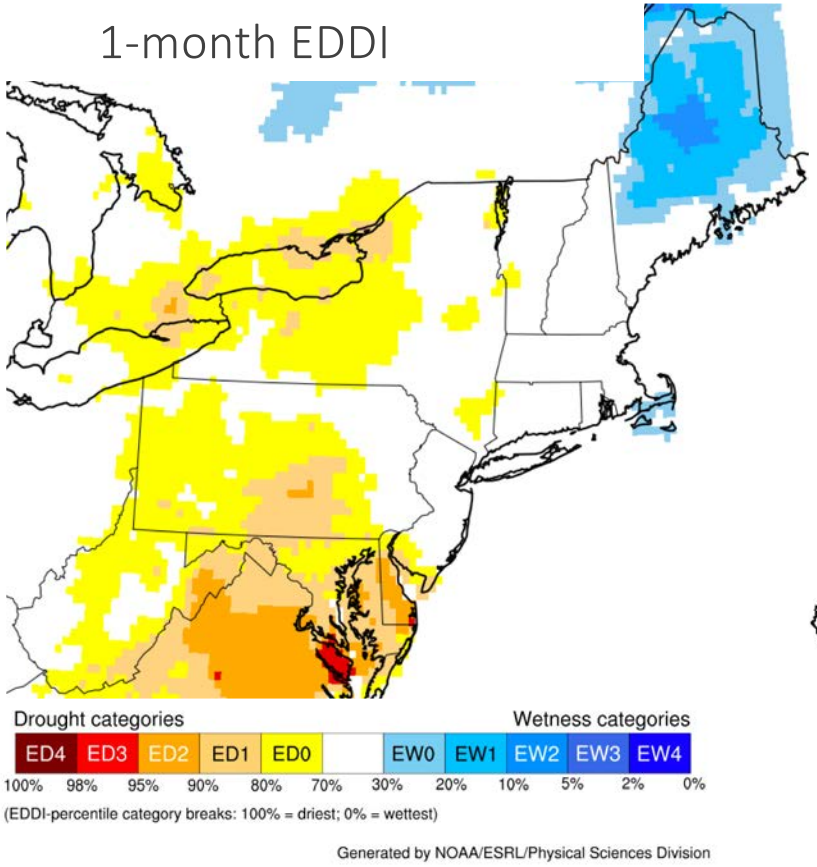
US Drought Monitor



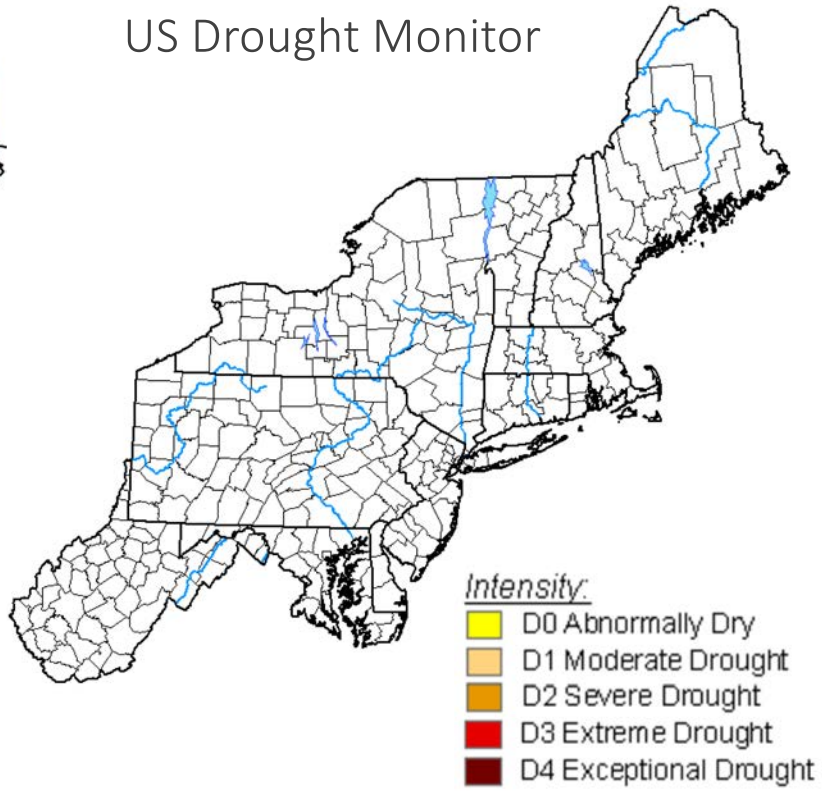
Case study |*Current Northeast drought*

April 14

1-month EDDI



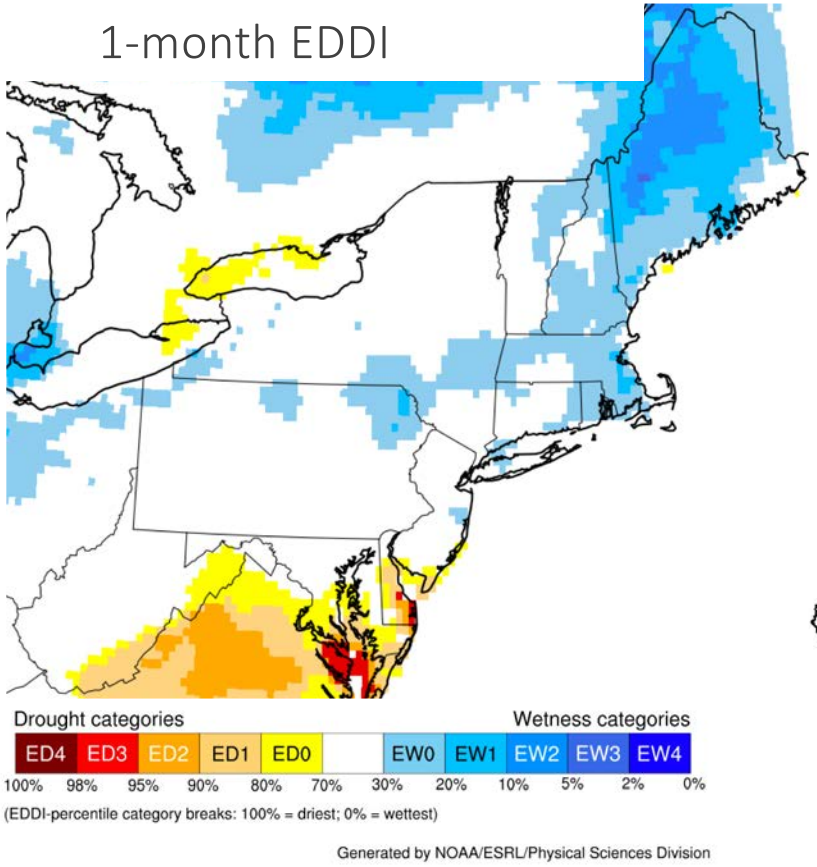
US Drought Monitor



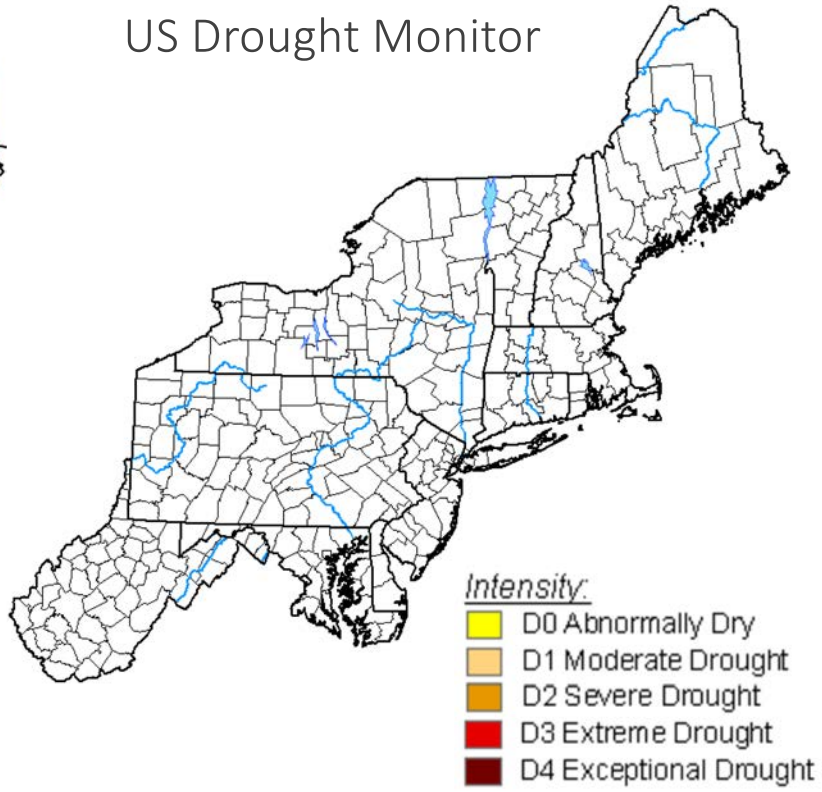
Case study |*Current Northeast drought*

April 21

1-month EDDI



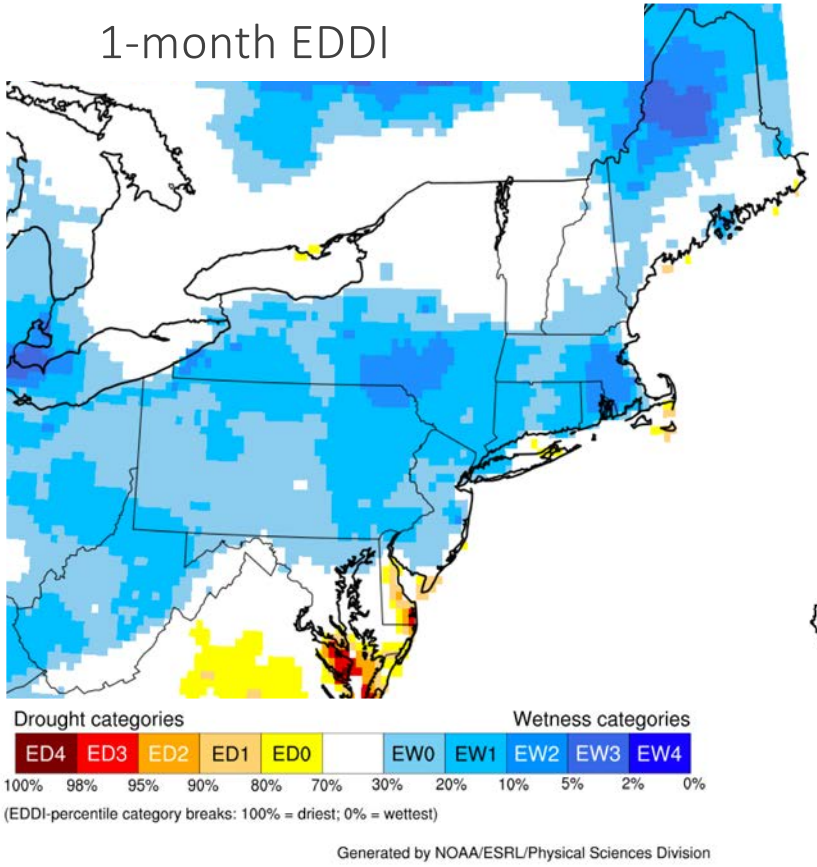
US Drought Monitor



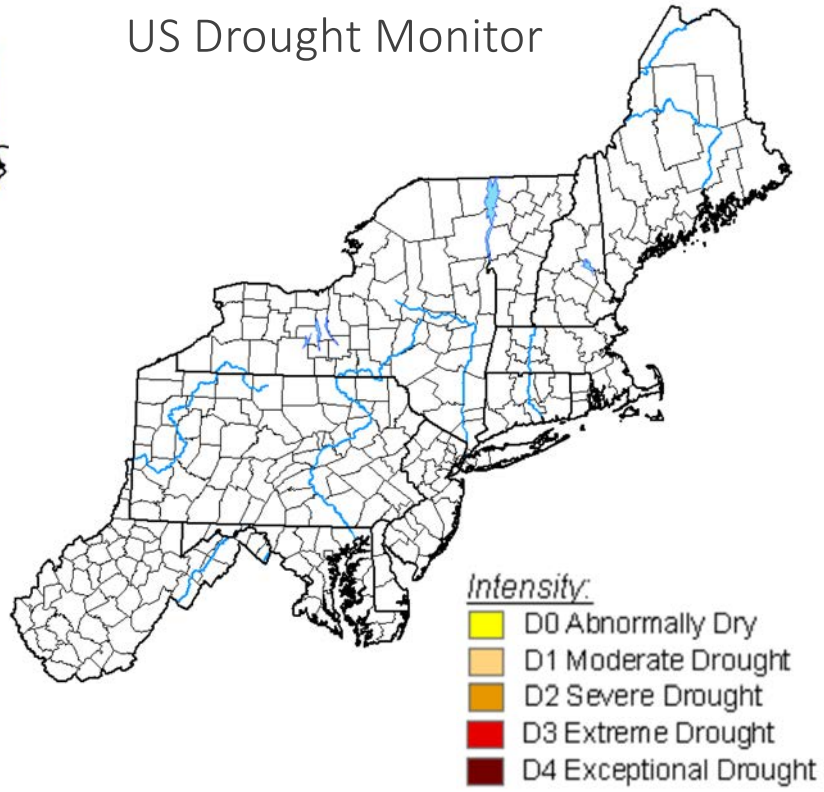
Case study |*Current Northeast drought*

April 28

1-month EDDI



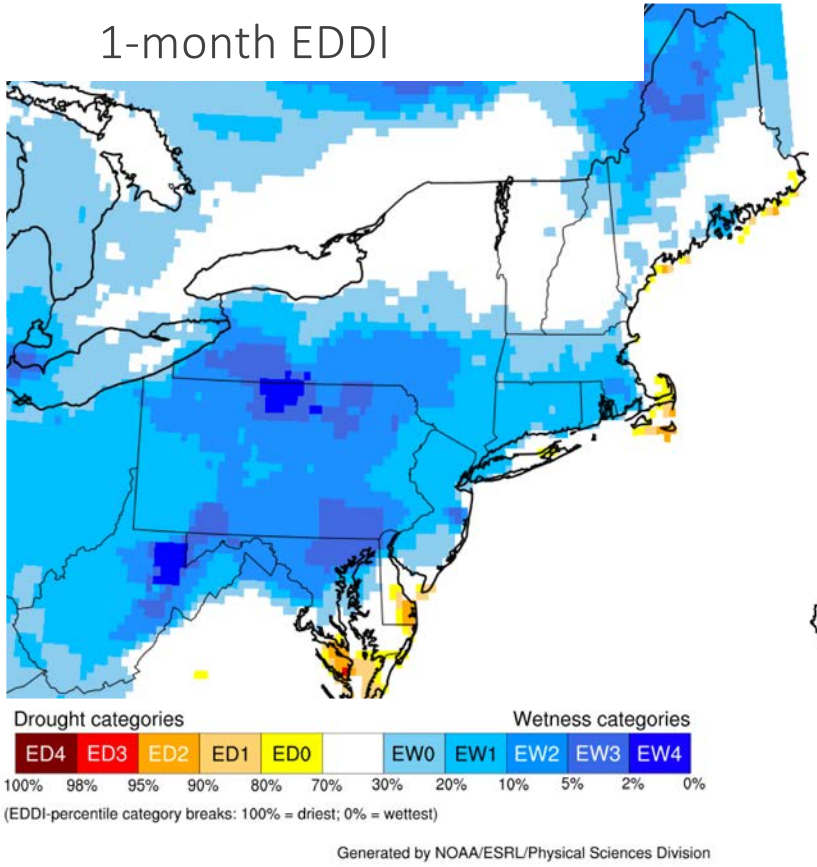
US Drought Monitor



