

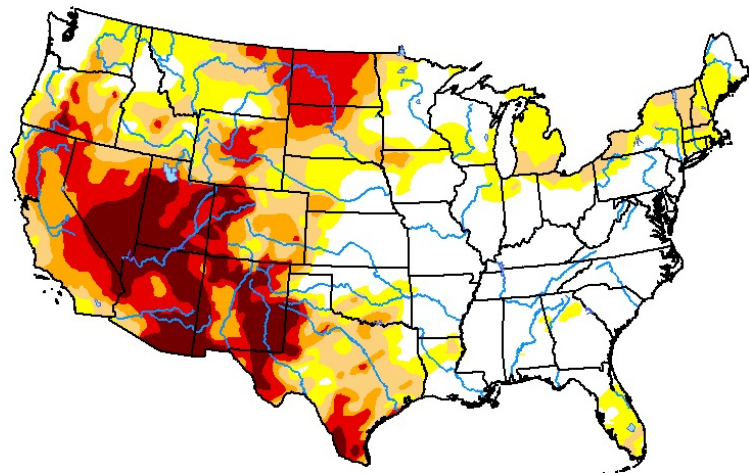
The 2020-21 Southwestern U.S. Drought A Preliminary Study on Its Causes and Prediction

Hailan Wang, Arun Kumar, Brad Pugh, Mingyue Chen, Bala Narapusetty
NOAA/NWS Climate Prediction Center

NOAA 46th Climate Diagnostics and Prediction Workshop
October 27, 2021

U.S. Drought Monitor

4/13/2021



Intensity:

- None
- D0 (Abnormally Dry)
- D1 (Moderate Drought)
- D2 (Severe Drought)
- D3 (Extreme Drought)
- D4 (Exceptional Drought)
- No Data

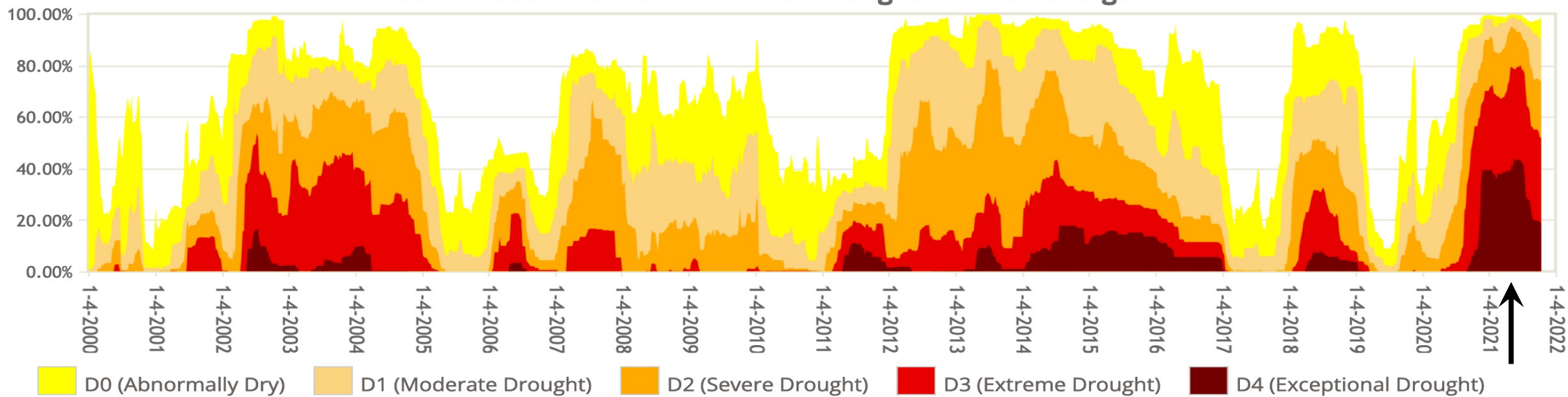
➤ The 2020-21 Southwest U.S. Drought

- Drought coverage and severity are unprecedented in the USDM record

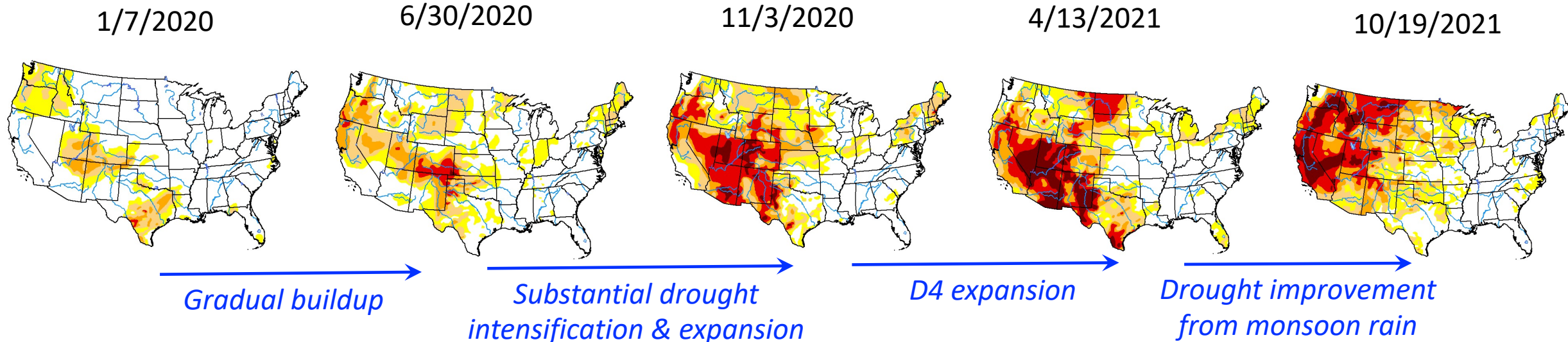
Southwest US: Percent Area in US Drought Monitor Categories

Week	None	D0-D4	D1-D4	D2-D4	D3-D4	D4	DSCI
2021-04-13	1.24	98.76	97.15	89.87	69.84	39.02	395

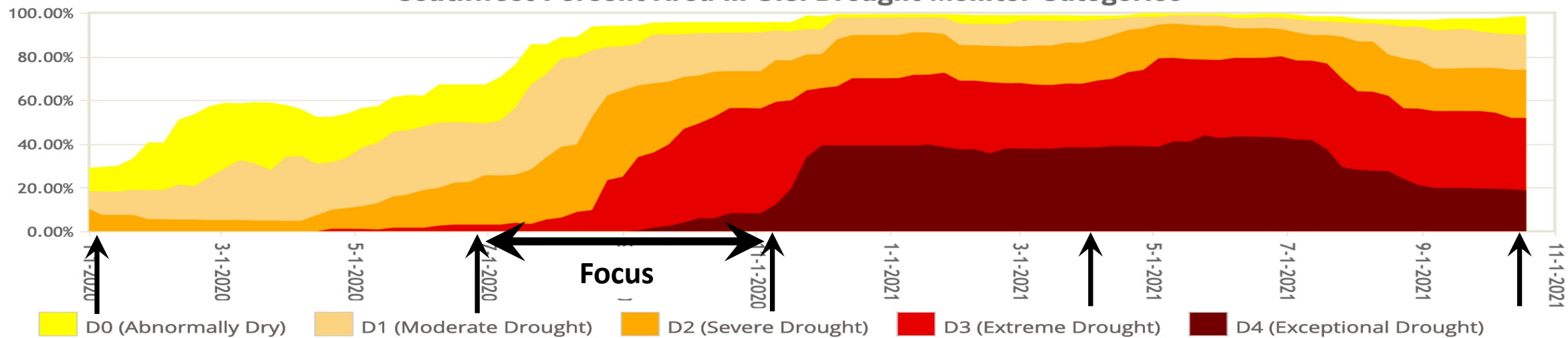
Southwest Percent Area in U.S. Drought Monitor Categories



