Evapotranspiration (ET) Index Revision

June 15, 2022

Massachusetts Drought Management Task Force meeting

DMP Indices

- Precipitation
- ET

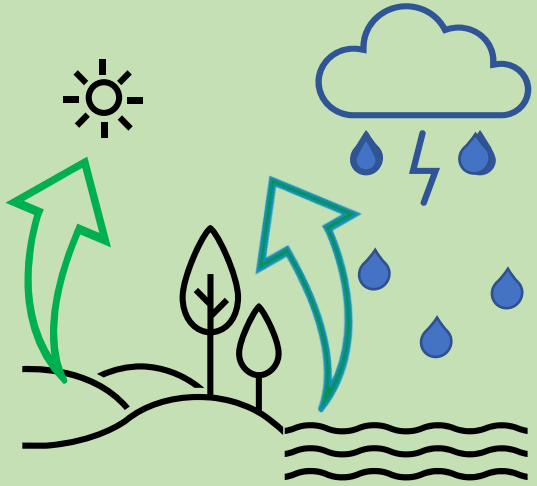
Causes → *One or both Index Severity Levels elevate first*

- Streamflow
- Groundwater
- Lakes & impoundments
- Fire – soil moisture in top 8”

Impacts → *Index Severity Levels elevate after Precipitation &/or ET*

Goals for Revision

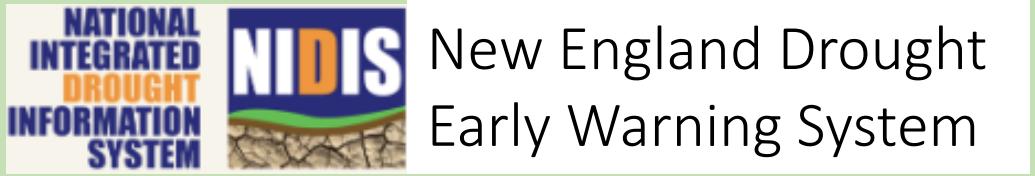
- **Timely identification of drought onset/intensification**
  - Currently, no signal from Crop Moisture Index (CMI) - can cause delays in drought onset/intensification identification



- Show the **effect of temperature/ET on "available" precipitation**
  - Help identify "flash droughts" by knowing when impacts will occur more quickly than when just low precip
  - With climate change, importance of identifying **heat/ET in addition to precip-induced dryness**

Process

- Analyses conducted by Cornell University



- Evaluation of results by technical group similar to 2019 DMP revision
- State and federal staff comprising of USGS, NOAA NWS, NOAA NERFC, MassDEP, DFG, DCR, EEA
- Reviewed analyses and made recommendation

Options Evaluated

- **Evaporative Stress Index** (ESI)– ET as calculated by energy balance using remotely sensed temperature
- **Gravity Recovery and Climate Experiment (GRACE), National Water Model (NWM), Climate Prediction Center Soil Moisture (CPCSM)** – Soil moisture → net effect of precip, ET and infiltration
- **Standardized Precipitation and Evapotranspiration Index (SPEI)** – Precip minus theoretical maximum ET
- **Evaporative Demand Drought Index (EDDI)** – Theoretical maximum ET (based on temperature, radiation, wind, etc.), aka ‘thirst of the atmosphere’

Evaluation Criteria

Logistics

- Spatial resolution - unique value per drought region
- Historical availability of data for evaluating against past droughts
- Long reference period/period of record for calculating percentiles
- Appropriate look-back periods or depths for drought monitoring
- Update frequency (at least 1/week)
- Timely availability

Performance

- Timely drought onset/intensification identification, especially when precipitation amounts are still near normal
- Effect of temperature/ET on drought – amount of precipitation expected to remain available

Logistics Criteria

Index	**Spatial Resolution** (average miles between points)	**Time Period Available for Use** (for evaluating index)	**Reference Period** (for percentile calculations)	**Lookbacks Calculated or Depths Available**	**Update Frequency**	**Timely Availability** (Days past observation)

Logistics Criteria

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CPCSM	**No, (50 - 68 mi)**	2008-present	1932-2000	Daily, Monthly	Daily, Monthly	1-day (daily), 5-day (month)
ESI	Yes (5 - 7 mi)	2002-present	**2000-present**	4-Week, 12-Week	Weekly	3+ day lag

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ESI	Yes (5 - 7 mi)	2002-present	**2000-present**	4-Week, 12-Week	Weekly	3+ day lag
GRACE	Yes (6 – 8.5 mi)	2002-present	1948-2014	surface (2cm), root zone (100cm)	Weekly	2+ days lag
NWMv2	Yes (1.2 mi)	2001-2020	1979- 2018	0-10 cm, 10-40 cm, 40-100 cm, 100-200 cm	Daily	Current
SPEIv2	Yes, at least 1 station per region	Varies by station like precipitation	Varies by station like precipitation	1-Month to 12-Months	Weekly	1-day
EDDI	Yes (6 - 8.5 mi)	1980-present	1979-2015	1-Week to 12-Months	Daily	5-day lag

[1] https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml; [2] https://www.drought.gov/data-maps-tools/evaporative-stress-index-esi; [3] https://nasagrace.unl.edu/; [4] https://water.noaa.gov/about/nwm; [5] https://spei.csic.es/home.html; [6] https://psl.noaa.gov/eddi/

How to Evaluate Performance

- Appropriate season
- Frequency – Matching the Index Severity Level percentiles specified in the DMP
- Timing – Earlier elevated signal relative to other indices and historical droughts when there are high temperatures
  - Early similar to precipitation index so it signals onset and/or intensification

Index Severity Level	Percentile Range
0	>30%
1	>20 and ≤30%
2	>10 and ≤20%
3	>2 and ≤10%
4	≤2%

Seasonality of ET

Monthly average **temperature (°F)**

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boston, MA	30	32	38	49	58	68	74	73	66	55	45	30
Worcester, MA	25	27	35	46	57	65	71	69	62	51	40	25

Monthly average potential evapotranspiration **(PET) estimates (inches)** for a grass-covered surface

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boston, MA	0.4	0.6	**1.2**	**2.0**	**3.1**	**3.6**	**4.0**	**3.5**	**2.3**	**1.4**	0.6	0.4
Worcester, MA	0.3	0.5	**1.1**	**2.0**	**3.2**	**3.6**	**4.0**	**3.5**	**2.3**	**1.3**	0.6	0.3

Values reflect averages over the years 1991-2020.
This table is adapted from data provided by the Northeast Regional Climate Center at http://www.nrcc.cornell.edu/wxstation/pet/pet.html and http://www.nrcc.cornell.edu/wxstation/nowdata.html .