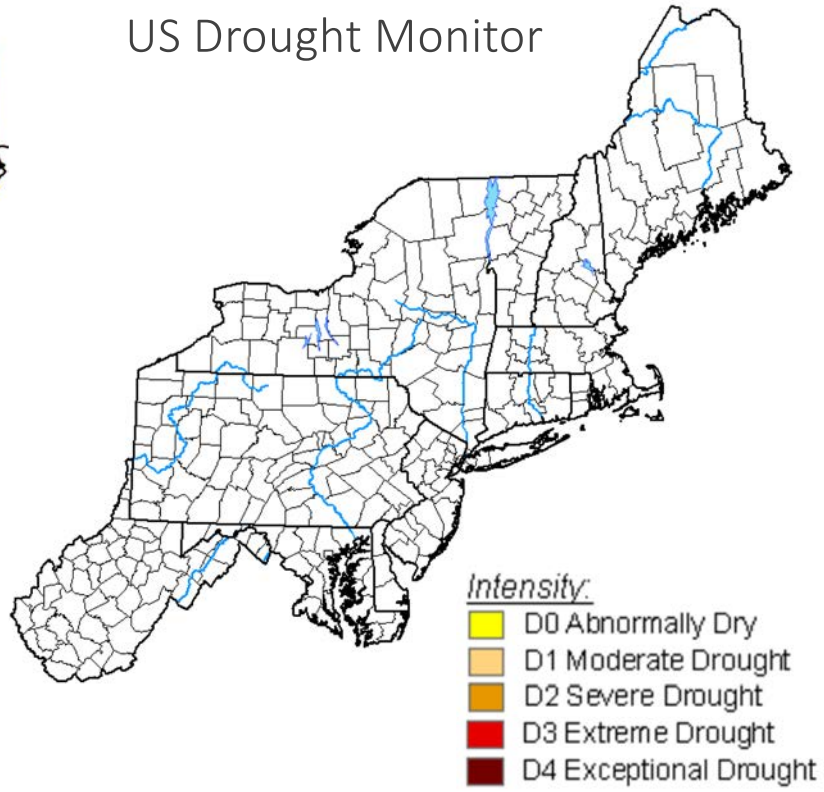
Case study |*Current Northeast drought*

May 5

1-month EDDI



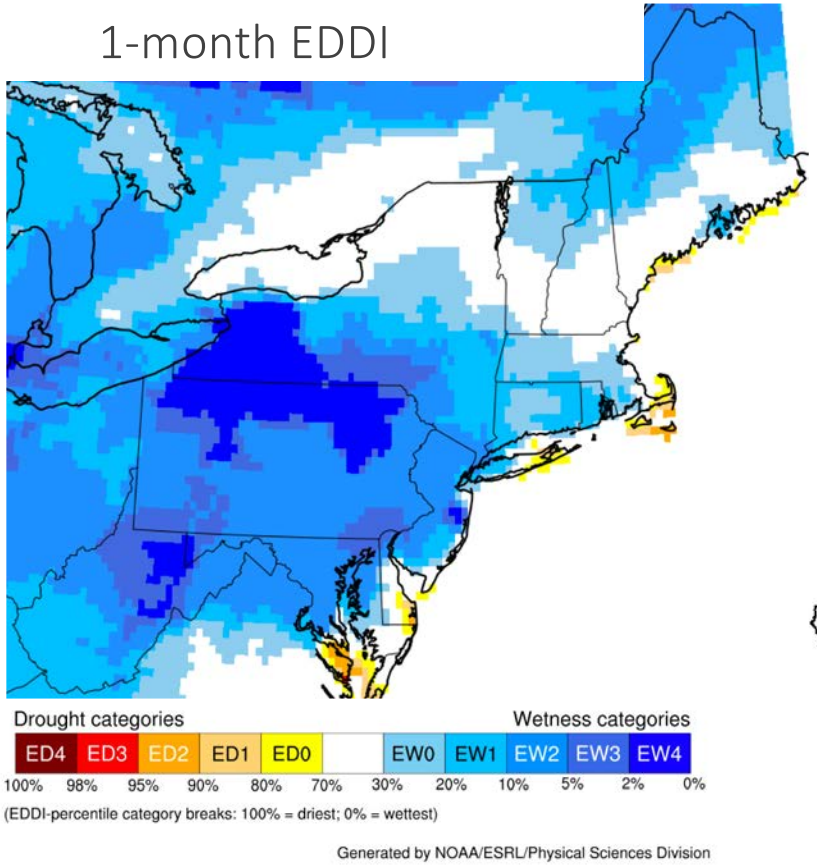
US Drought Monitor



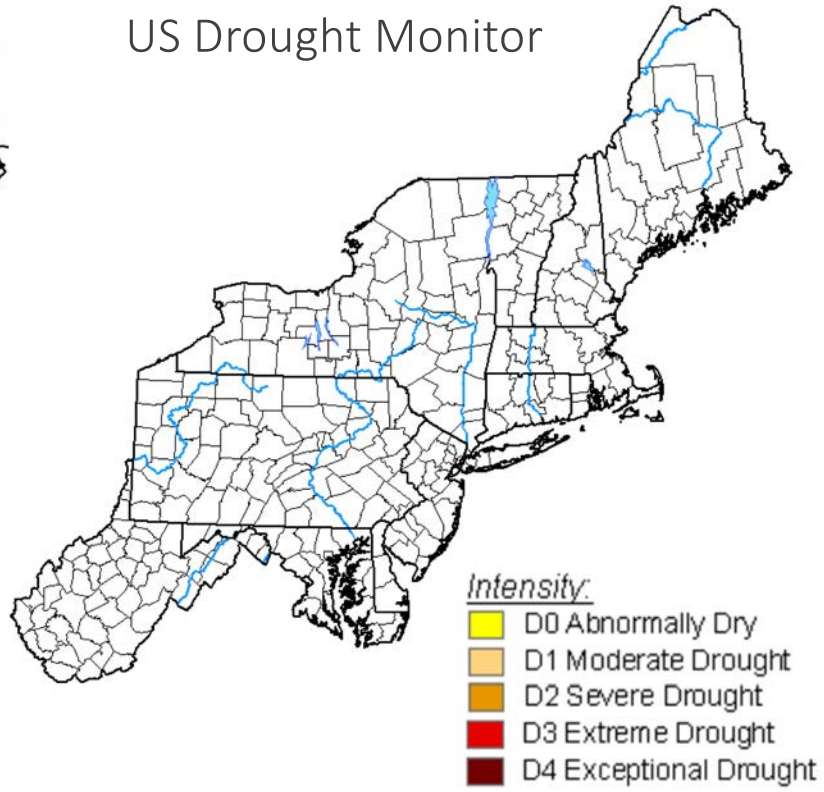
Case study |*Current Northeast drought*

May 12

1-month EDDI



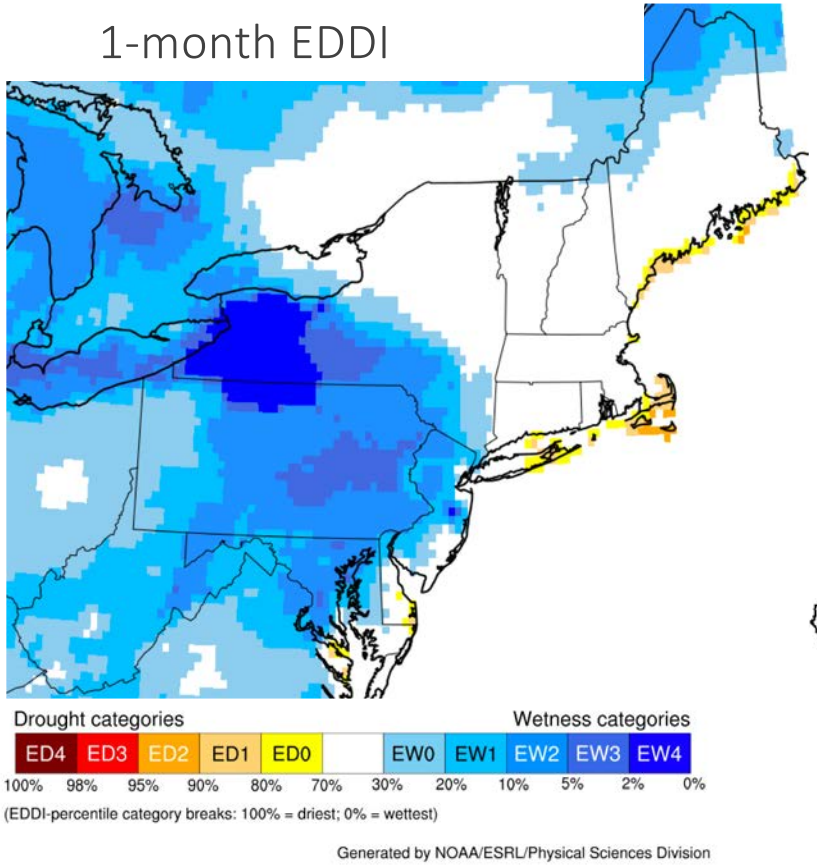
US Drought Monitor



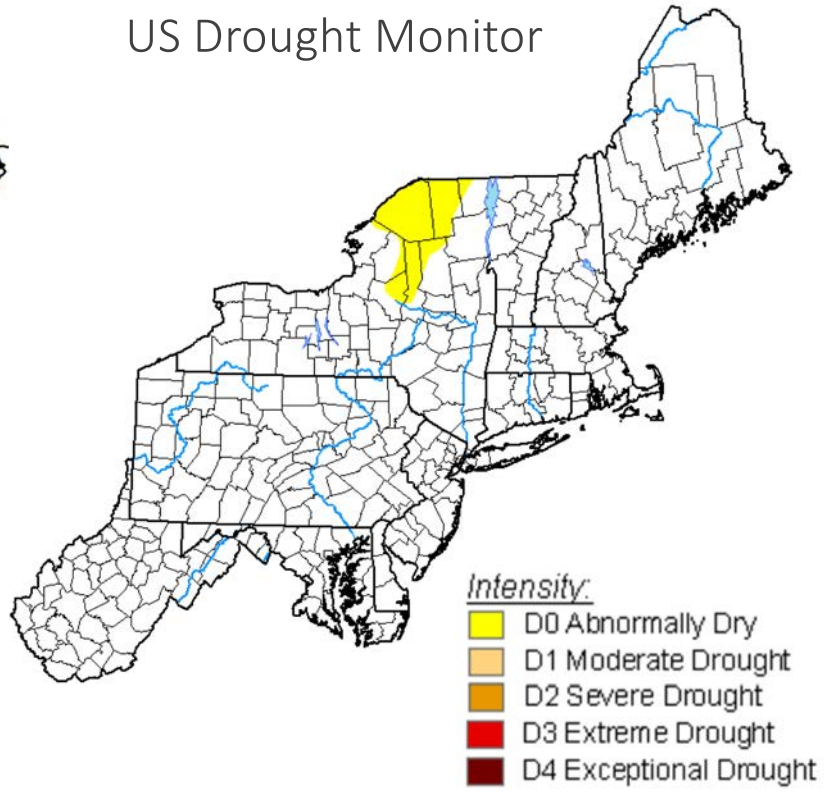
Case study |*Current Northeast drought*

May 19

1-month EDDI



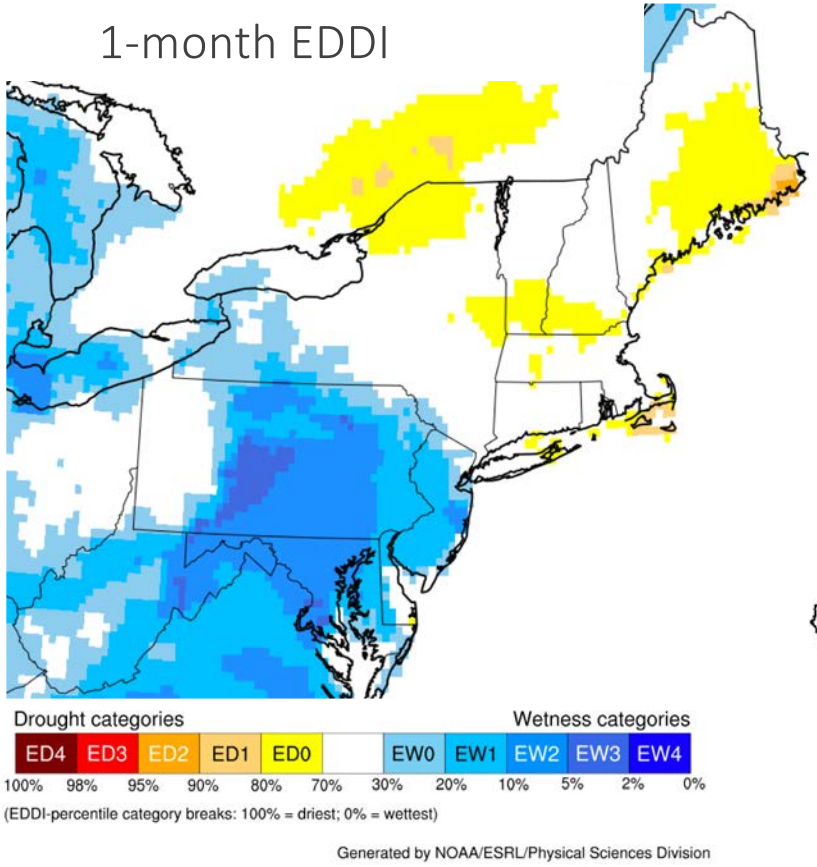
US Drought Monitor



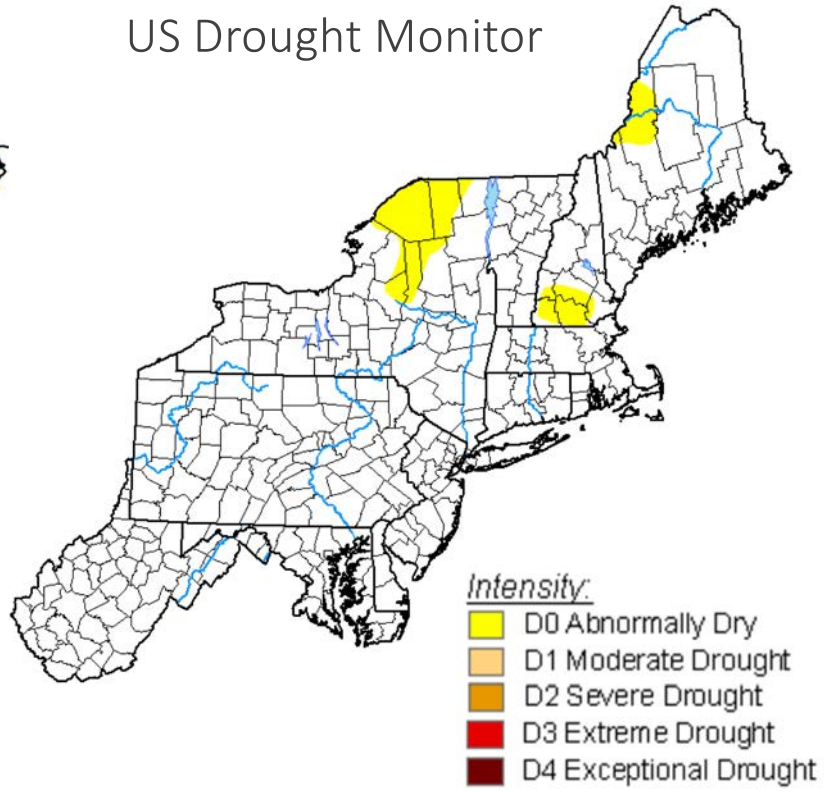