U.S. Drought Monitor: Temporal Evolution

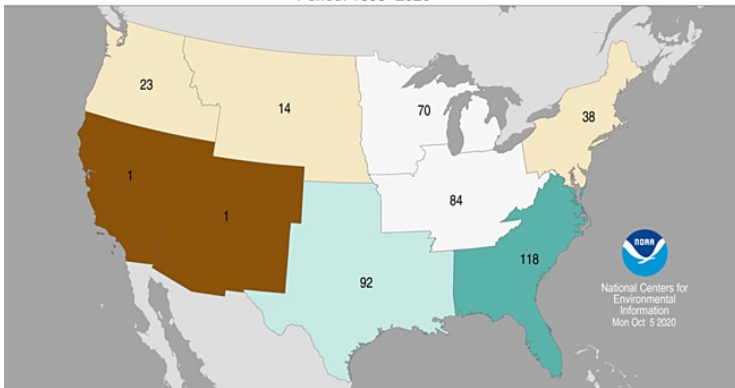


Southwest Percent Area in U.S. Drought Monitor Categories

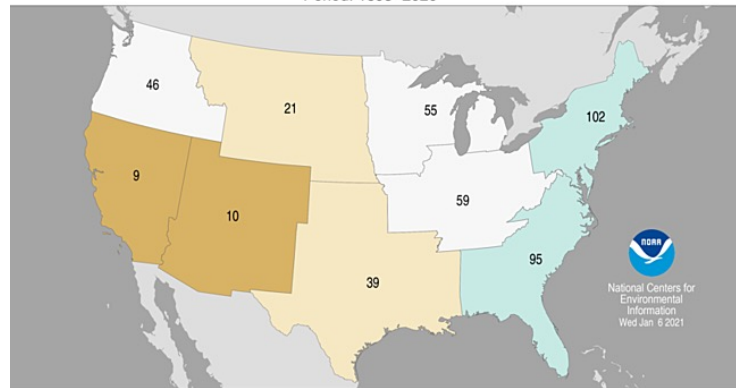


Precip and Temp Rank (relative to 1895-2020)

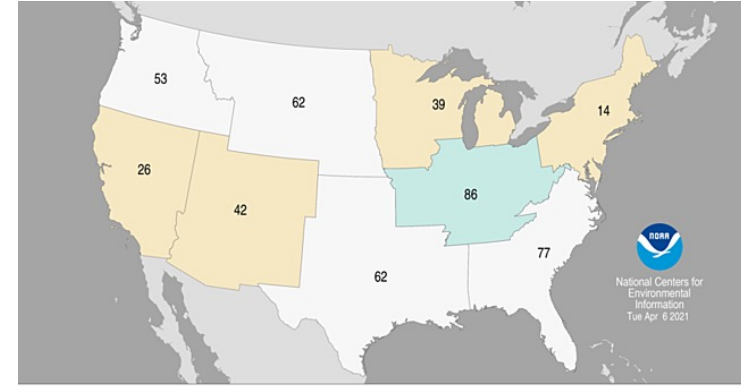
Jul-Sep 2020



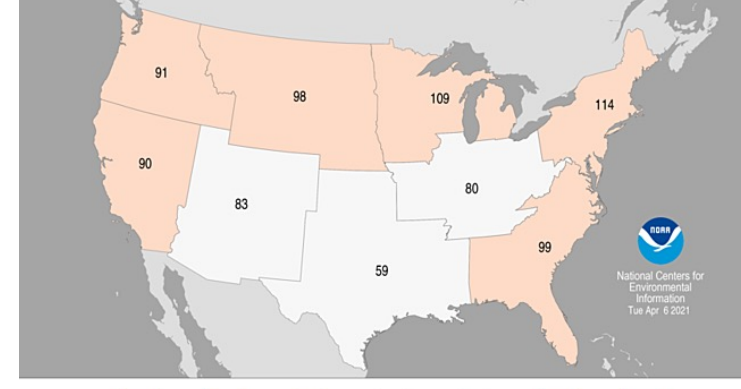
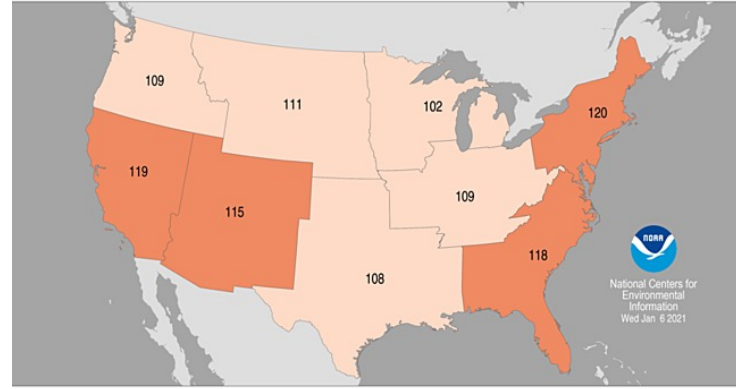
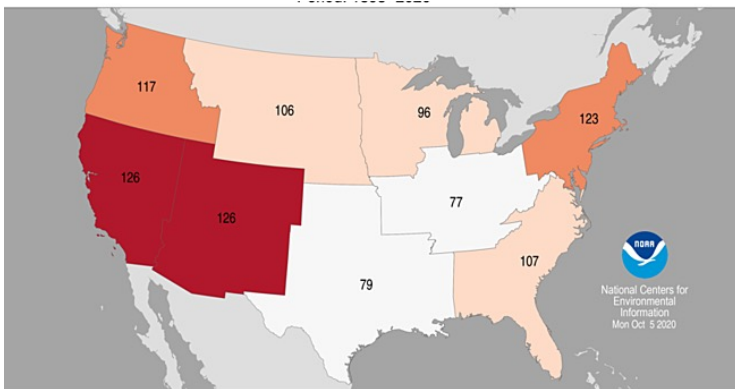
Oct-Dec 2020



Jan-Mar 2021



Precip



Temp



[://www.ncdc.noaa.gov/temp-and-precip/](http://www.ncdc.noaa.gov/temp-and-precip/)

US Southwest:

➤ *Jul-Sep 2020: record driest and warmest. Oct 2020-Mar 2021: below-average P and above-average T continued*

Effect of P and T Anomalies (Jul-Oct 2020) on Drought Evolvement

Objective: Assess the effect of observed P and T anomalies during Jul-Oct2020 on the concurrent and subsequent evolution of land surface anomalies

Model: VIC land surface model

Region of forcing variations: CONUS west of 94°W

Model output: focus on soil moisture percentile

VIC Experiments	P forcing Jul-Oct2020	T forcing Jul-Oct2020
PT_Anom (Control)	Obs	Obs
P_Anom	Obs	Clim
T_Anom	Clim	Obs
PT_Clim	Clim	Clim

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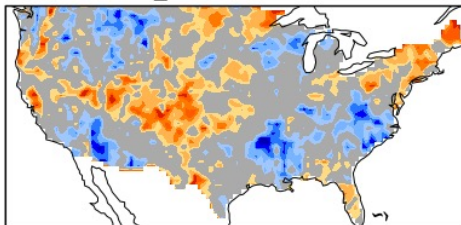
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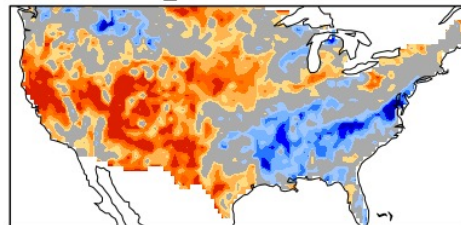
6/30/2020