Matching Index Severity Level Percentiles

Index Severity Level	**0**	**1**	**2**	**3**	**4**
DMP Percent of Months	**70**	**10**	**10**	**8**	**2**
+/-10%	**63-77**	**9-11**	**9-11**	**7.2-8.8**	**1.8-2.2**
CMI	96	3	1	0	0
ESI-04wk	71	11	7	6.1	4.8
GRACE-rtzsm-100cm	67	11	12	10.3	0.4
NWM-SM-40cm	74	13	8	5.5	0
SPEI-02mn	73	10	8	7.9	1.5
EDDI-02mn	67	11	12	7.2	3.2

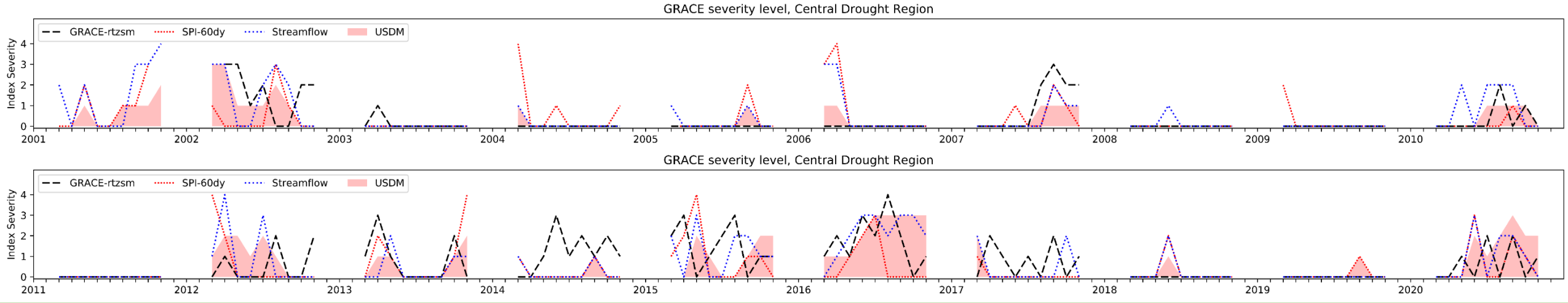
Most indices perform well:

- relative to CMI
- for Level 0 and Level 1 droughts (i.e., onset)

Crop Moisture Index (CMI), Central Region

- Rarely provides a signal
- Can delay drought calls
  - 1 of 3 onset signals like precipitation & streamflow
- More important with newer, faster developing flash droughts
- Why doesn't it work? Developed and calibrated for central US; not as appropriate for the NE US

Used USDM drought levels in analyses because more consistent methods across time than MA DMP but the 5 USDM drought levels were converted to the corresponding 4 MA drought levels


GRACE severity level, Central Drought Region
GRACE-rtzsm
SPI-60dy
Streamflow
USDM
Index Severity
0
1
2
3
4
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