Case study |*Current Northeast drought*

May 26

1-month EDDI



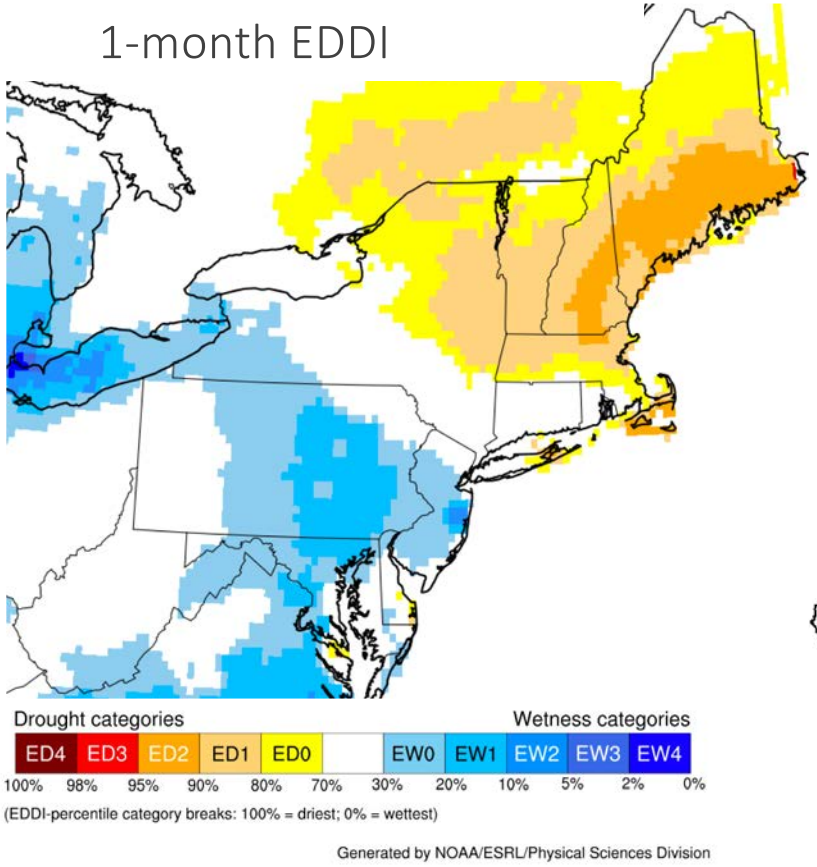
US Drought Monitor



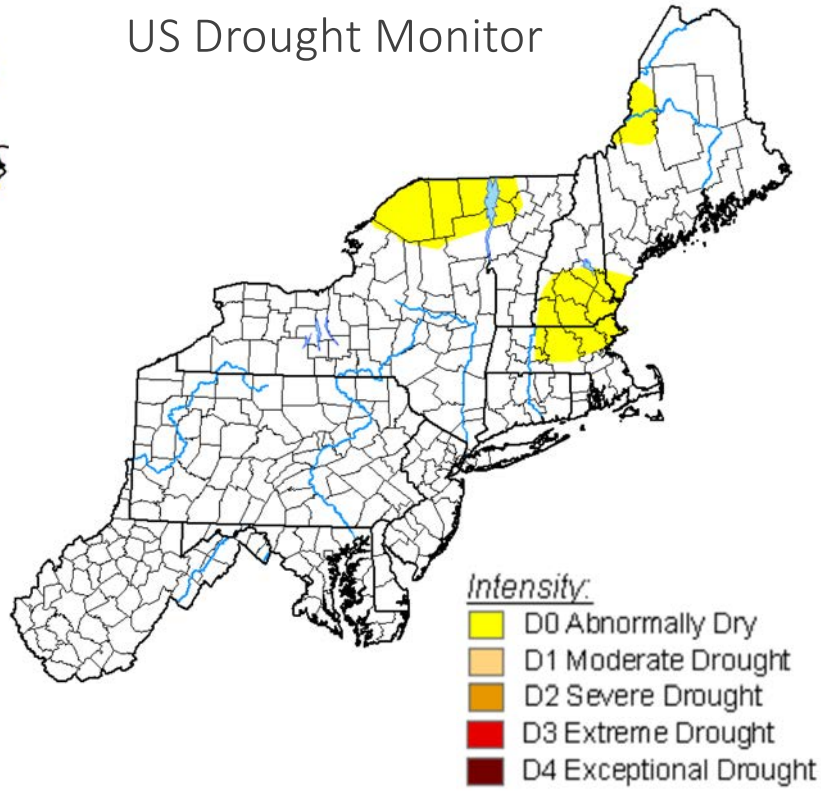
Case study |*Current Northeast drought*

June 2

1-month EDDI



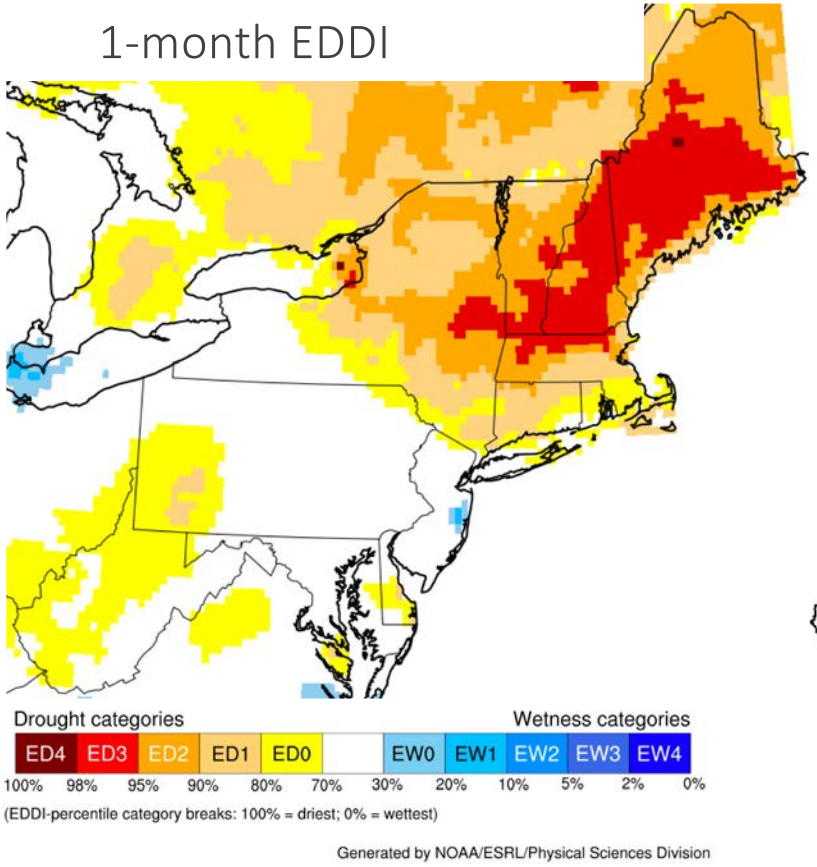
US Drought Monitor



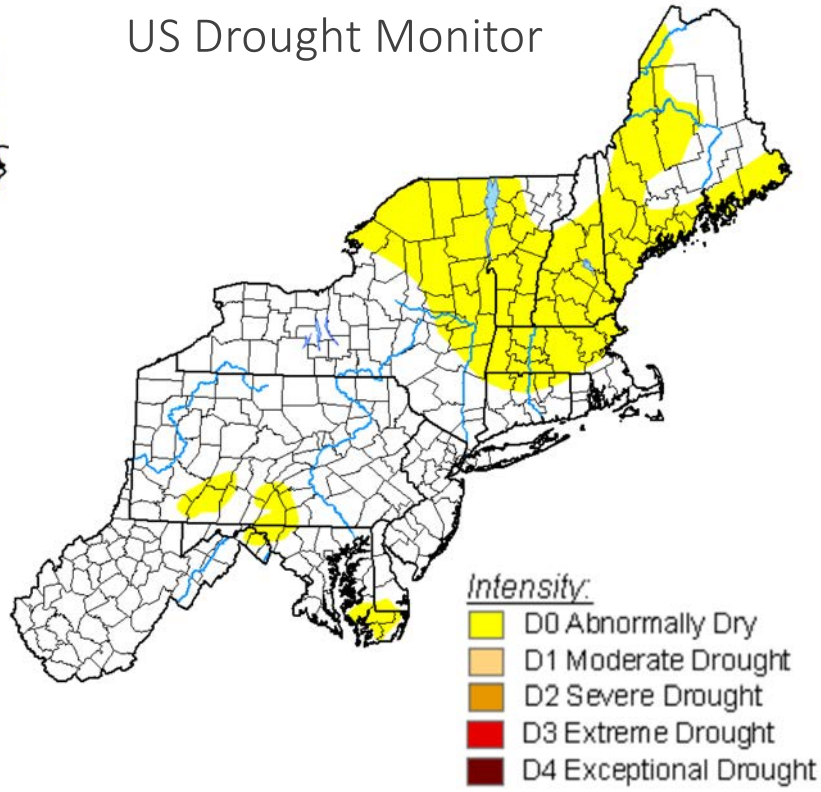
Case study |*Current Northeast drought*

June 9

1-month EDDI



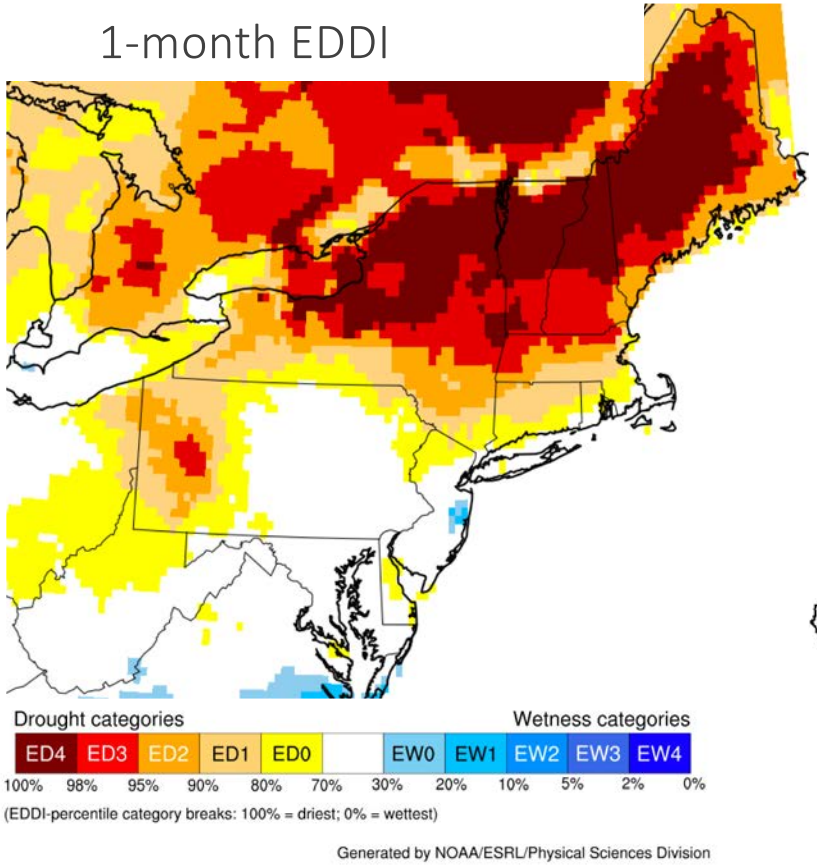
US Drought Monitor



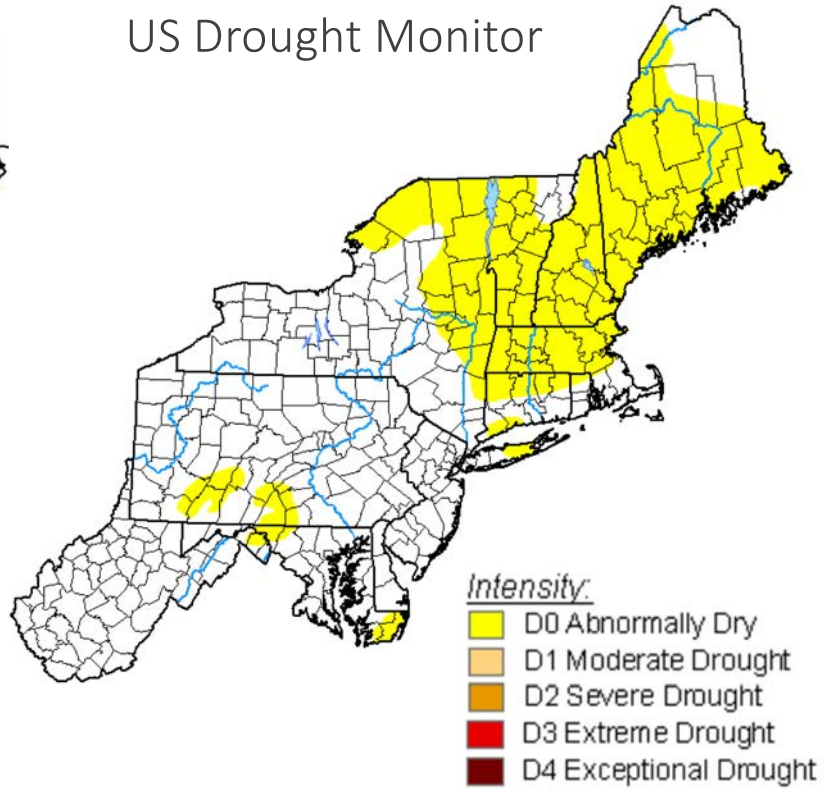
Case study |*Current Northeast drought*

June 16

1-month EDDI