PT_anom 30Jun2020



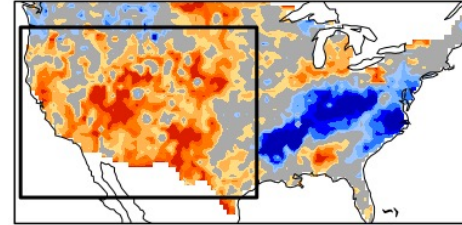
11/3/2020

PT_anom 3Nov2020



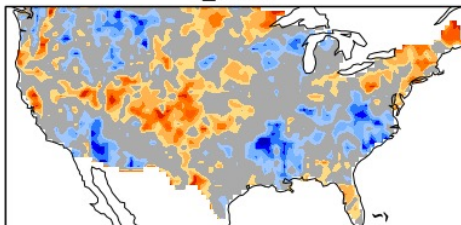
3/1/2021

PT_Anom 1Mar2021

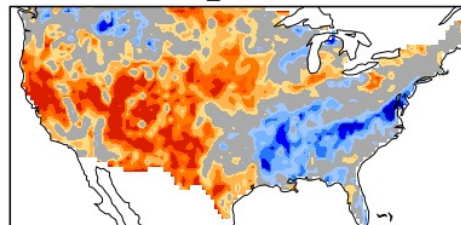


PT_Anom
(Control)

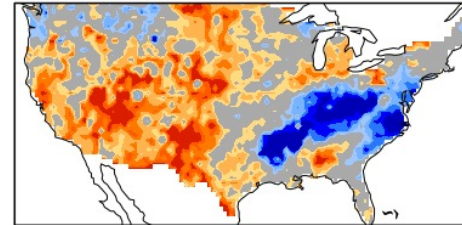
P_anom



P_anom



P_Anom



P_Anom

➤ The P deficits during Jul-Oct 2020 played a key role in rapidly drying local soil moisture, intensifying and shaping the southwest U.S. drought.

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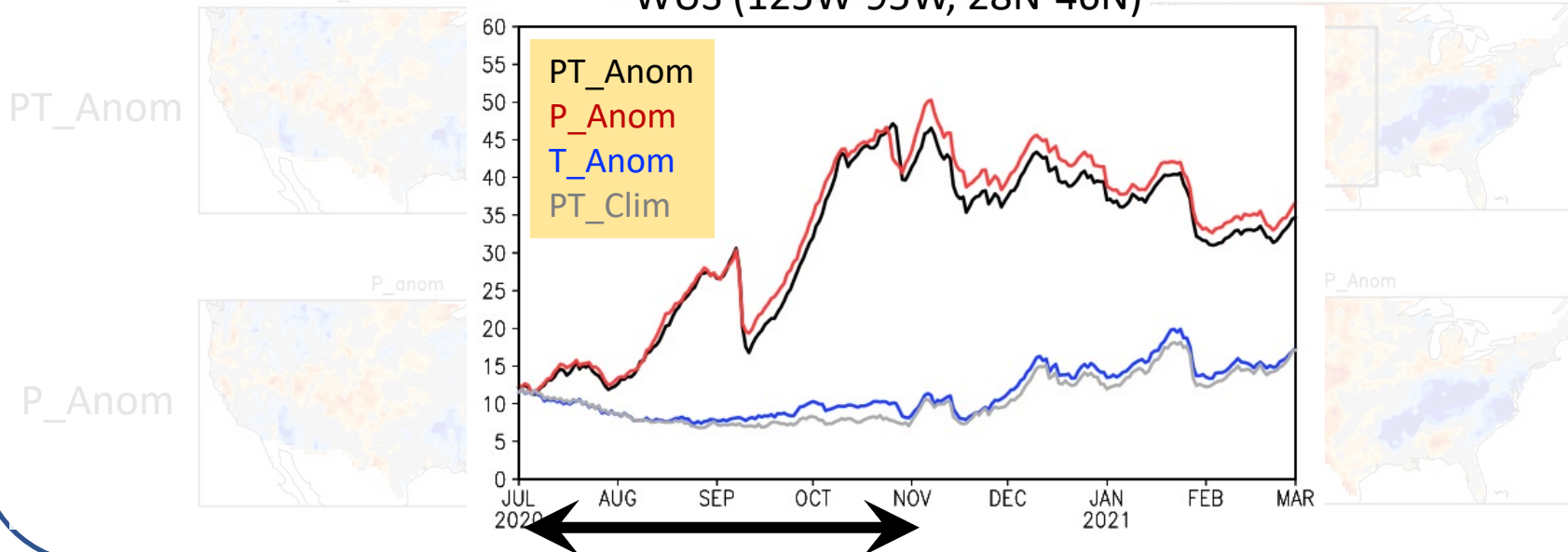
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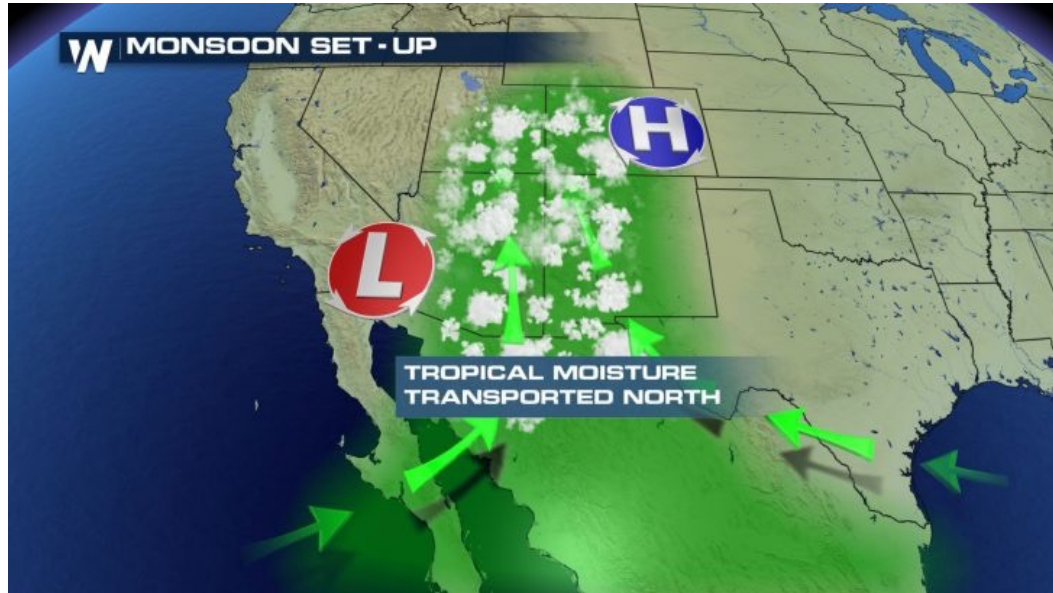
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6/30/2020 SMP-based D2-D4 ($\leq 10\%$) Percent Area WUS (125W-95W, 28N-46N) 3/1/2021



- The P deficits during Jul-Oct 2020 played a key role in rapidly drying local soil moisture, intensifying and shaping the southwest U.S. drought.
- The effect of T warming is overall modest.

North American Monsoon: JAS2020



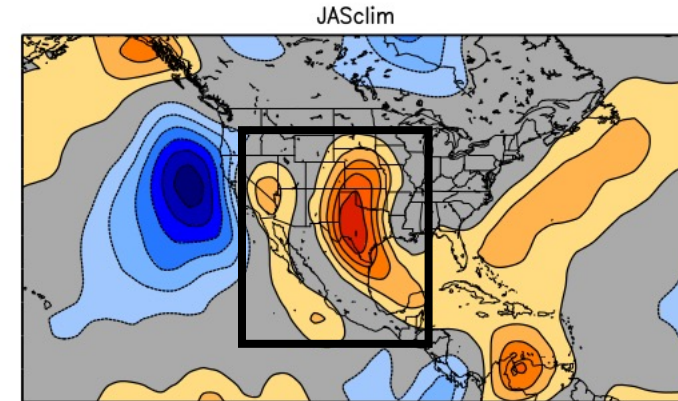
Climatologically, the North American monsoon in CONUS:

- runs from July through September each year,
- is characterized by a shift in the prevailing wind direction.