GRACE severity level, Central Drought Region
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2011
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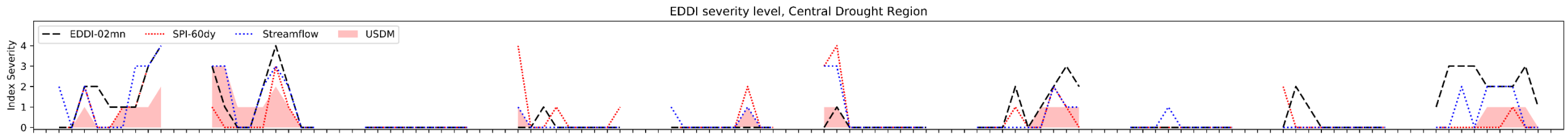
2016
2017
2018
2019
2020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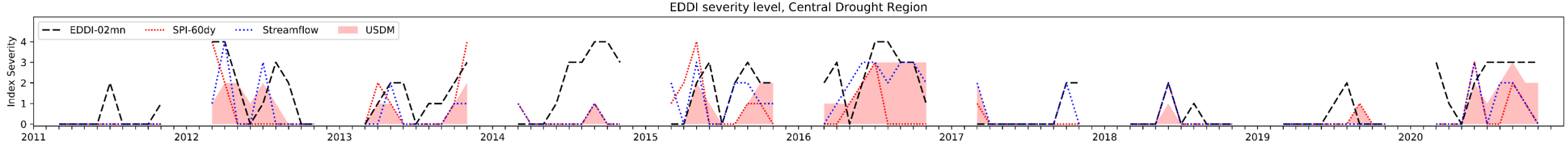
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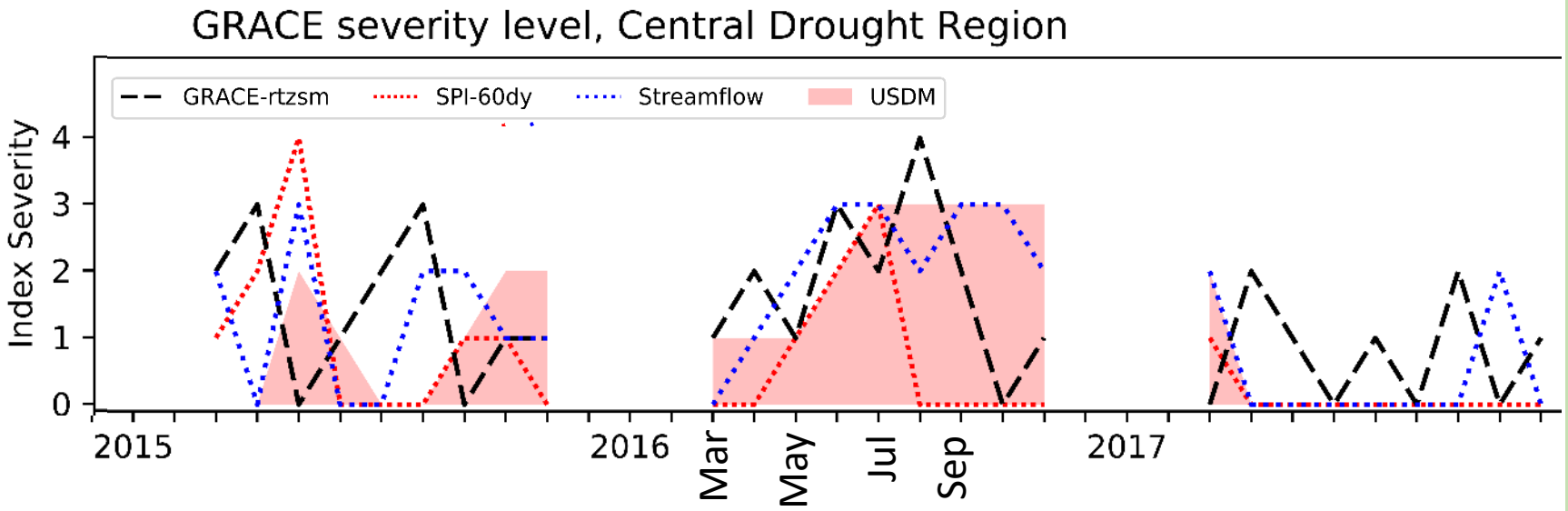
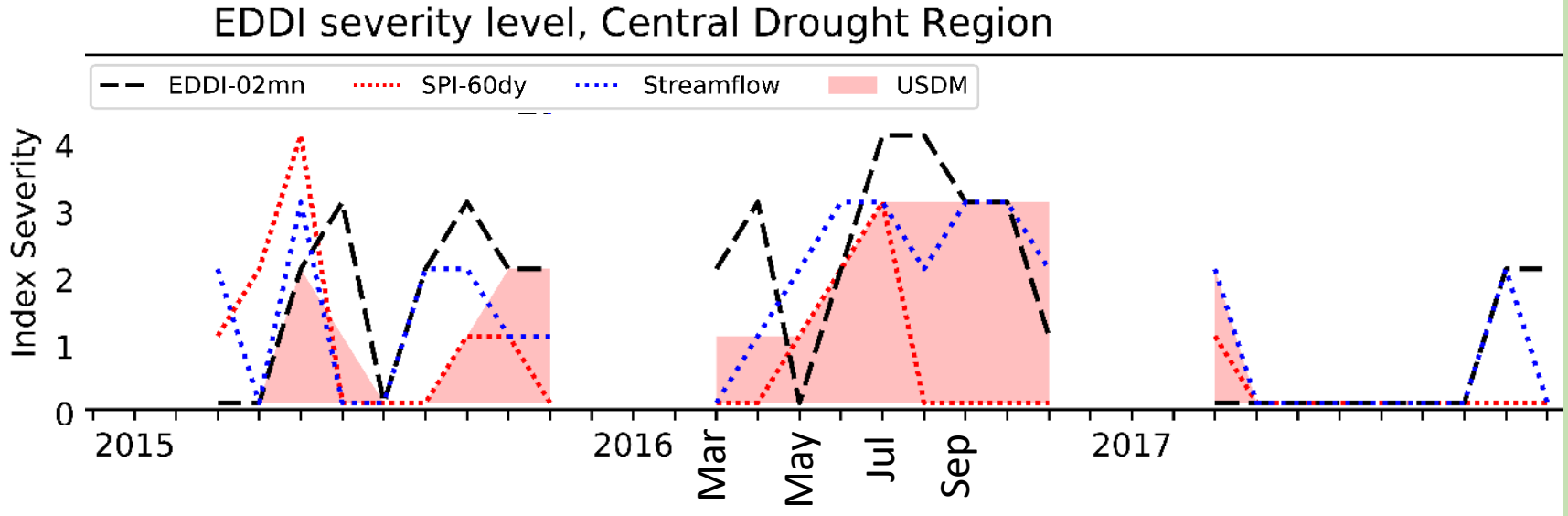
2018
2019
2020

Product Comparison - 2016 Drought

GRACE root zone – soil moisture at 40 in
- Satellite product
- Ref period: 1948-2014

EDDI – max evapotranspiration demand /PET
- Penman-Monteith, uses reference crop of well watered 0.5m alfalfa
- Ref period 1979-2015

