Colorado River Drought, Past, Present, and Future

The Precipitation Story

Coda: Importance of (changing) boundary forcing for Subseasonal Predictability

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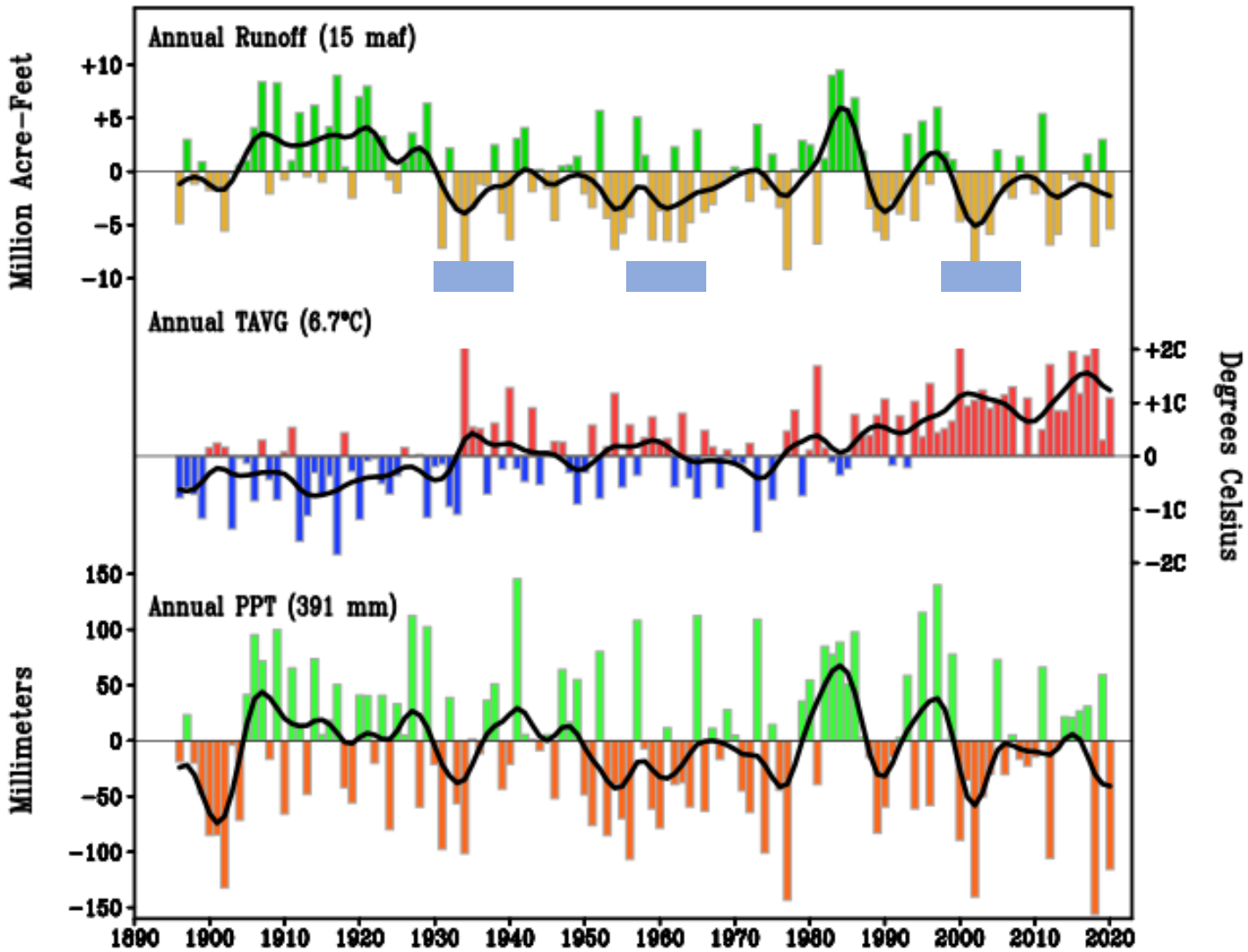
Western States Water Council S2S Prediction Workshop, May 17-19, 2022