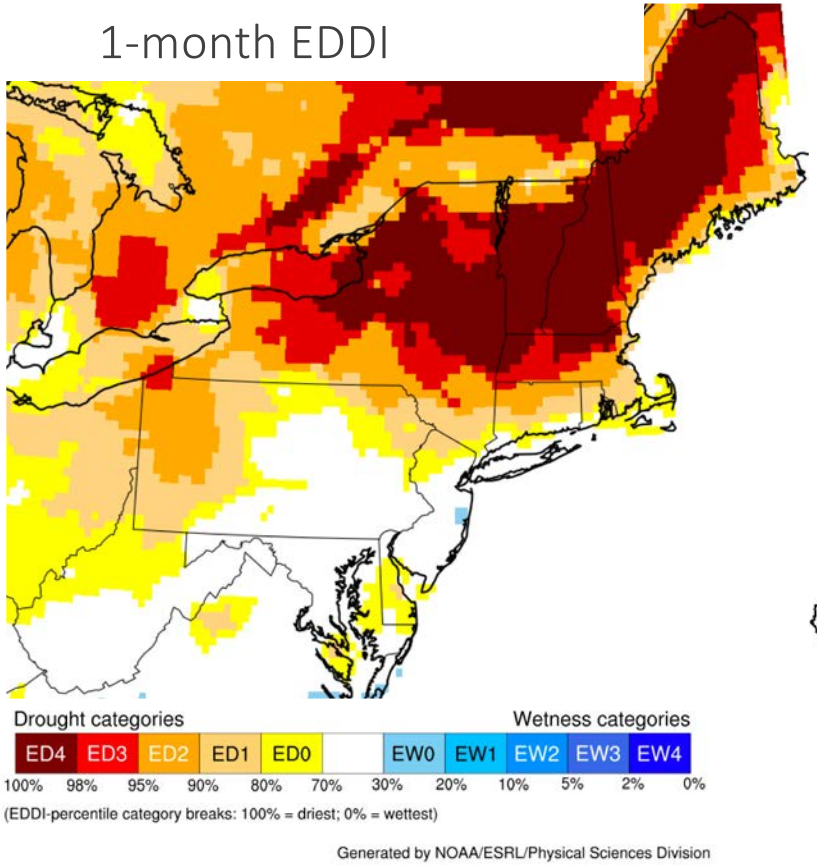
US Drought Monitor



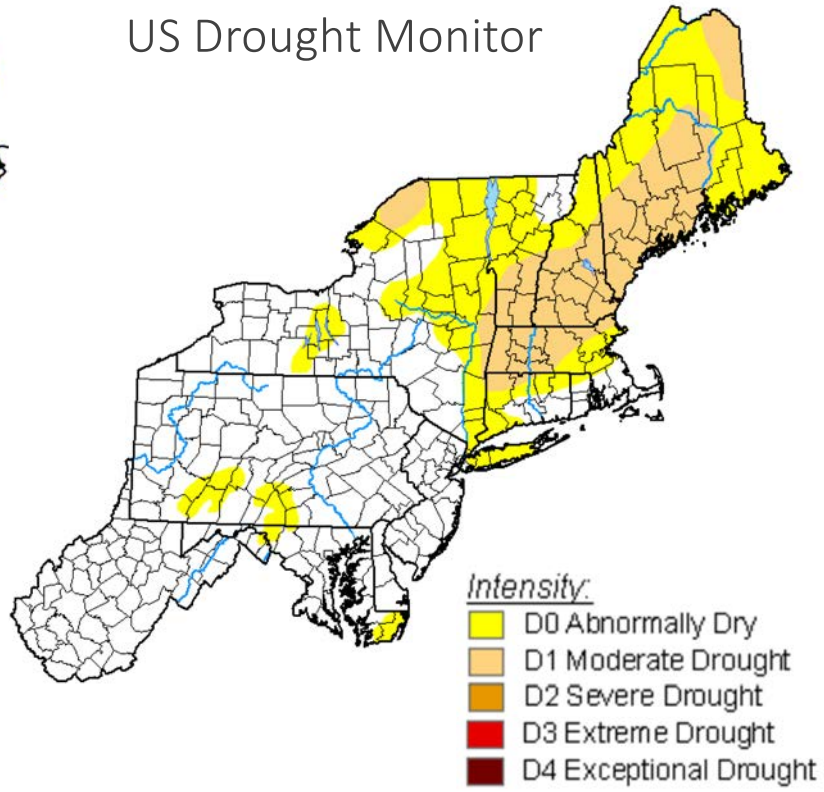
Case study |*Current Northeast drought*

June 23

1-month EDDI



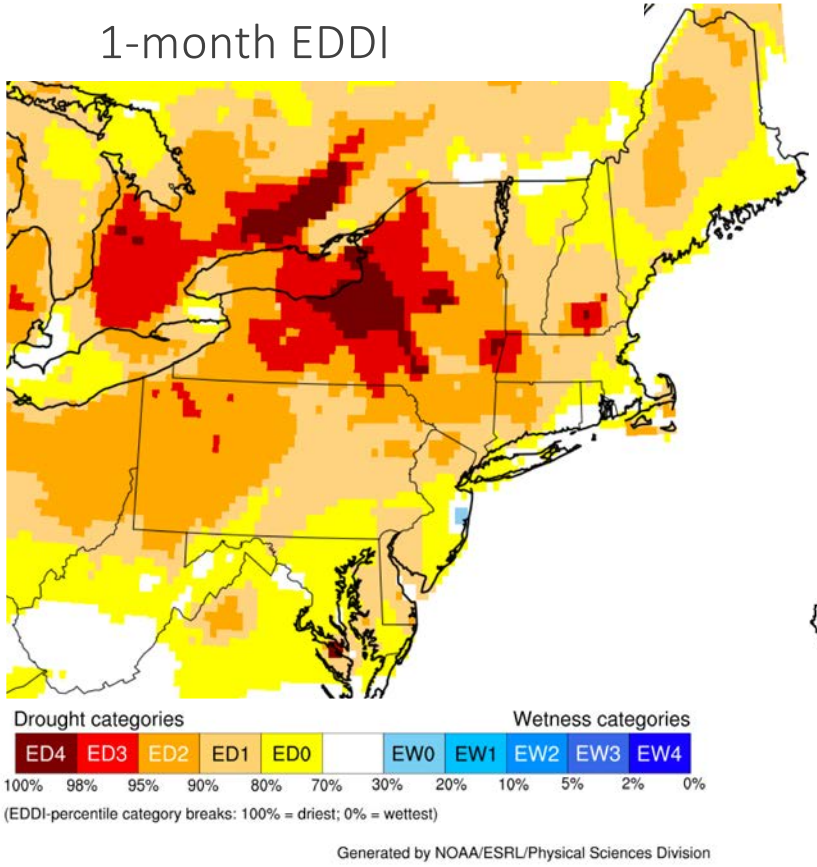
US Drought Monitor



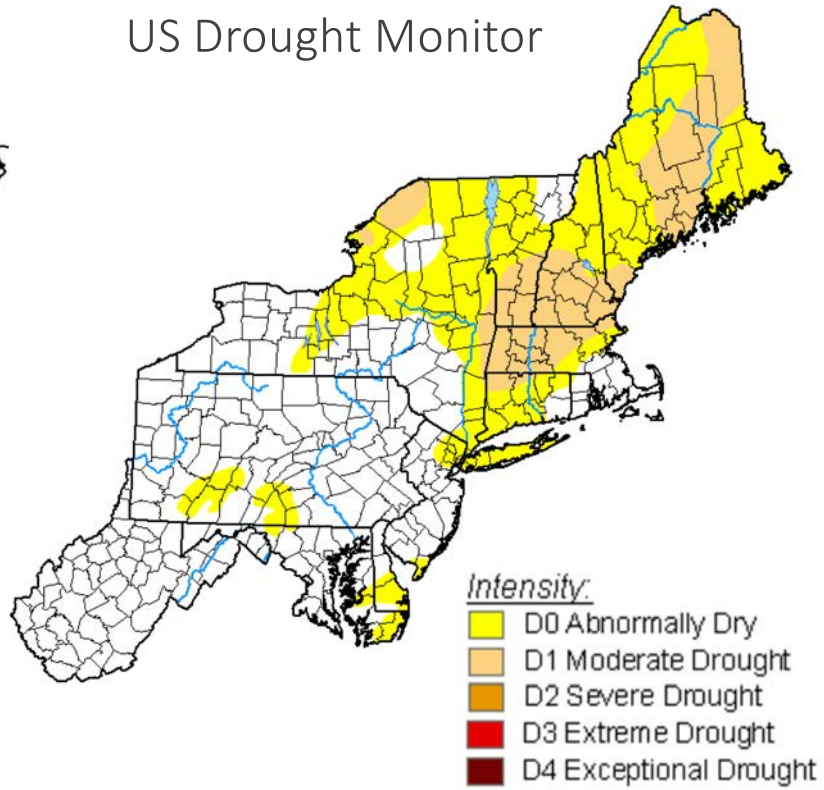
Case study |*Current Northeast drought*

June 30

1-month EDDI



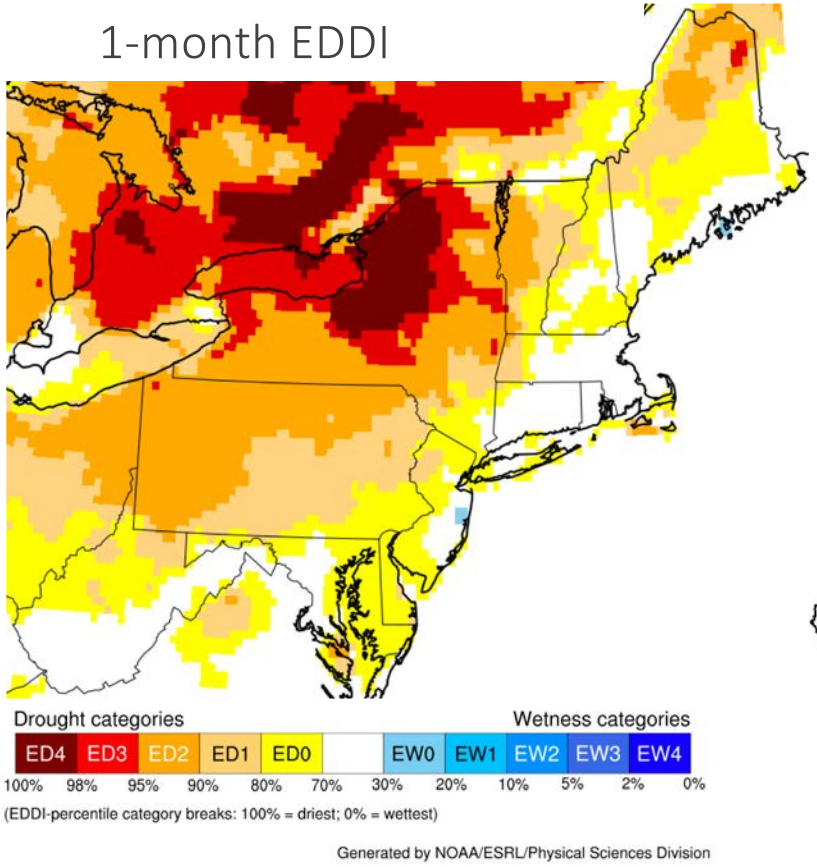
US Drought Monitor



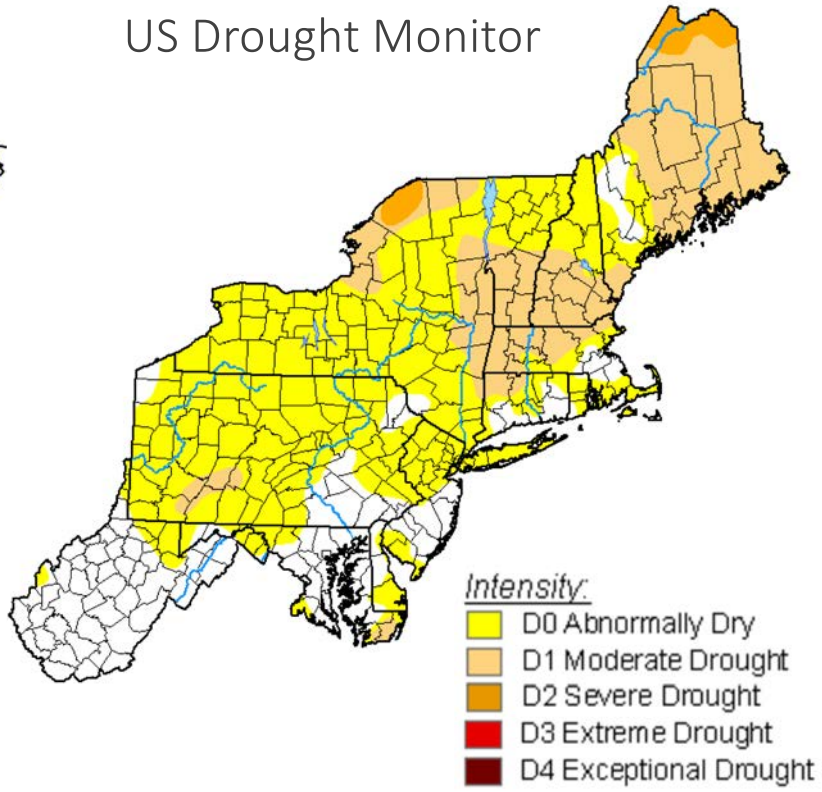
Case study |*Current Northeast drought*

July 7

1-month EDDI



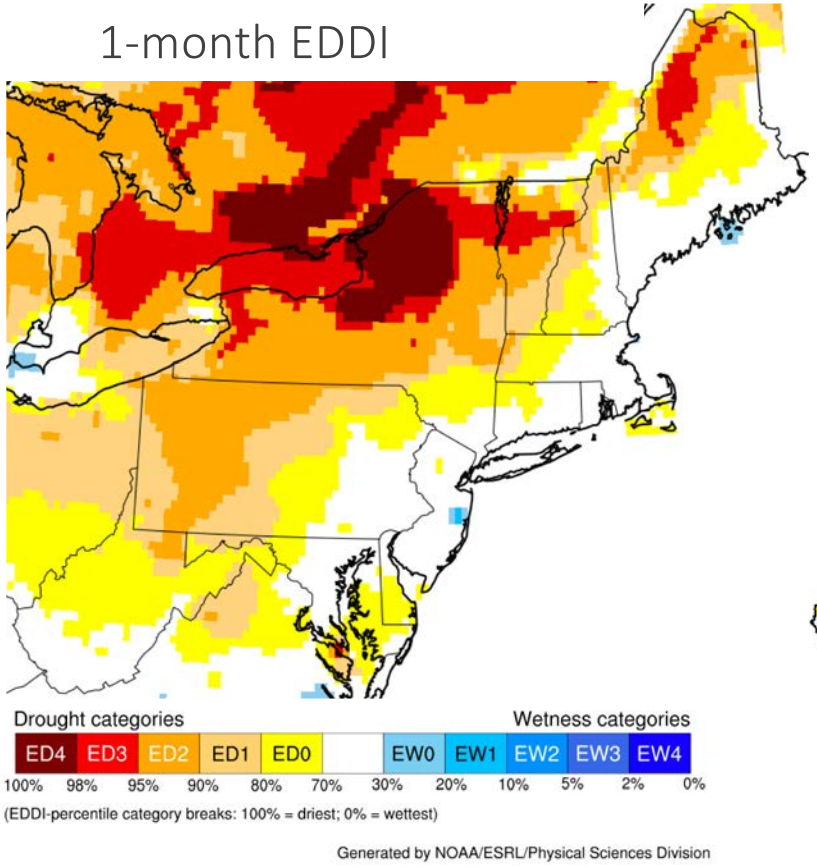
US Drought Monitor