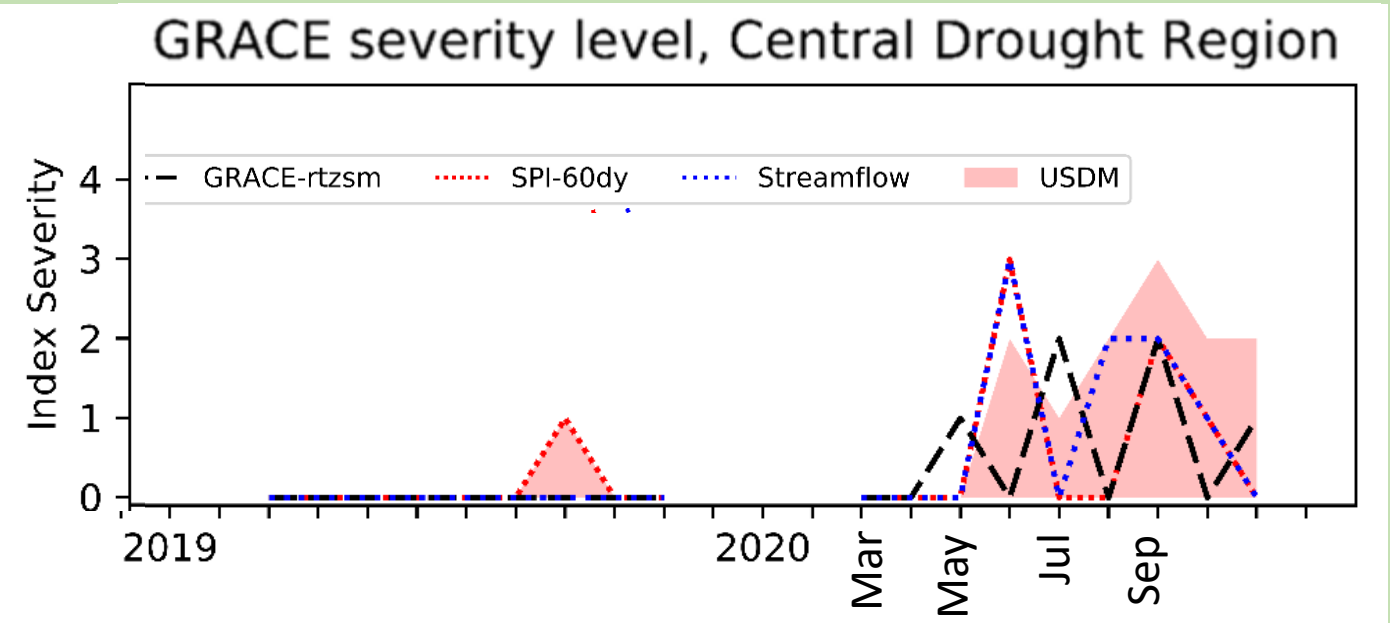


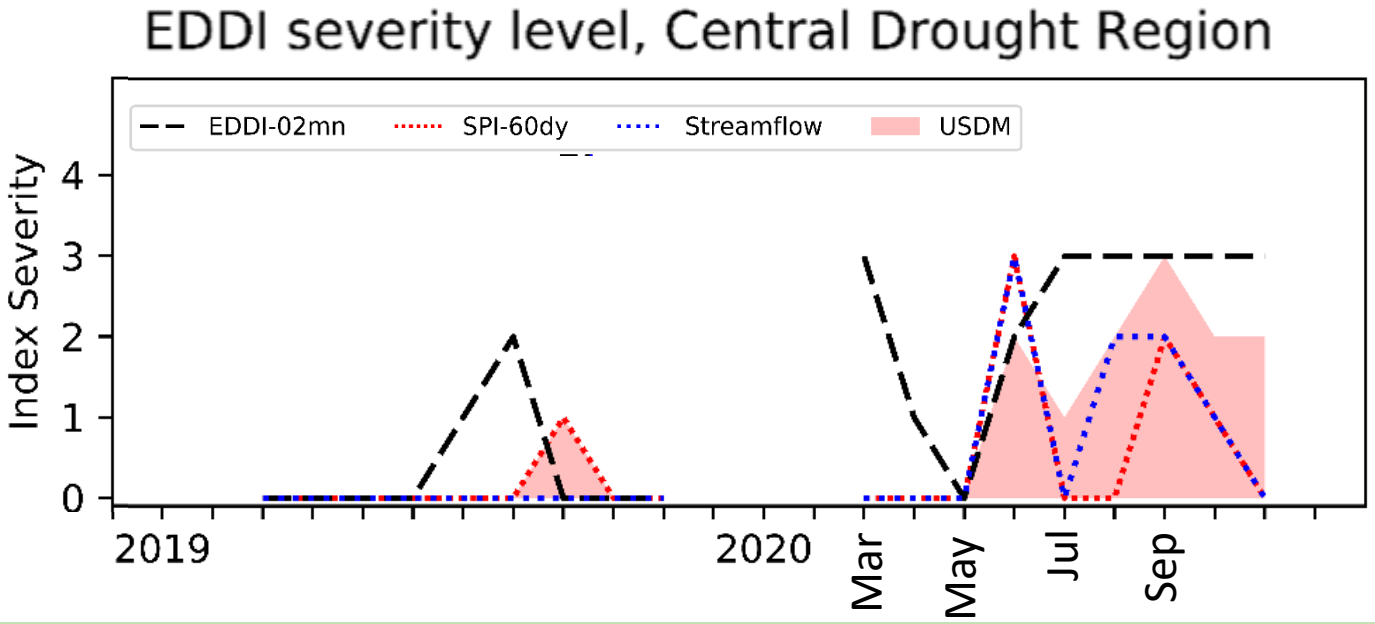


2016 Average Temperature	
Month	**Percentile over POR**
Mar	**11th**
Apr	67th
May	51th
Jun	47th
Jul	**23th**
Aug	**7th**
Sep	**15th**
Oct	47th
Nov	**23th**
Annual	***12th***

Percentiles are for the 129 years between 1892 and 2021. Lower percentiles=warmer months/year

Product Comparison - 2020 Drought





2020 Average Temperature	
Month	**Percentile over POR**
Mar	**12th**
Apr	85th
May	63th
Jun	**15th**
Jul	**2th**
Aug	**7th**
Sep	**28th**
Oct	43th
Nov	**2th**
Annual	***4th***

record high summer

Percentiles are for the 129 years between 1892 and 2021. Lower percentiles=warmer months/year