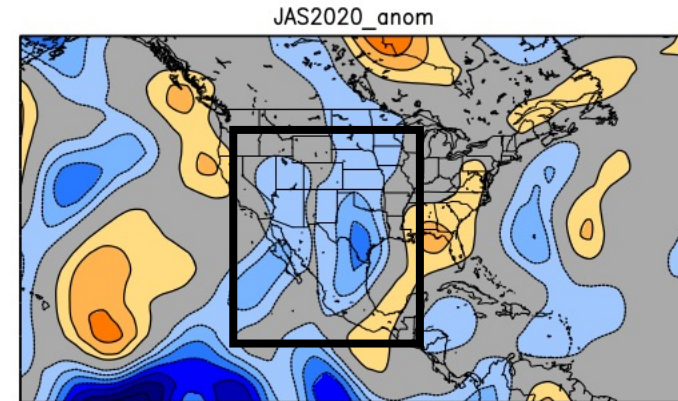
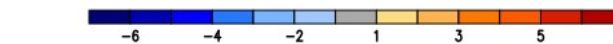
2020 monsoon:

- Features substantially weakened southerlies and reduced northward inland moisture transport to the southwest U.S.
- Circulation anomalies largely maintained by diabatic heating anomalies

NCEP/NCAR Reanalysis: V850mb



JAS_Clim



JAS2020_Anom



Q: Which regional heating anomalies are most effective in driving the JAS2020 weakened low-level southerly in the monsoon region?

Optimal Forcing Pattern Analysis (*Heating*): JAS

Tool: Stationary Wave Model (SWM)

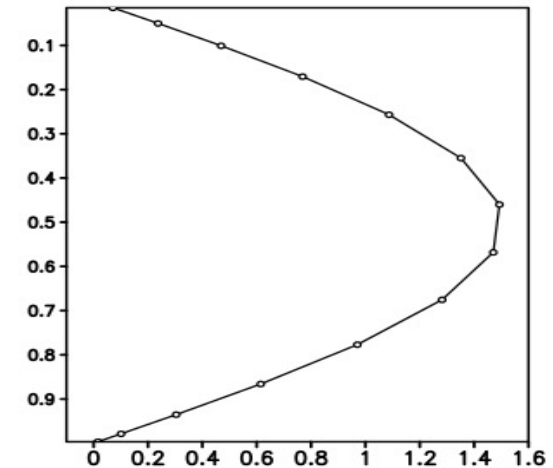
Forcing: Idealized latent heating anomalies

- Width (20lon, 10lat), peak (1.5K) in the middle troposphere

Experiment: Consists of 1188 (36x33) SWM runs, forced with an idealized heating anomaly imposed every 10 longitudes and 5 latitudes across the globe

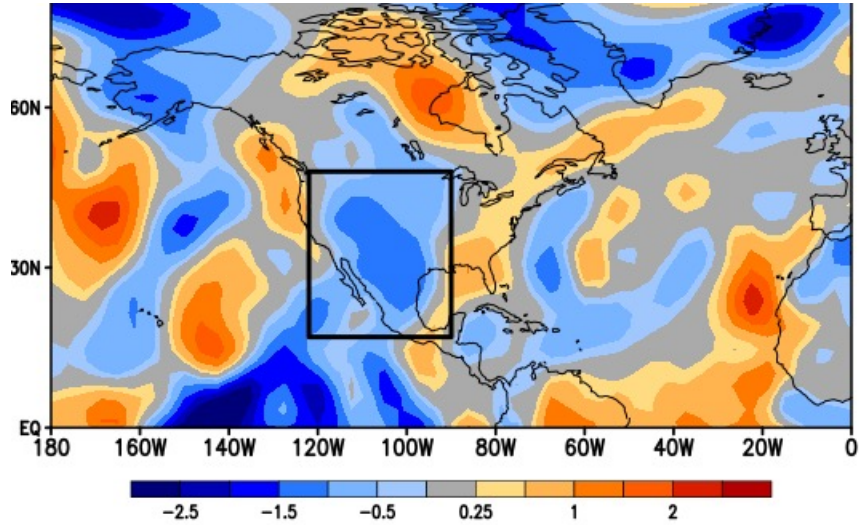
Calculation: Compute inner product between the SWM response and circulation anomaly of interest, and place it at the heating location (Schubert et al. 2011)