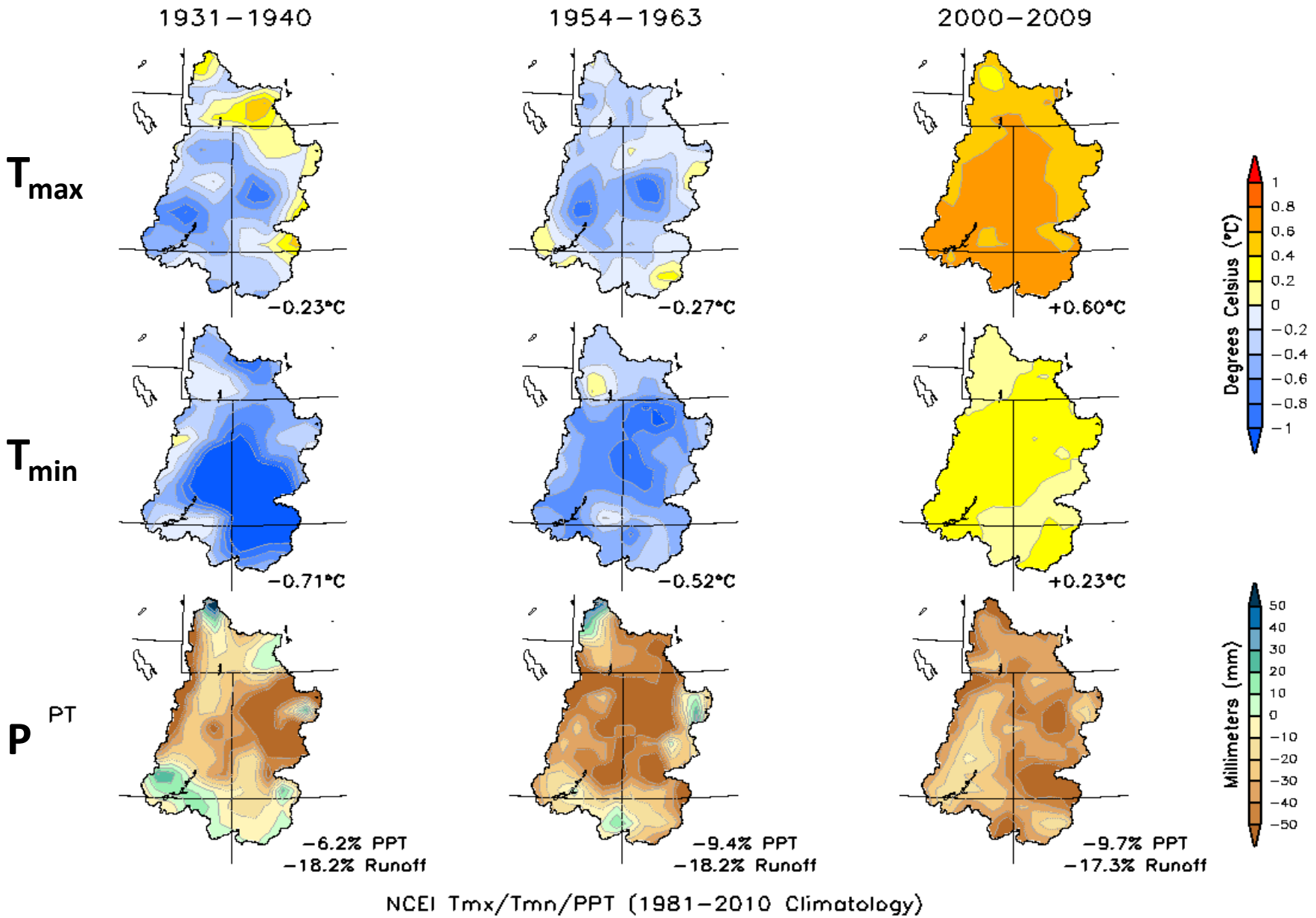
Goals:

- To provide some context for climatic changes in the Upper Colorado River Basin and in the West
- To highlight the potential role of forced precipitation changes
- To motivate discussion about the robustness of S2S predictions going into the future