<u>GRACE</u>

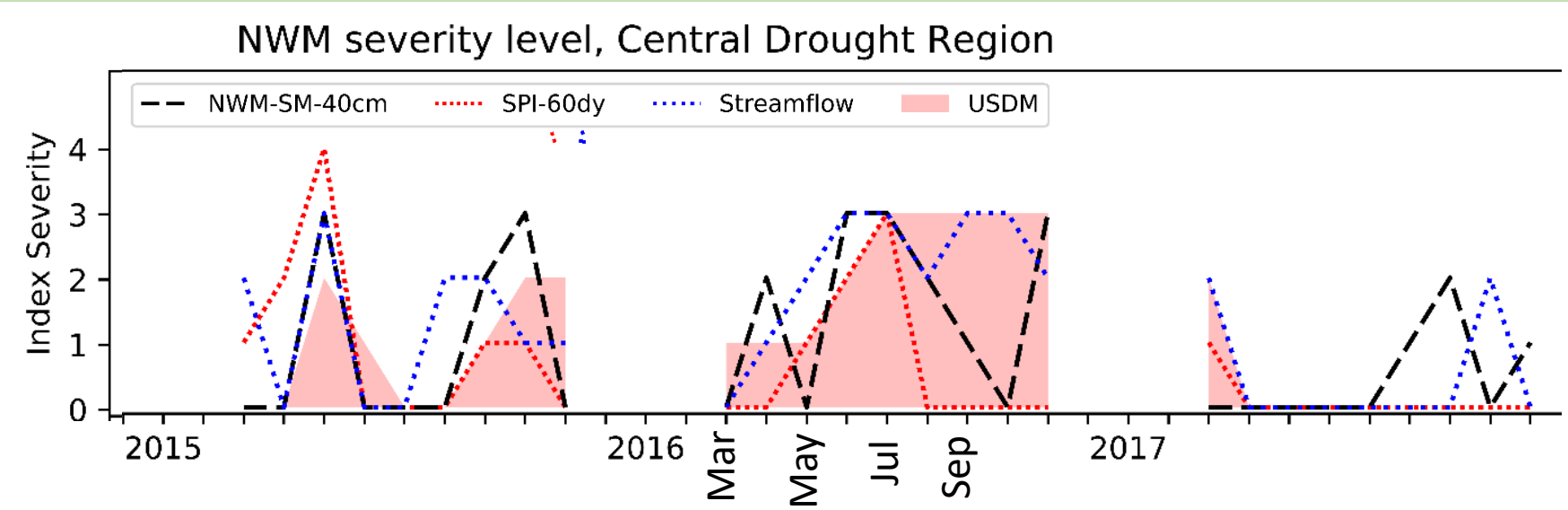
-generally running low despite **record** heat months

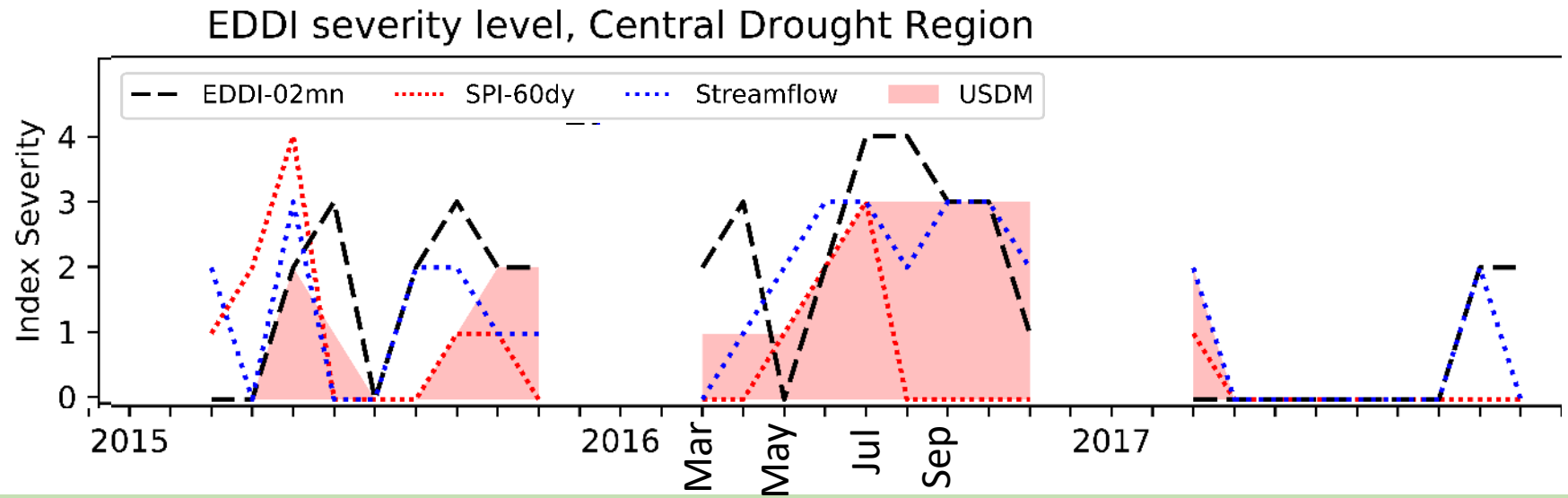
- may be due to moderation by precip rewetting soil moisture as seen by relatively low index levels

Product Comparison - 2016 Drought

NWM 40 cm – soil moisture at 0-16 in depth
- modeling
- Ref period: 1979-2020

EDDI – max evapotranspiration demand /PET
- Penman-Monteith uses reference crop of well watered 0.5m alfalfa
- Ref period 1979-2015