Vertical profile of the idealized heating anomaly

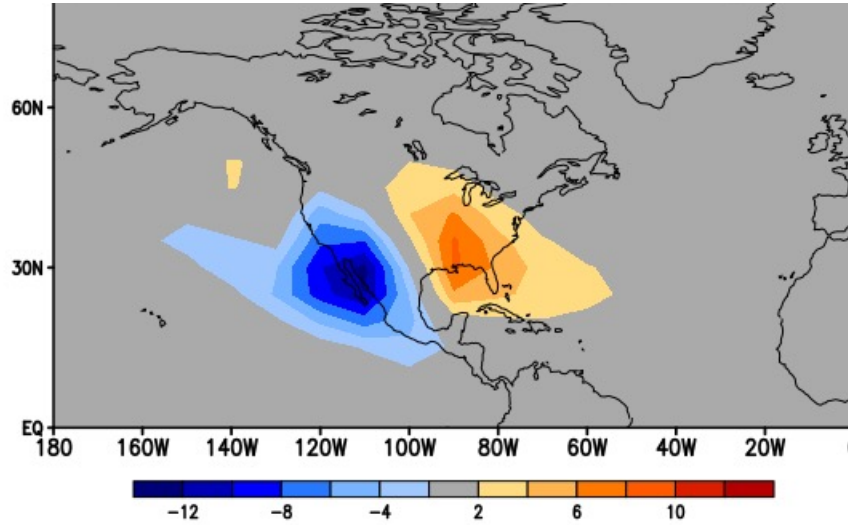


Optimal Forcing Pattern Analysis (*Heating*): JAS

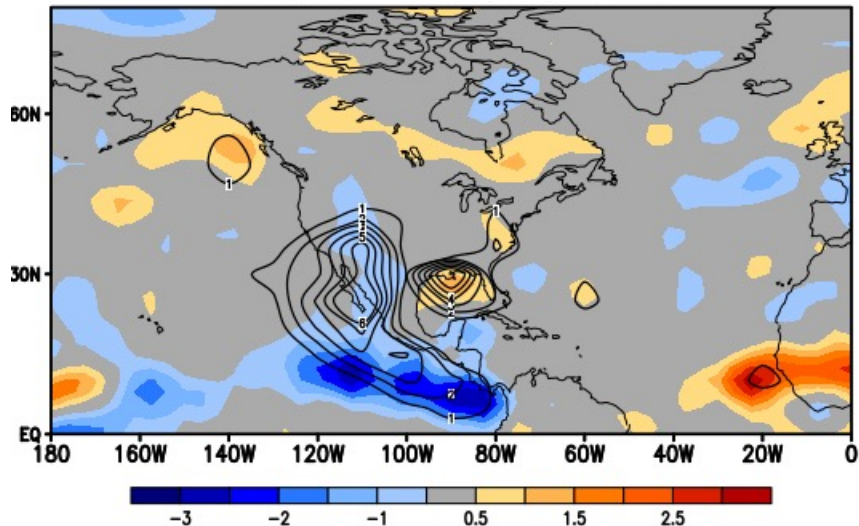
(a) R1: low-level eddy Vwind



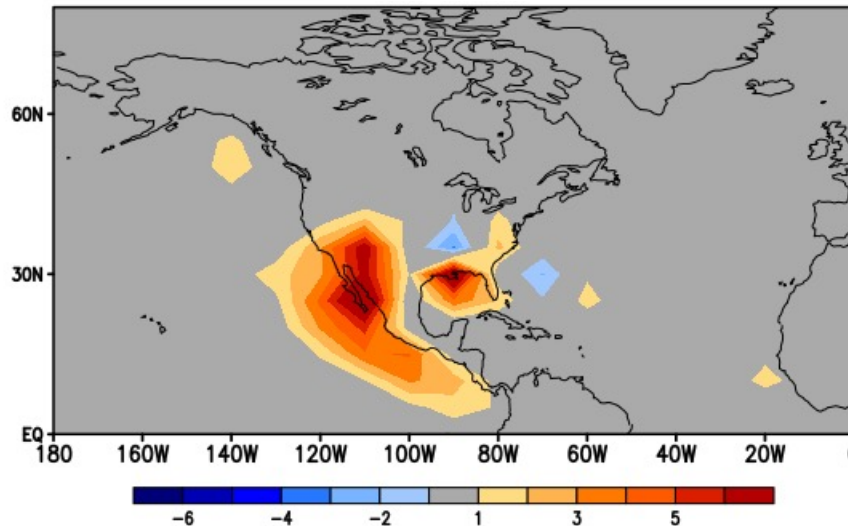
(b) Optimal forcing pattern for (a)



(c) Residual heating (mid-troposphere)

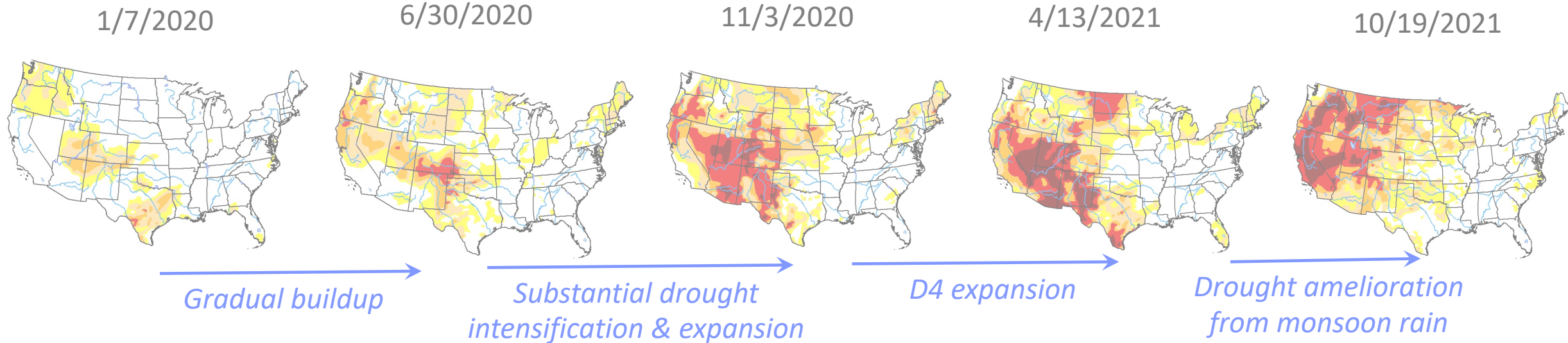


(d) (b)x(c)

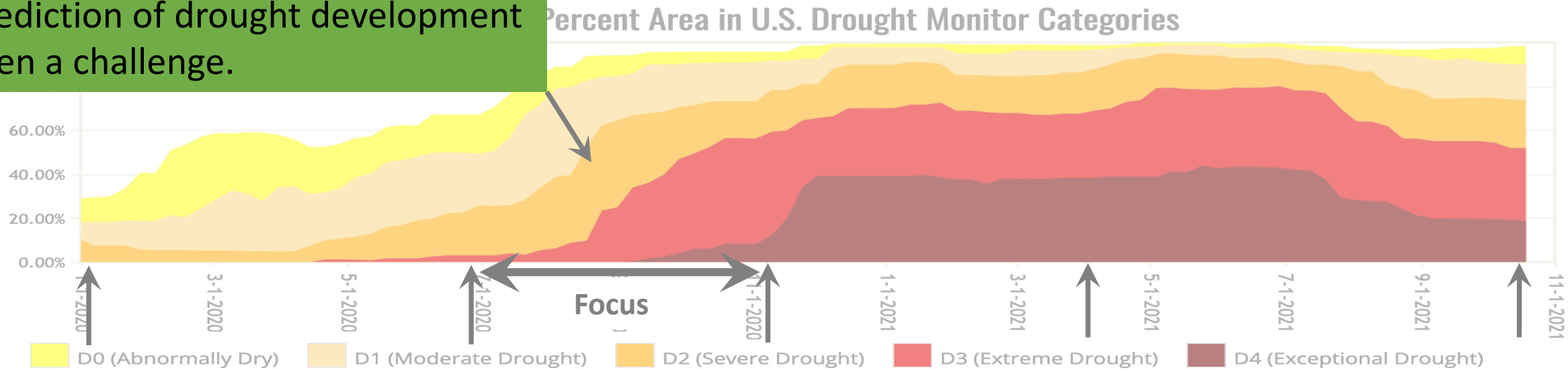


- Effective heating anomalies:
- coolings in the monsoon region & eastern tropical Pacific
 - heatings in the Gulf of Mexico

Drought Prediction and Predictability



The prediction of drought development has been a challenge.



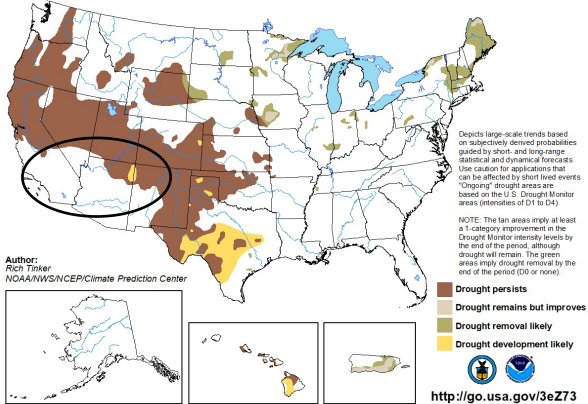
Drought Prediction and Predictability: CPC Seasonal Drought Outlook (SDO)

SDO: Aug-Oct 2020

Outlook

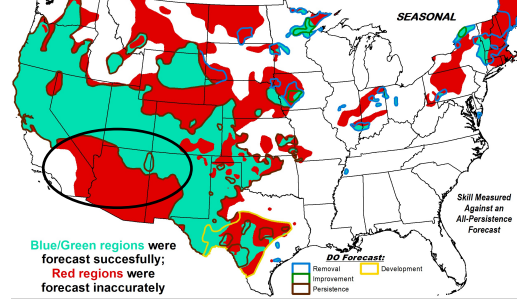
U.S. Seasonal Drought Outlook Drought Tendency During the Valid Period

Valid for July 16 - October 31, 2020
Released July 16



Verification Score: 47.8%

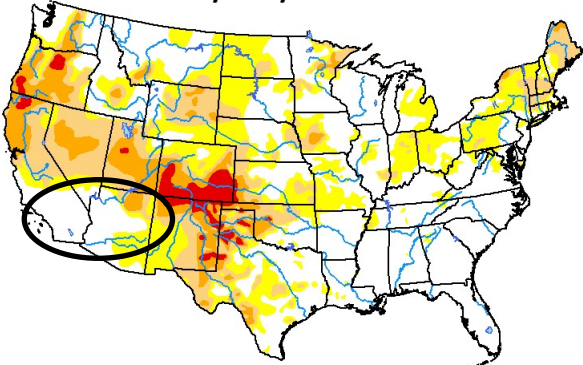
DROUGHT OUTLOOK VERIFICATION: Drought Monitor Change Jul 14, 2020 to Oct 27, 2020 (ASO 2020 Drought Outlook)