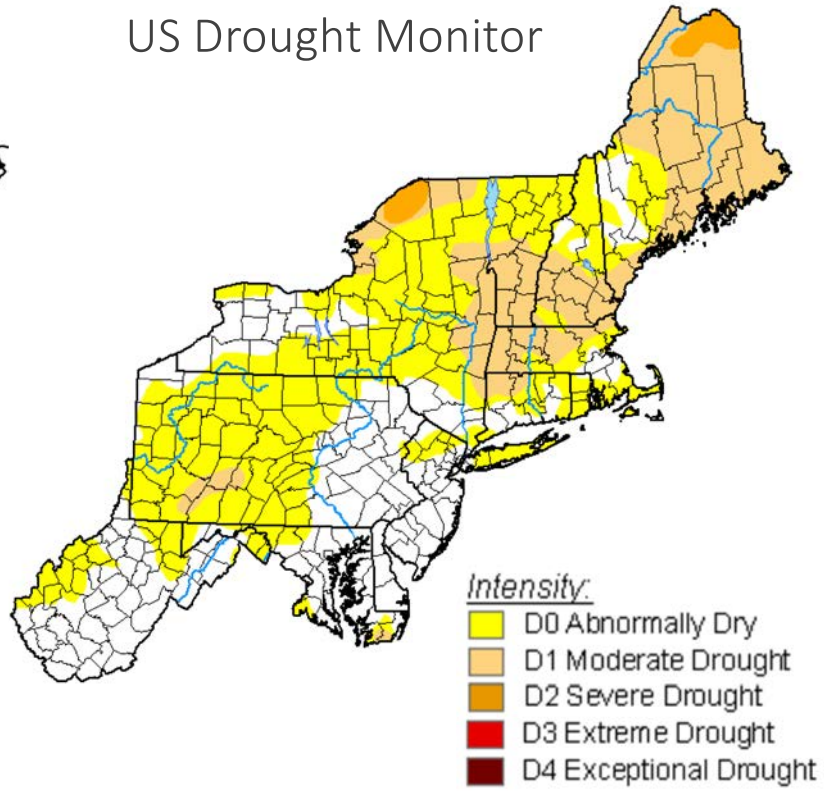
Case study |*Current Northeast drought*

July 14

1-month EDDI



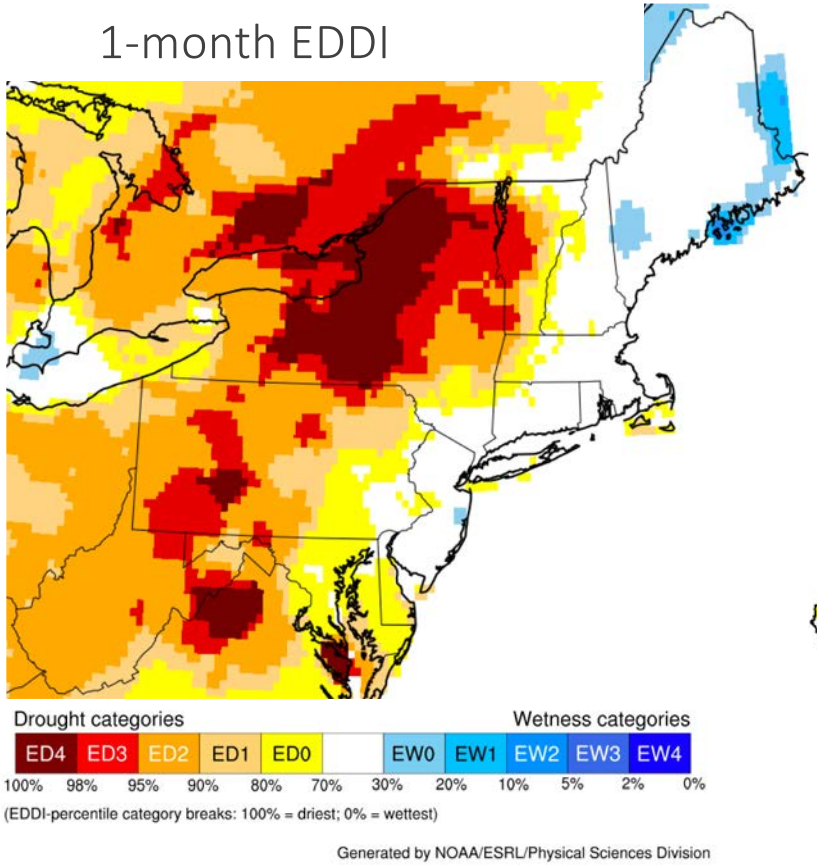
US Drought Monitor



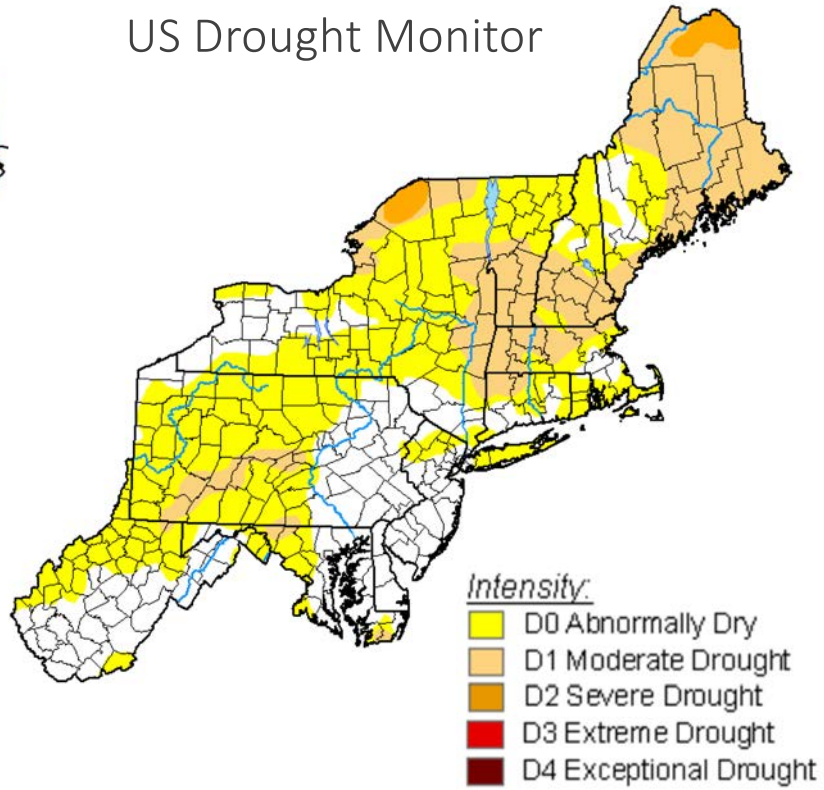
Case study |*Current Northeast drought*

July 21

1-month EDDI



US Drought Monitor

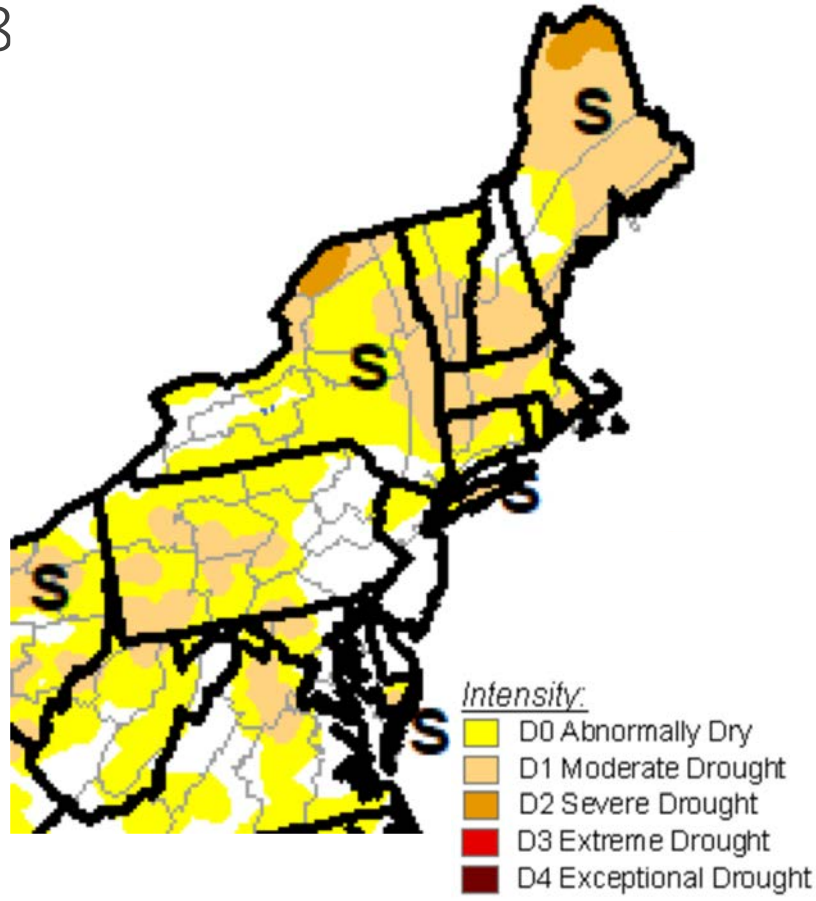


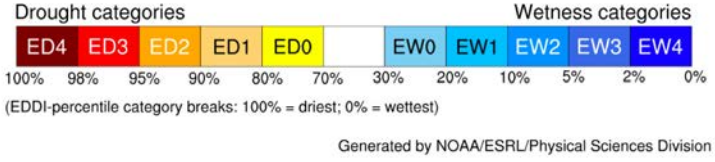
Case study | *Current Northeast drought*

July 28

1-month EDDI

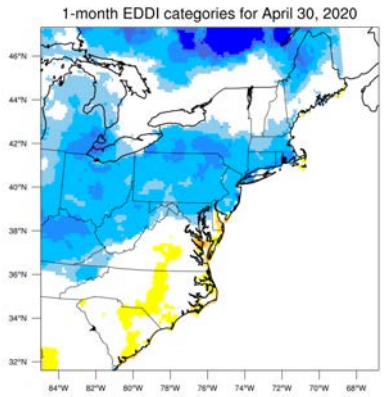
EDDI for July 28 not available until August ~1st