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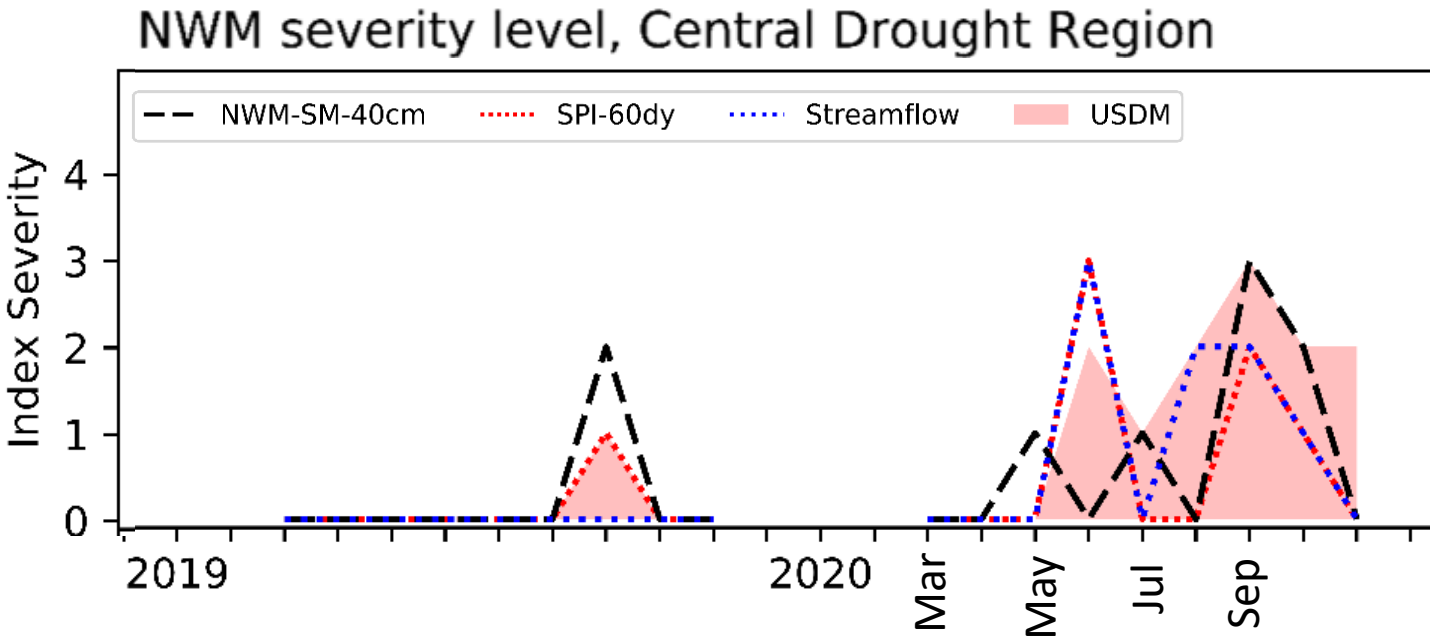