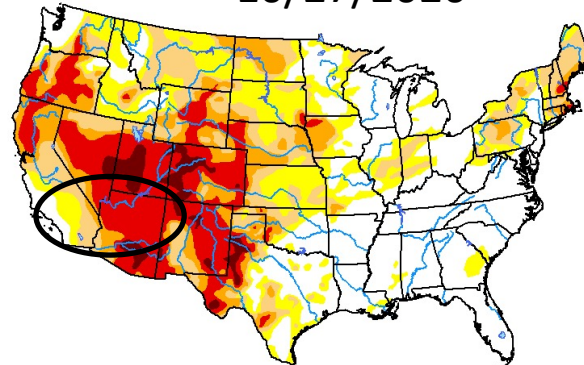
Blue/Green regions were forecast successfully;
Red regions were forecast inaccurately

U.S. Drought Monitor

7/14/2020



10/27/2020



CPC Seasonal Drought Outlook (SDO)

- Shows drought tendency
 - 4 categories: persist, remain but improve, develop, remove
- Production
 - Initialized using the most recent USDM
 - Produced by integrating dynamical forecasts, climatologies and analogs, and feedback from stakeholders
- Verification
 - Compare SDO with U.S. drought monitor changes

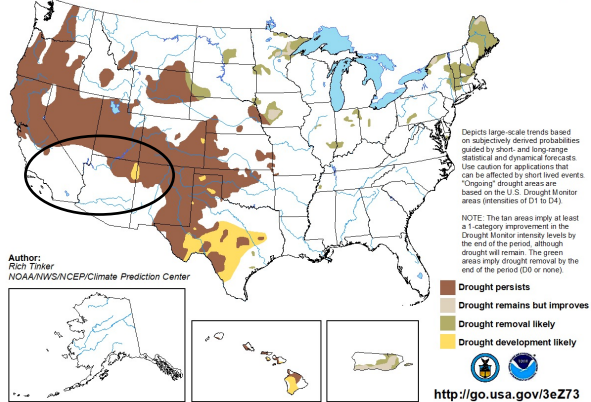
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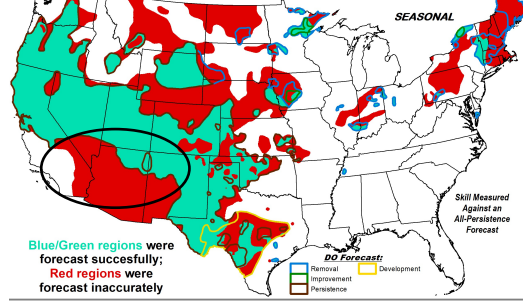
U.S. Seasonal Drought Outlook
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DROUGHT OUTLOOK VERIFICATION: Drought Monitor Change
Jul 14, 2020 to Oct 27, 2020 (ASO 2020 Drought Outlook)



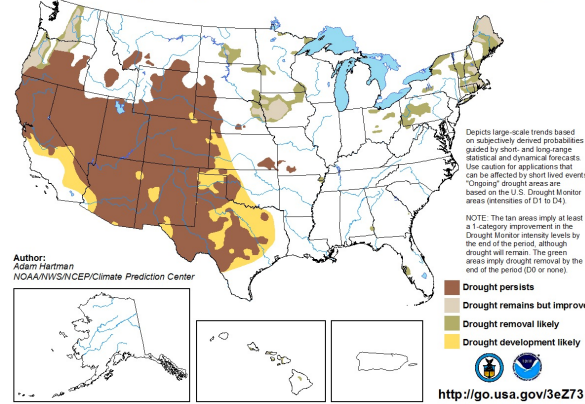
Forecast successfully
Forecast inaccurately

SDO: Sep-Nov 2020

Outlook

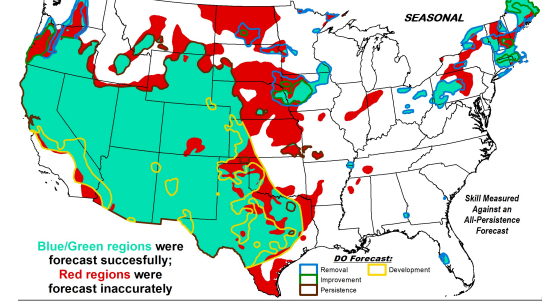
U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period

Valid for August 20 - November 30, 2020
Released August 20



Verification
Score: 67.0%

DROUGHT OUTLOOK VERIFICATION: Drought Monitor Change
Aug 18, 2020 to Dec 01, 2020 (SON 2020 Drought Outlook)

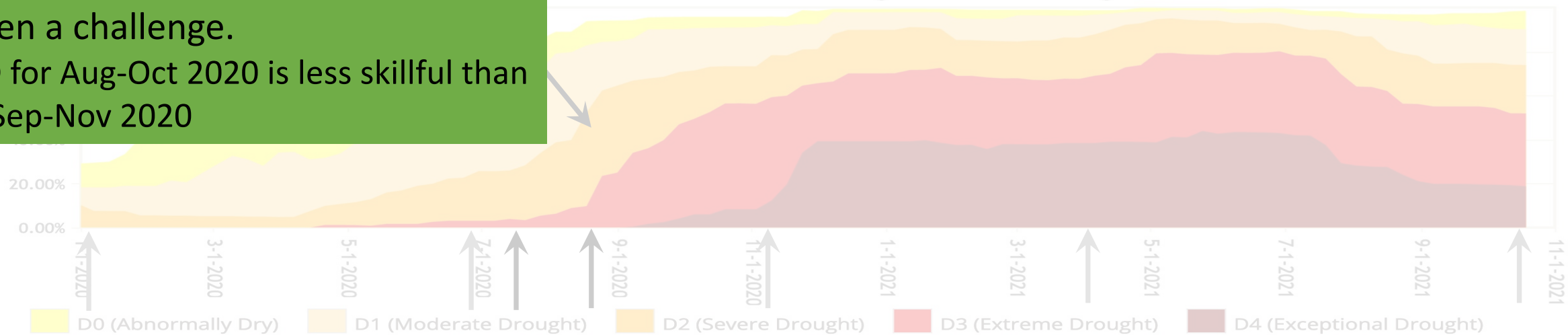


Forecast successfully
Forecast inaccurately

The prediction of drought development has been a challenge.

➤ SDO for Aug-Oct 2020 is less skillful than for Sep-Nov 2020

Percent Area in U.S. Drought Monitor Categories



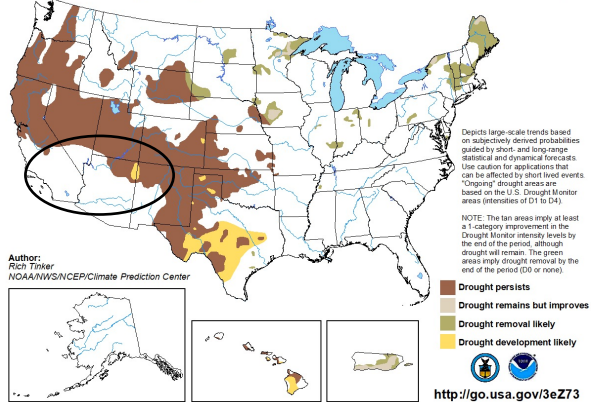
Drought Prediction and Predictability: CPC Seasonal Drought Outlook (SDO)

SDO: Aug-Oct 2020

Outlook

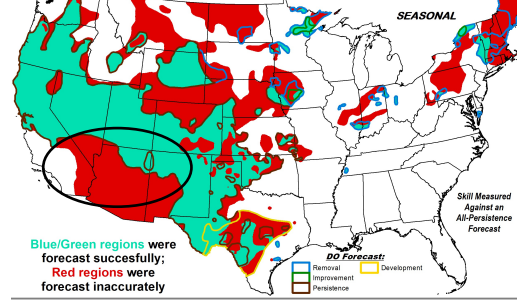
U.S. Seasonal Drought Outlook
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DROUGHT OUTLOOK VERIFICATION: Drought Monitor Change
Jul 14, 2020 to Oct 27, 2020 (ASO 2020 Drought Outlook)