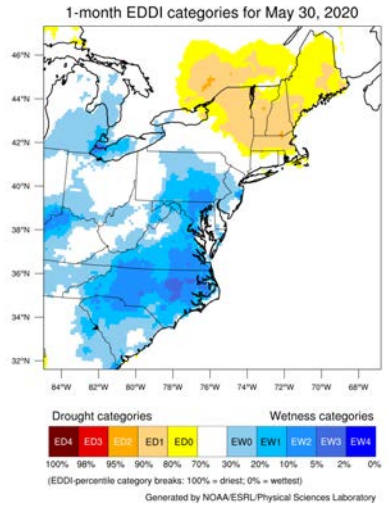
EDDI | *Change maps*

1-month EDDI
April 30, 2020

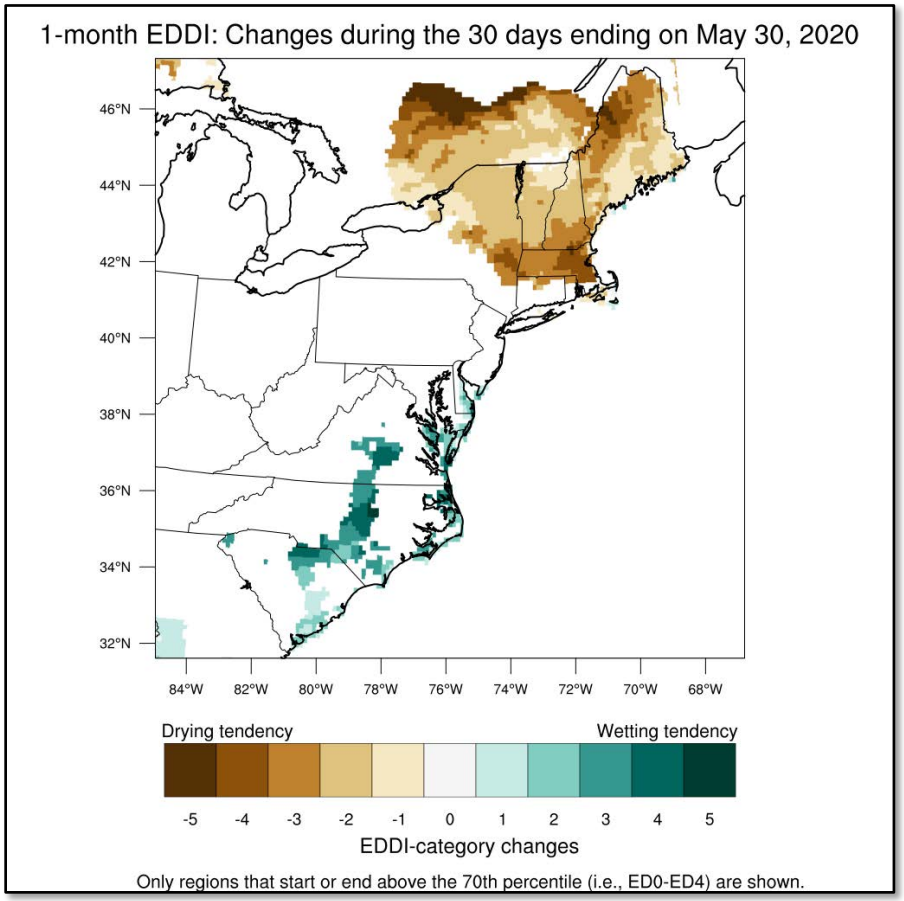


30 days

1-month EDDI
May 30, 2020

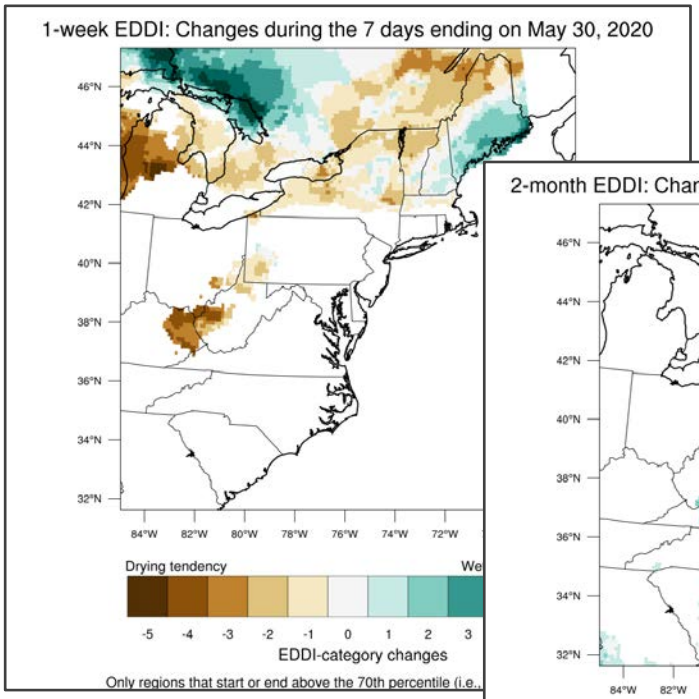


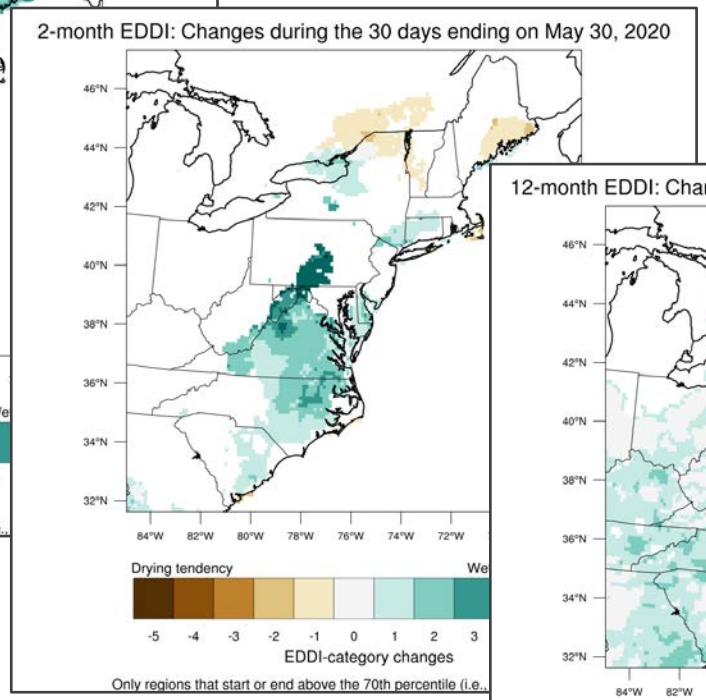
30-day changes in 1-month EDDI



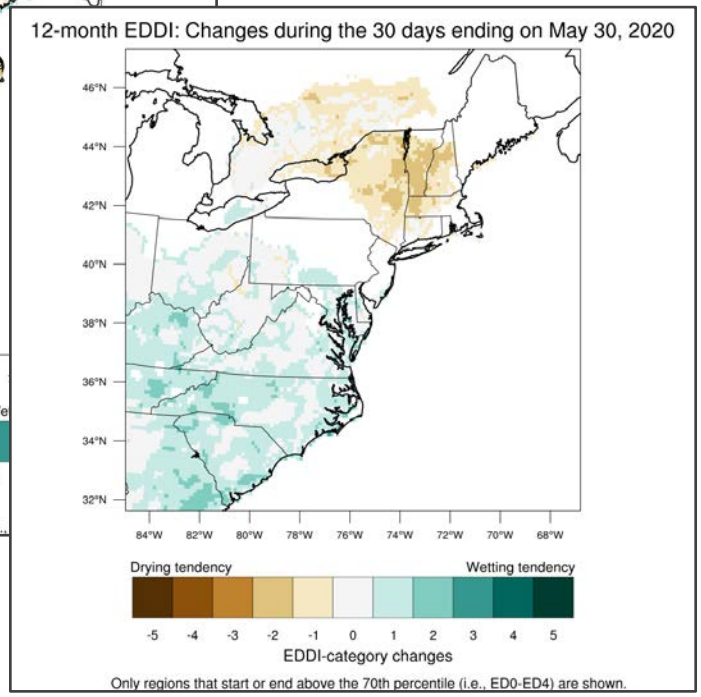
EDDI | *Change maps*

Very dynamic:
timescale =
change interval





Long memory:
timescale = 12 x change interval



EDDI and E_0 application | *Attribution – diagnosing drought's demand side*

How much are changes in E_0 due to each driver's changes?