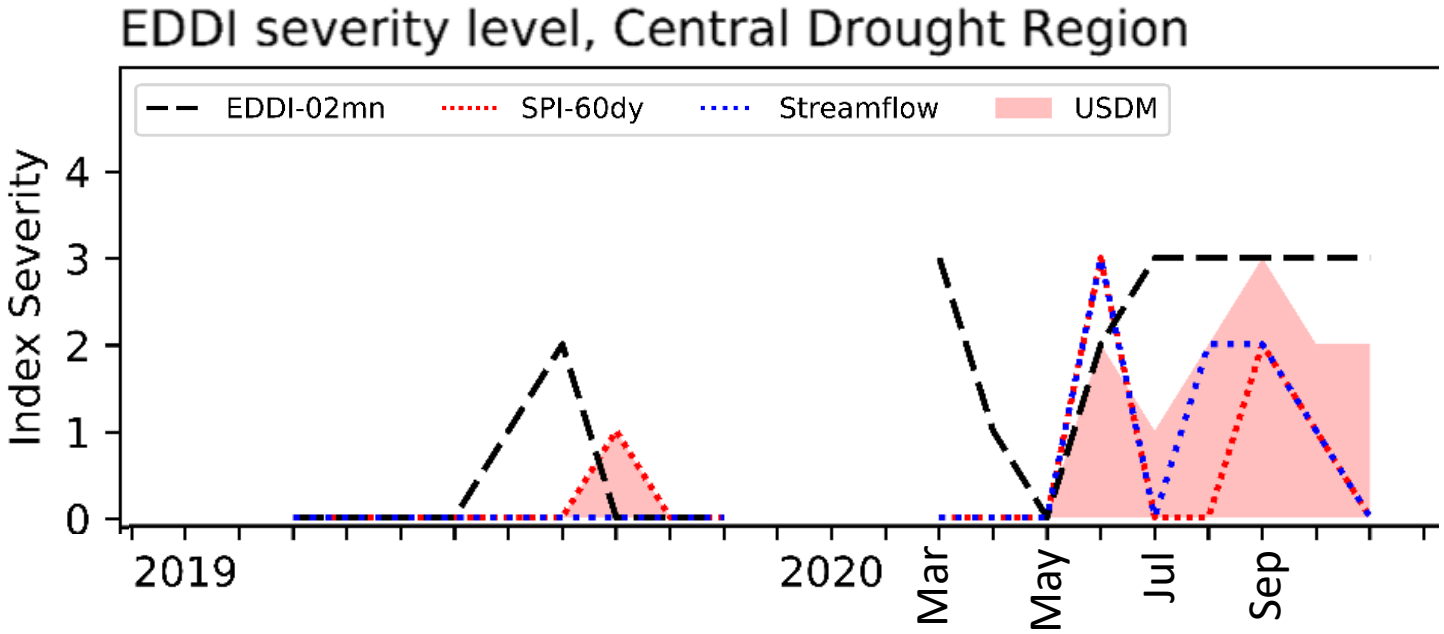

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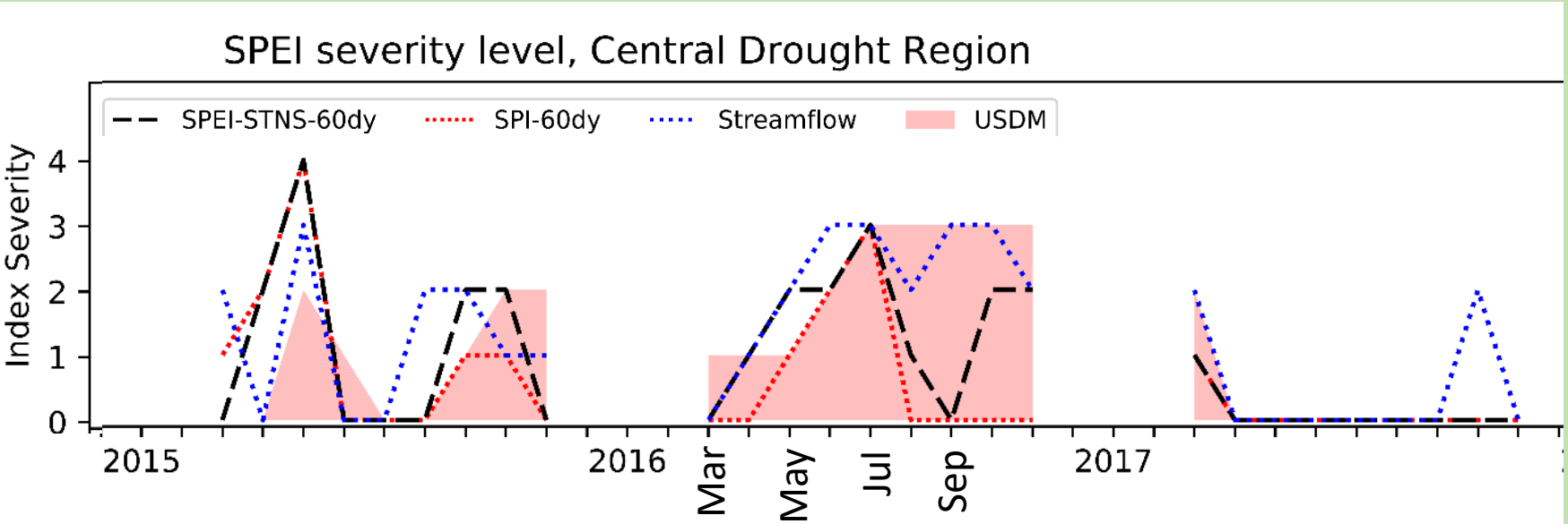
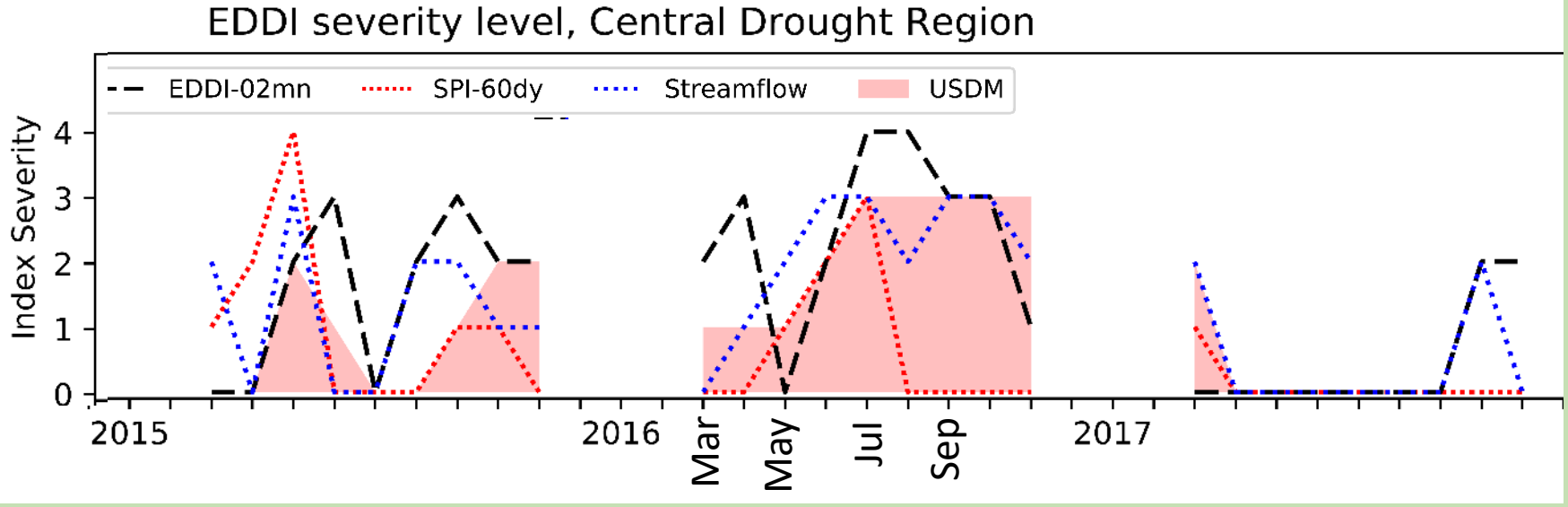
<u>NWM</u>

-does not spike until September despite July and August record heat

-may have been moderated by precipitation in July & August

Product Comparison - 2016 Drought





SPEI – Precip minus PET

- Thornthwaite PET method uses monthly temp, latitude to adjust sunlight hours based on date
- Ref period varies by station

EDDI – max evapotranspiration demand /PET

- Penman-Monteith uses reference crop of well watered 0.5m alfalfa crop
- Ref period 1979-2015