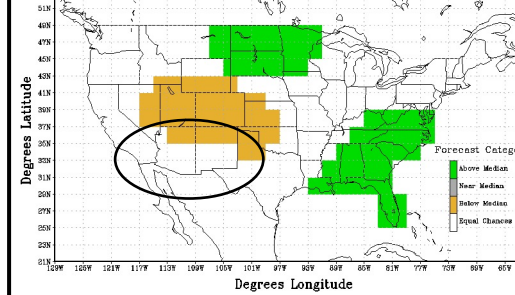
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Forecast successfully
Forecast inaccurately

Precip Outlook: Aug-Oct 2020

Outlook

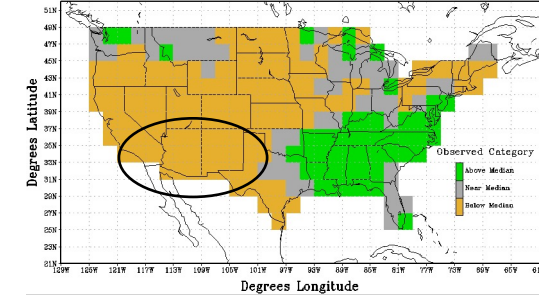
Categorical Precipitation Official Forecast
Issued: Jul 2020 Valid: Aug-Sep-Oct 2020



Categorical: Above Median, Near Median, Below Median

Observations

Categorical Precipitation Observations
Valid: Aug-Sep-Oct 2020



The limited forecast skill in AZ and NM:

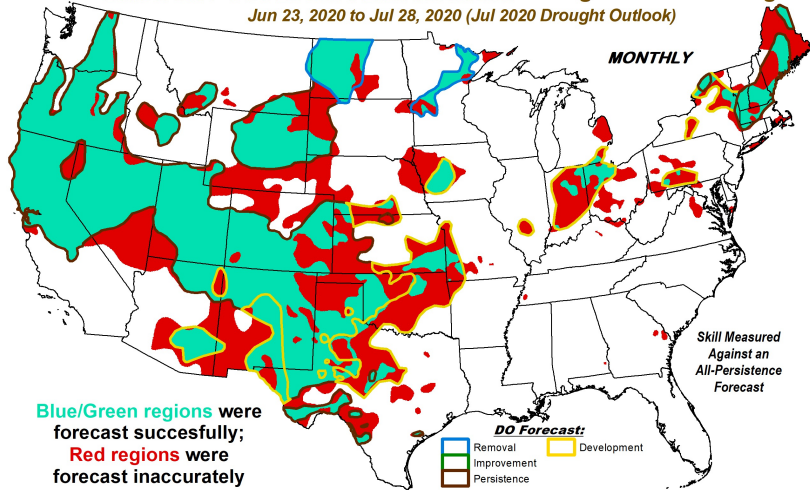
- Inherently limited predictability of North American monsoon rainfall variability at seasonal lead time?
- Forecast tools?
 - Example: dynamical forecast models

Drought Prediction and Predictability: CPC Drought Outlooks

Monthly Drought Outlook

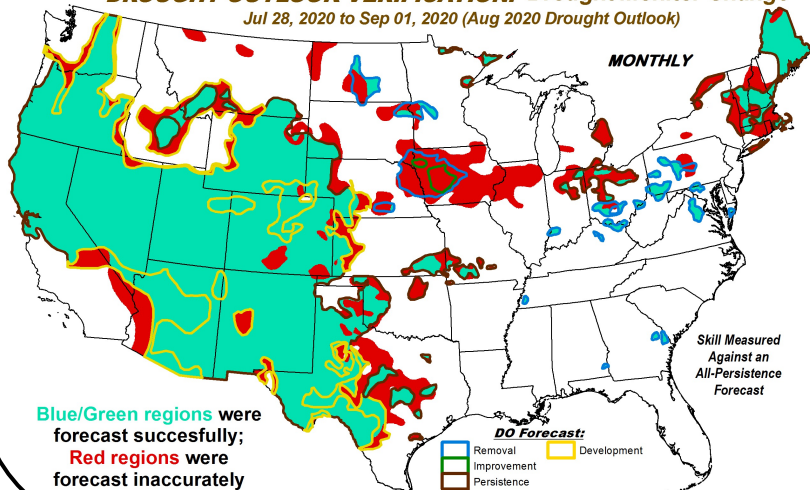
Jul2020 (Score: 58.5%)

DROUGHT OUTLOOK VERIFICATION: Drought Monitor Change
Jun 23, 2020 to Jul 28, 2020 (Jul 2020 Drought Outlook)



Aug2020 (Score: 73.1%)

DROUGHT OUTLOOK VERIFICATION: Drought Monitor Change
Jul 28, 2020 to Sep 01, 2020 (Aug 2020 Drought Outlook)



Users may consider:

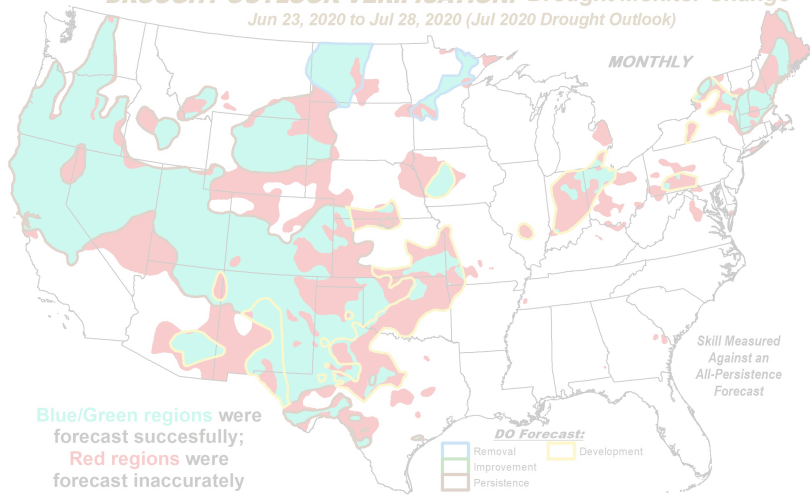
- **DOs at shorter lead time**, where Monthly Drought Outlooks (MDOs) have generally higher forecast skills

Drought Prediction and Predictability: CPC Drought Outlooks

Monthly Drought Outlook

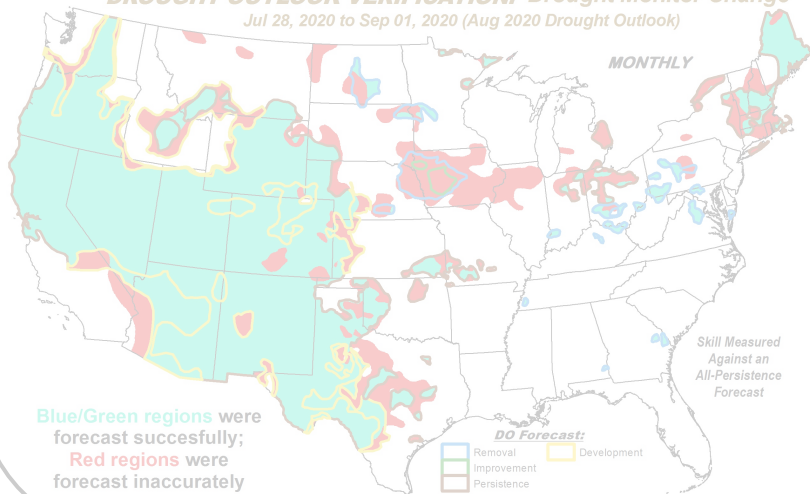
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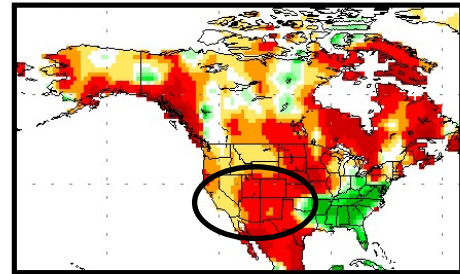