$E_0 = f(T, R_d, q, U_2)$, 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

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

(*Hobbins*, TransASABE 2016)

T = temperature
R_d = solar radiation
q = humidity
U_2 = wind speed

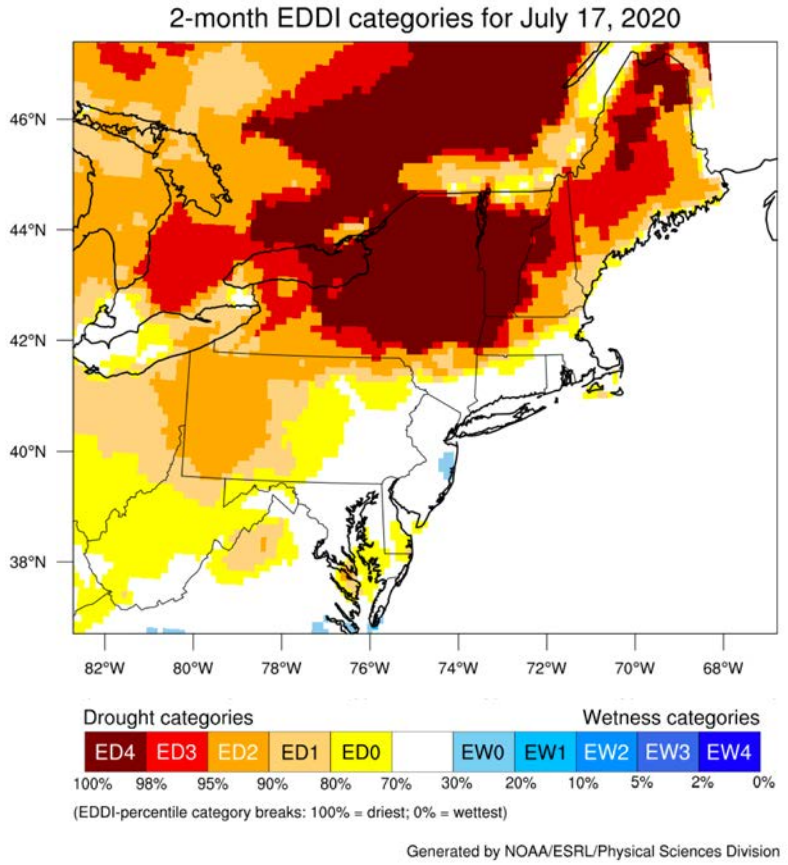
EDDI and E_0 application | *Attribution – diagnosing drought's demand side*

Decomposition of 2-month E_0 anomaly, May 18 – July 17, 2020

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

T = temperature
R_d = solar radiation
q = humidity
U_2 = wind speed

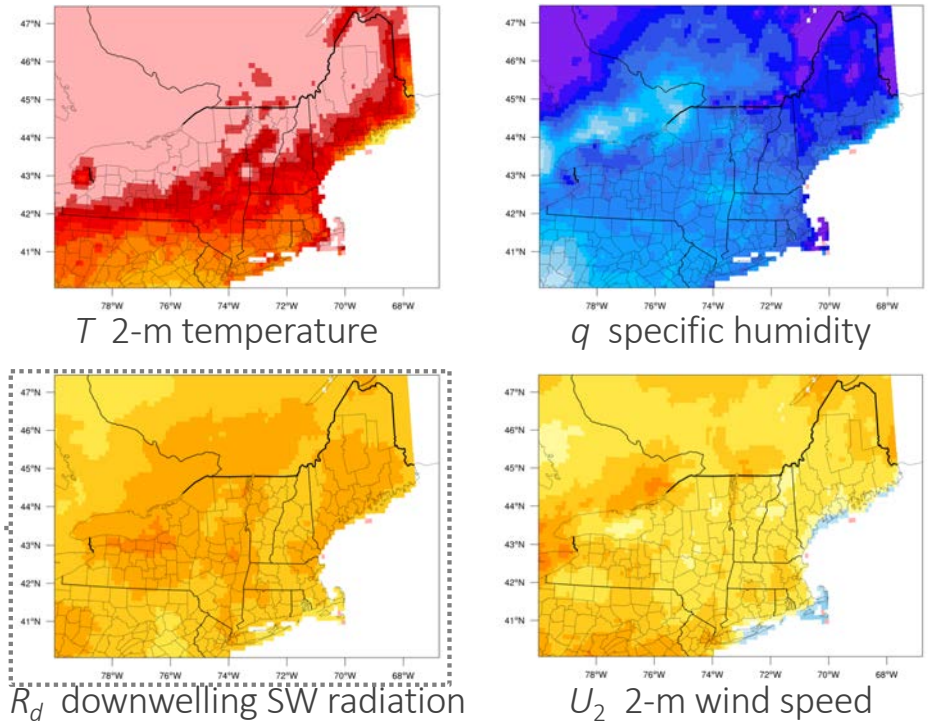
EDDI across length of drought so far (per US Drought Monitor)



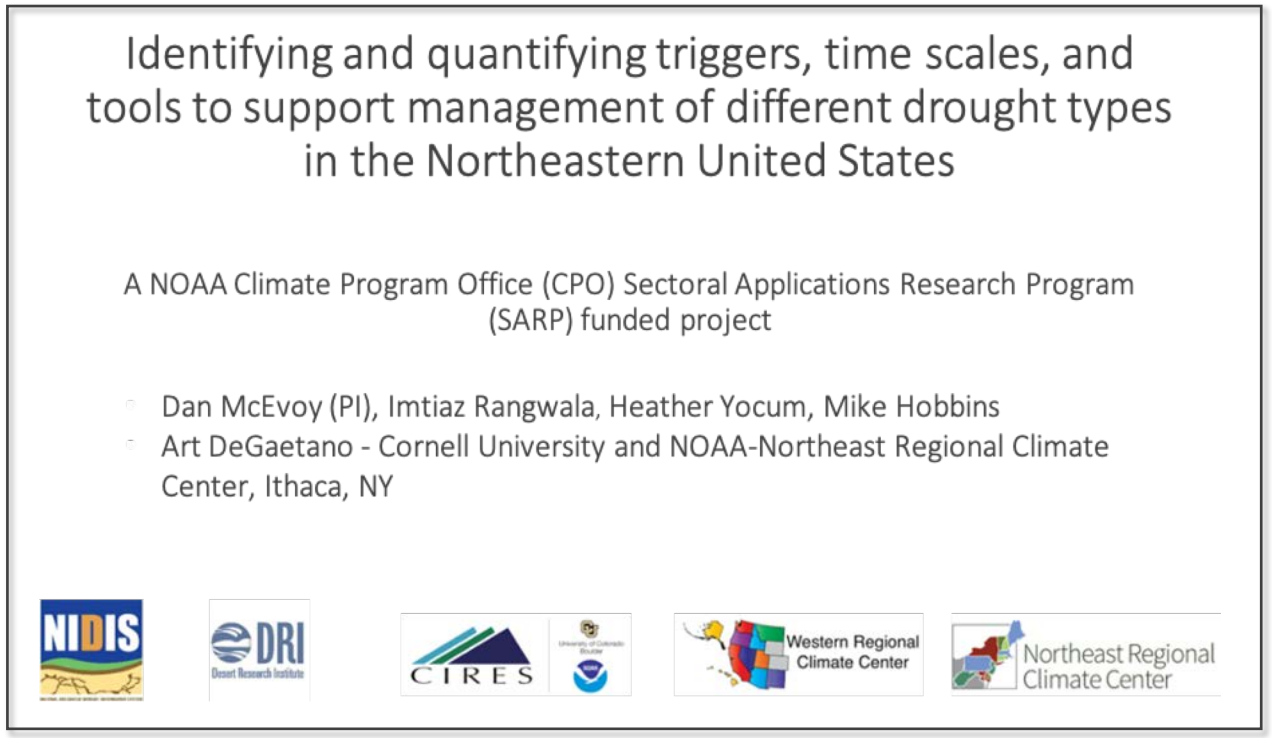
EDDI and E_0 application | *Attribution – diagnosing drought's demand side*

Decomposition of 2-month E_0 anomaly,
May 18 – July 17, 2020

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



Coming work | *NIDIS-funded project for Northeast DEWS*



Coming work | *NIDIS-funded project for Northeast DEWS*

Project Objectives

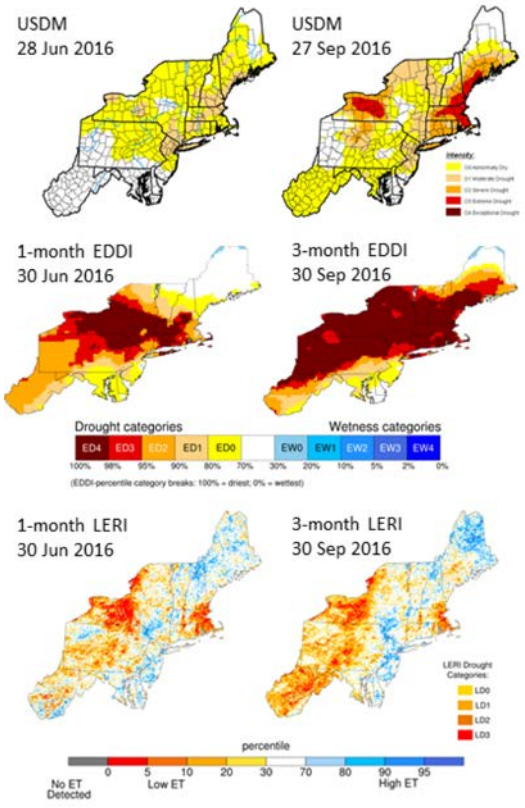
Identify the most effective drought indicators for hydrologic and agricultural drought monitoring in the Northeast DEWS region:

- What time scales align with impacts seen on the ground?
- What index or combination of indices works best?
- Some drought index inputs: Prcp, Temp, E_0, ET, soil moisture, snow water equivalent, runoff

Understand how to use this information to strengthen the Northeast DEWS and incorporate it into management, planning, and decision-making.

Coming work | *NIDIS-funded project for Northeast DEWS*

Example indices during 2016 drought



United States Drought Monitor (USDM)

Evaporative Demand Drought Index (EDDI)

Landscape Evaporative Response Index (LERI)

Coming work | *NIDIS-funded project for Northeast DEWS*

Questions for project collaborators

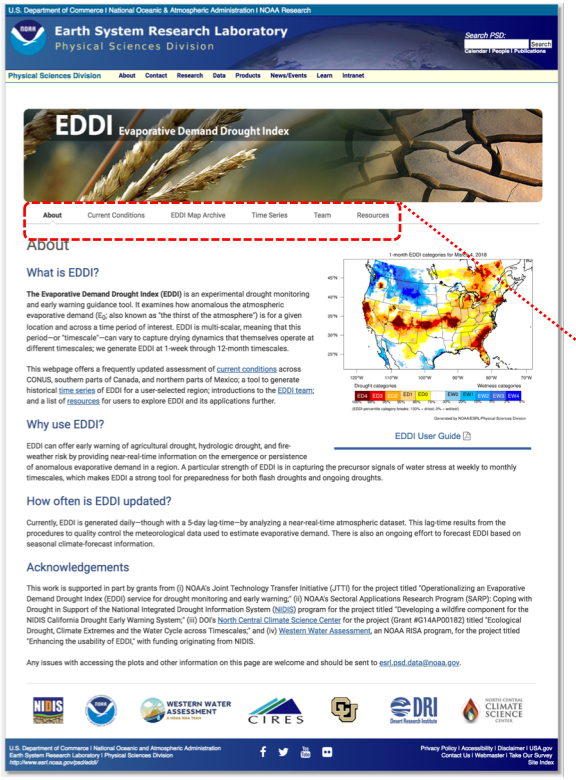
How is drought information and data used in different sectors?

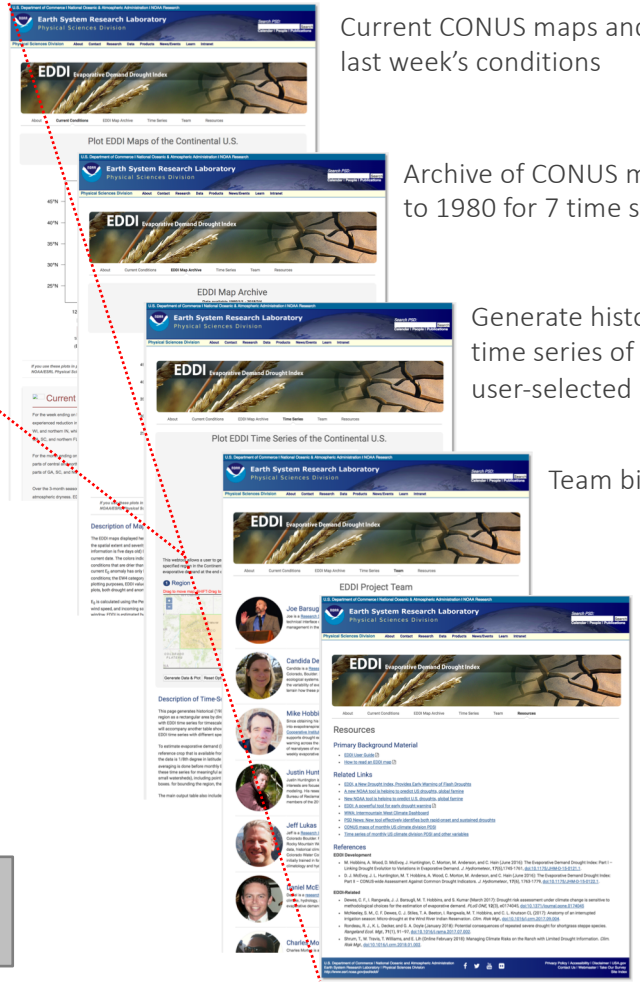
- Agriculture
- Water resources
- City, county, or state drought planning
- Research and academics
- Recreation
- Others?