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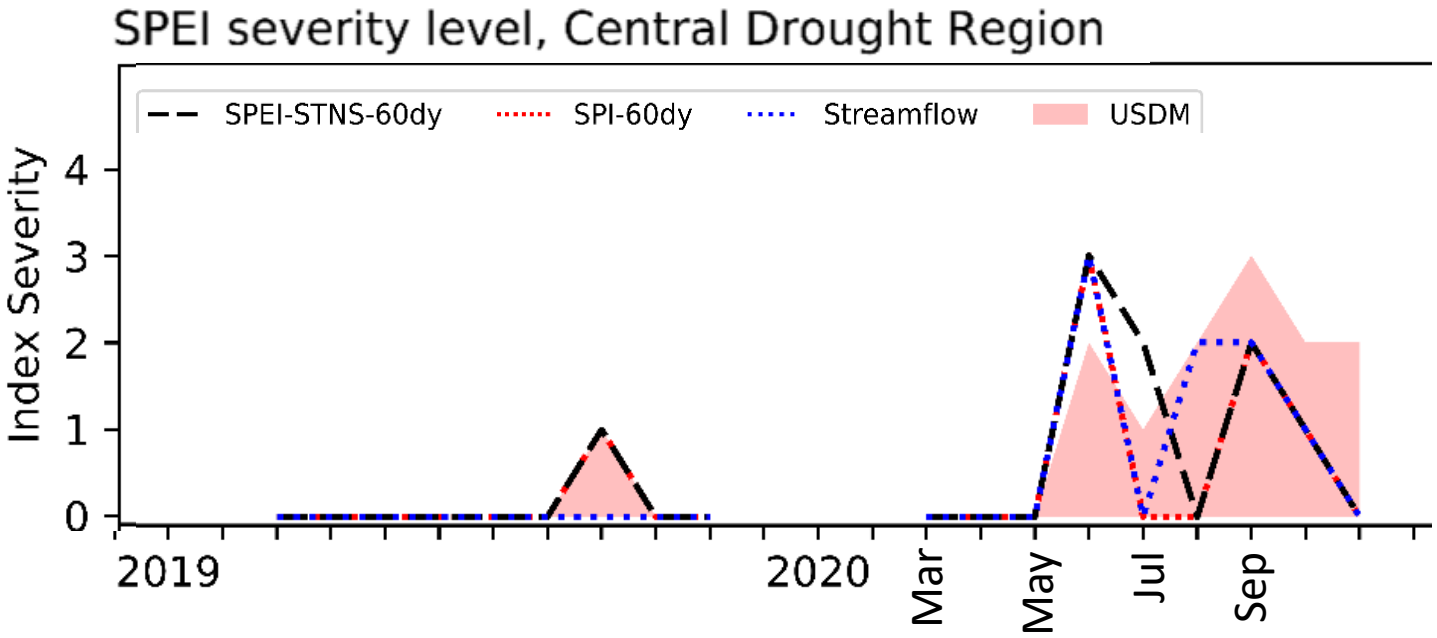

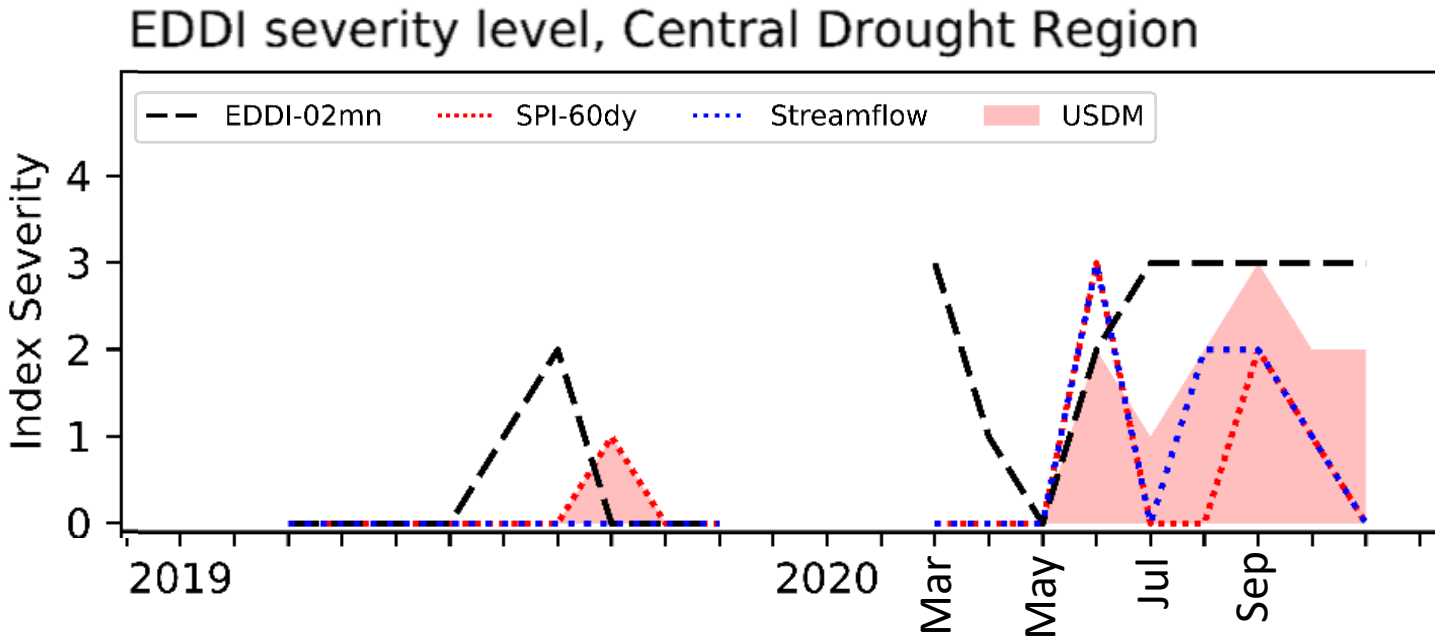

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SPEI

-does not signal record high heat in July and may be due to moderation by precip =L0

-this also delays intensification signal in August and moderates signal in September despite increasing impacts in streamflow

Recommendation - 2-month EDDI

- Is better than CMI and other options at signaling the role of temperature and ET in drought
- Helps identify drought onset/intensification in a timelier manner especially when it is ET rather than precipitation-induced
- Provides additional information to complement the other indices