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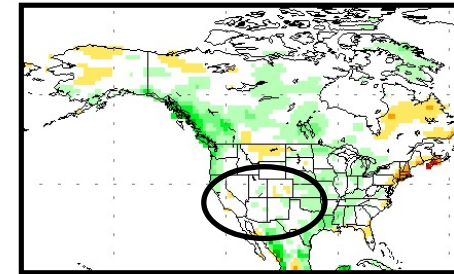
CFSv2 forecasts: ASO2020 Precip

Obs



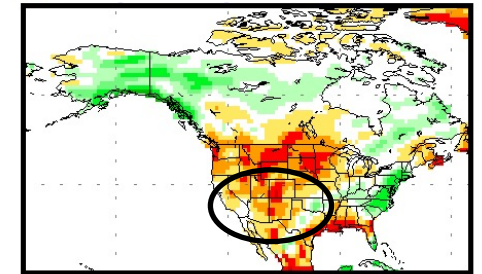
150W 120W 90W 60W

Seasonal Forecast

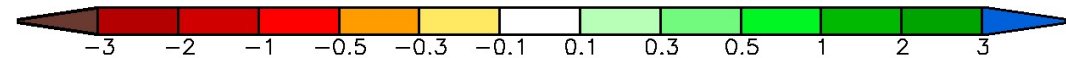


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Monthly Forecast



150W 120W 90W 60W



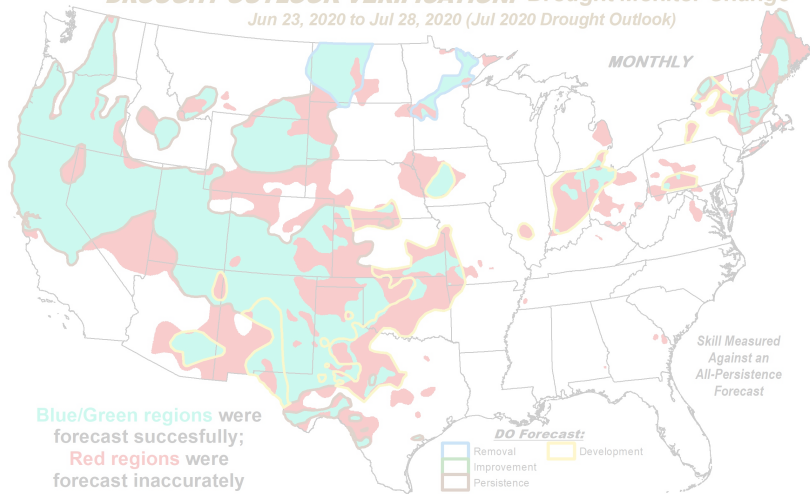
- Middle:** ASO2020 **seasonal** forecast based on 40 members from the last 10 days of July 2020 initial conditions (ICs)
- Right:** Average of **monthly** Aug/Sep/Oct 2020 forecasts from the last 10 days of Jul/Aug/Sep 2020 ICs; has more contribution from ICs

Drought Prediction and Predictability: CPC Drought Outlooks

Monthly Drought Outlook

Jul2020 (Score: 58.5%)

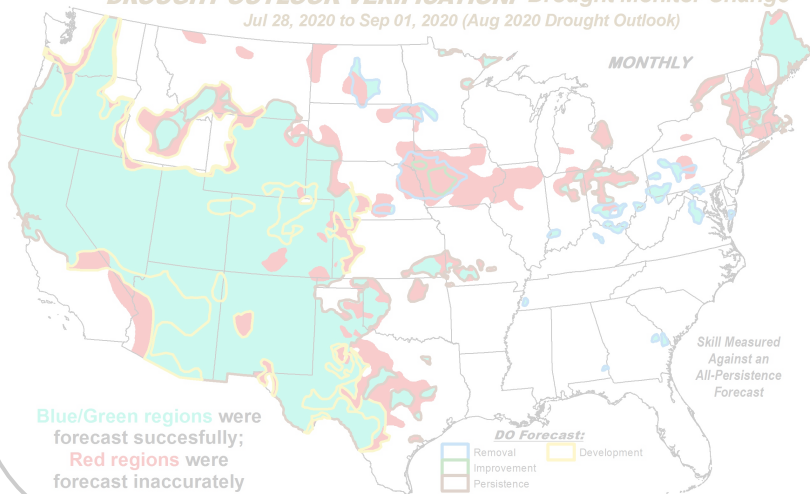
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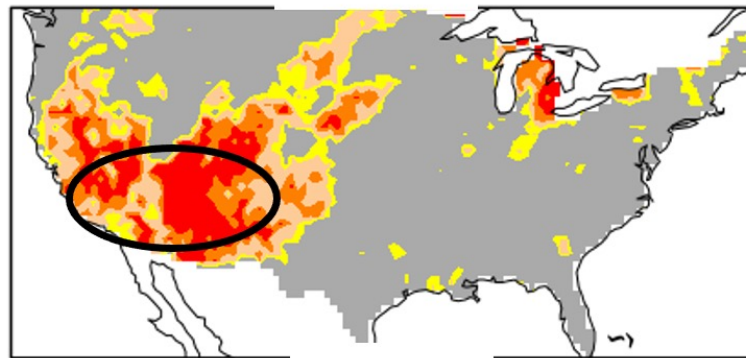
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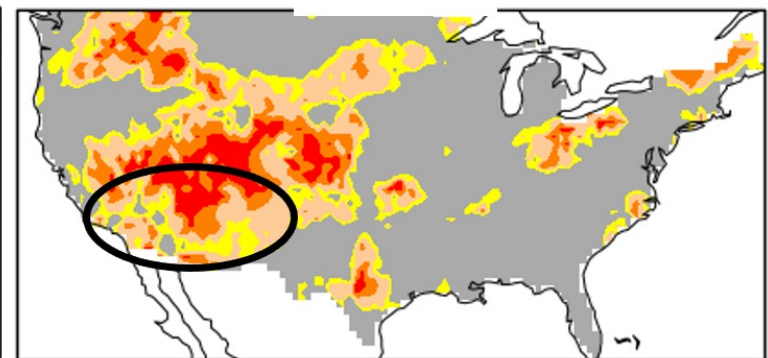
- DOs at shorter lead time, where Monthly Drought Outlooks (MDOs) have generally higher forecast skills
- **probabilistic drought outlooks**, which are under development at CPC
 - The probability of capturing observed drought development in AZ and NM is low but not zero

Initial Condition: 1Jul2020; Short-term Drought Forecast for Oct2020

Ens06



Ens08



- Average of SPI3, SMP and SRI3 in percentiles
- **NMME GFDL SPEAR: 2 out of the 15 members capture the obs.**

Summary

- **The 2020-21 Southwest U.S. drought is unprecedented in the USDM record**
 - The rapid drought development during Jul-Oct 2020 helped shape the drought
- **Causes**
 - **JAS2020**: lack of North American monsoon rainfall
 - Record driest and warmest conditions in the southwest U.S.
 - The considerably weakened southerlies in the monsoon region are maintained by heating anomalies in the monsoon and nearby regions and transients in the northeastern Pacific
 - **Subsequent months**: drought persisted due to below-average P and above-average T
- **Prediction**
 - The prediction of drought development is a main challenge
 - The limited forecast skill for drought development results from the challenge in predicting the JAS2020 precipitation deficits, which are likely due to the inherently limited predictability of North American monsoon rainfall at seasonal lead time
 - The forecast challenge can be in part remedied by considering
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