Are there obvious needs for development of new drought information resources?

Are there other people or agencies who might be interested in providing feedback on this project?

Got EDDI? | *NOAA webpage*





Current CONUS maps and synopsis of last week's conditions

Archive of CONUS maps back to 1980 for 7 time scales

Generate historical (> 38-year) time series of EDDI values for user-selected rectangle

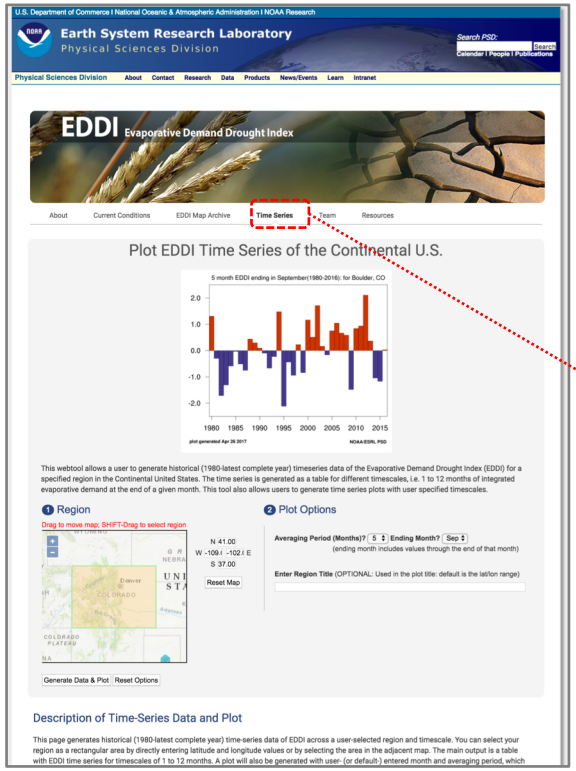
Team bios

Resources:

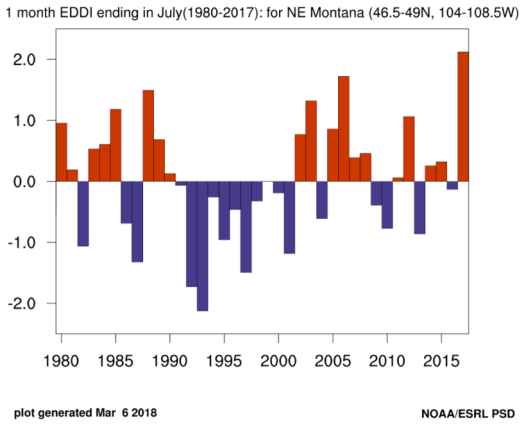
- user guide
- papers
- related links

https://www.esrl.noaa.gov/psd/eddi/
- or search for "EDDI NOAA"

Got EDDI? | *NOAA webpage – historical timeseries tool*

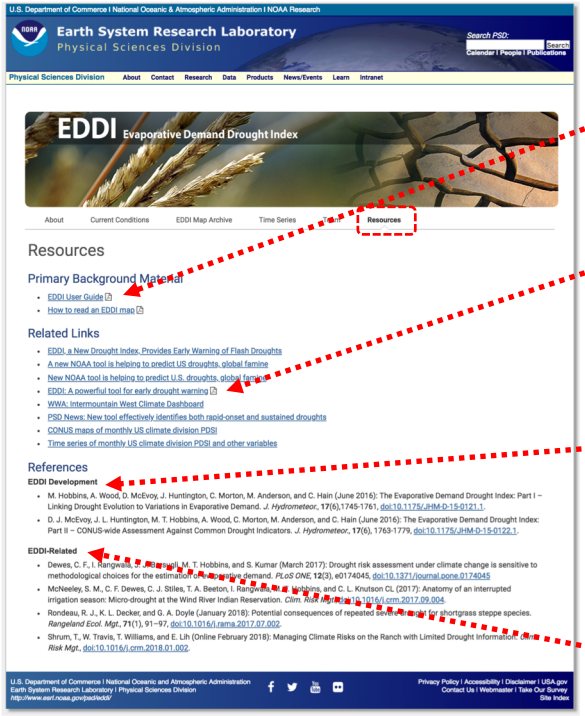


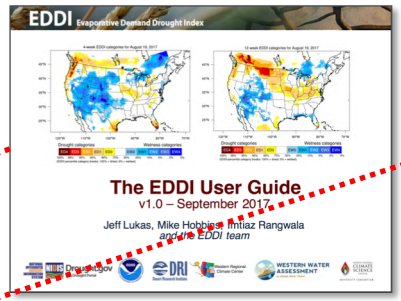
- Tool generates and plots historical EDDI time series for user-selected rectangle at 1- to 12-monthly time scales
- Time period: 1980-present
- Research into understanding past impacts
- Helpful for exploring relevant EDDI timescales for user-relevant impacts



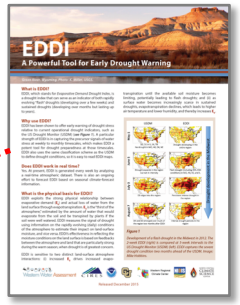
https://www.esrl.noaa.gov/psd/eddi/
- or search for “EDDI NOAA”

Got EDDI? | *NOAA webpage – resources and user guide*





(*Lukas et al.*, WWA 2017)



(*Rangwala et al.*, NOAA 2015)


The Evaporative Demand Drought Index. Part I: Linking Drought Evolution to Variations in Evaporative Demand

Michael T. Hobbins, Andrew Wood, Daniel J. McEvoy, Justin L. Huntington, Charles Morton, Martha Anderson, and Christopher Hain

The Evaporative Demand Drought Index. Part II: CONUS-Wide Assessment against Common Drought Indicators

Daniel J. McEvoy, Justin L. Huntington, Michael T. Hobbins, Andrew Wood, Charles Morton, Martha Anderson, and Christopher Hain


Drought risk assessment under climate change is sensitive to methodological choices for the estimation of evaporative demand

Candida F. Dewes, Imtiaz Rangwala, Joseph J. Barsugli, Michael T. Hobbins, Sanjiv Kumar

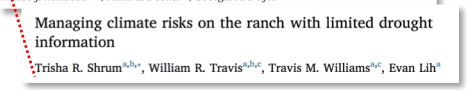

Anatomy of an interrupted irrigation season: Micro-drought at the Wind River Indian Reservation

Shannon M. McNeeley, Candida F. Dewes, Crystal J. Stiles, Tyler A. Beeton, Imtiaz Rangwala, Michael T. Hobbins, Cody L. Knutson


Original Research

Potential Consequences of Repeated Severe Drought for Shortgrass Steppe Species

Renée J. Rondeau, Karin L. Decker, Georgia A. Doyle

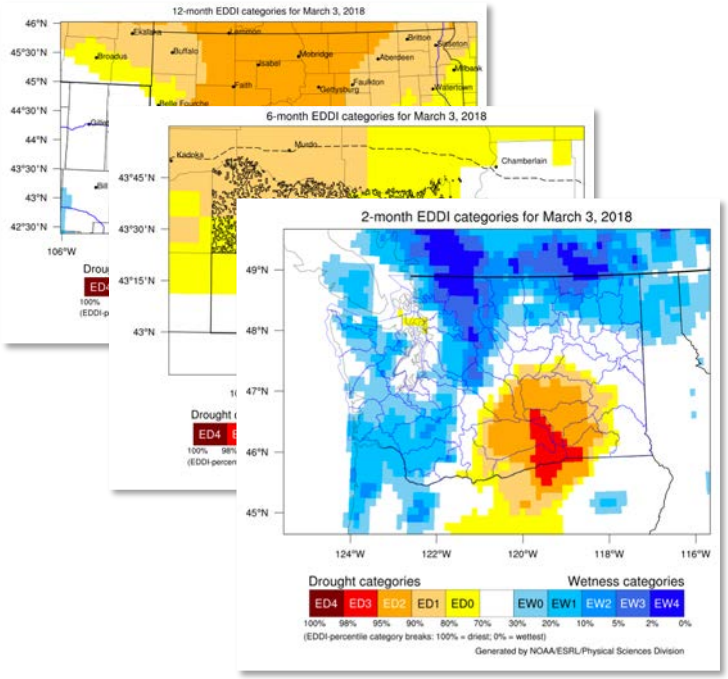

Managing climate risks on the ranch with limited drought information

Trisha R. Shrum, William R. Travis, Travis M. Williams, Evan Lih

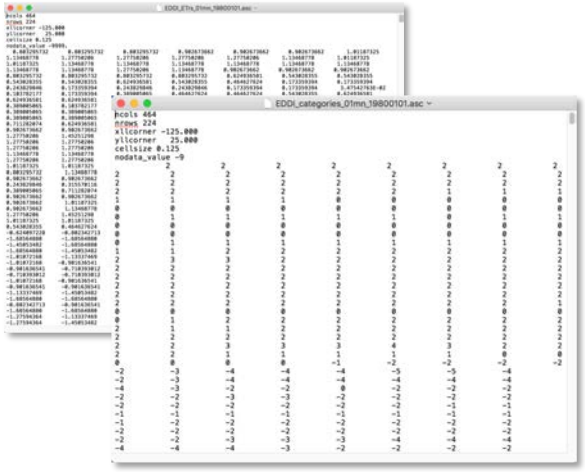
https://www.esrl.noaa.gov/psd/eddi/
- or search for “EDDI NOAA”

Got EDDI? | *Variety of formats*

EDDI maps with user-provided context:
e.g., highways, towns, reservations, watersheds, rivers



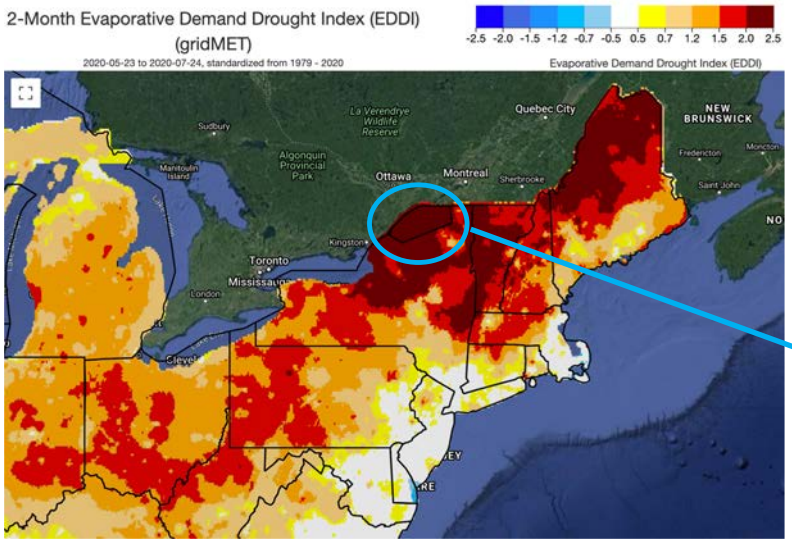
Flat ascii grids of EDDI data:
e.g., raw EDDI values, EDDI drought / wetness categories



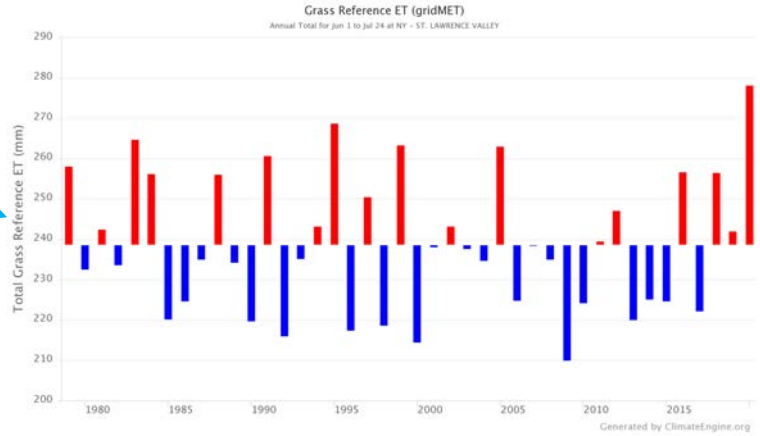
Coming soon…

…NetCDFs

EDDI in the Cloud | *Climate Engine*



St. Lawrence Valley, NY Climate Division
Total E_0, June 1 – July 24, 2020



- Interactive maps; zoom to desired region
- Download maps as geotiffs
- Download time series graphs and data

https://app.climateengine.org/climateEngine
- or contact Dr. Dan McEvoy, DRI at Daniel.McEvoy@dri.edu

- Other drought indices: SPEI, SPI, PDSI
- Remote sensing data (e.g., NDVI), and other climate data available globally

Got EDDI? | *Access to data*

EDDI and downloadable archives:

- EDDI - ftp://ftp.cdc.noaa.gov/Projects/EDDI/

EDDI webpage:

- https://www.esrl.noaa.gov/psd/eddi/
  - or search for "EDDI NOAA"

FTP map and data access for Denver Water:

- ftp://ftp.cdc.noaa.gov/Public/mhobbins/EDDI/DW/

Off-site hosting:

- Drought.gov
- NIDIS DEWS pages
- RISA and RCC climate dashboards

Contact the EDDI team:
Mike Hobbins
303-497-3092
mike.hobbins@noaa.gov