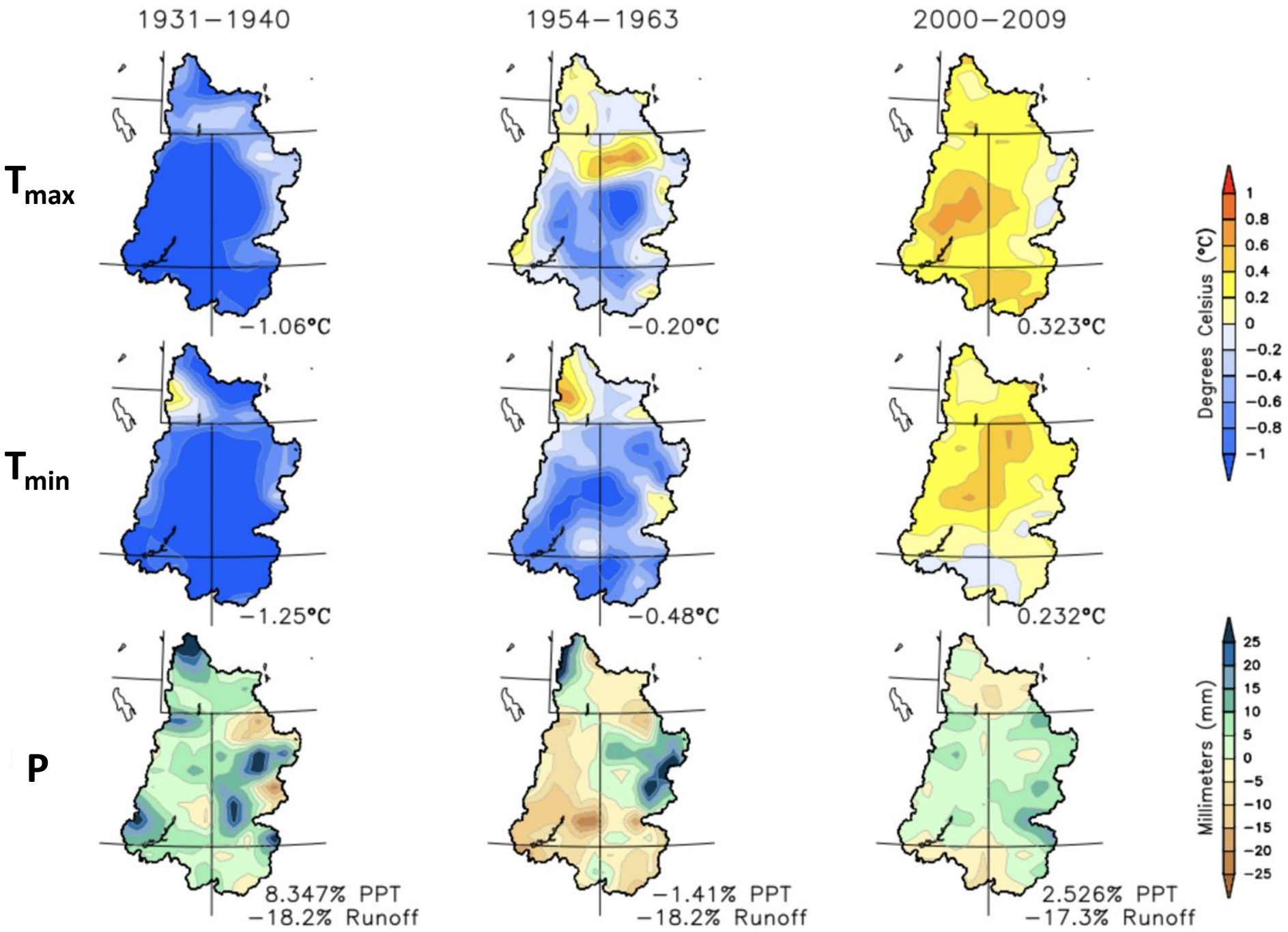
Upper Colorado River



UCRB Droughts: Past

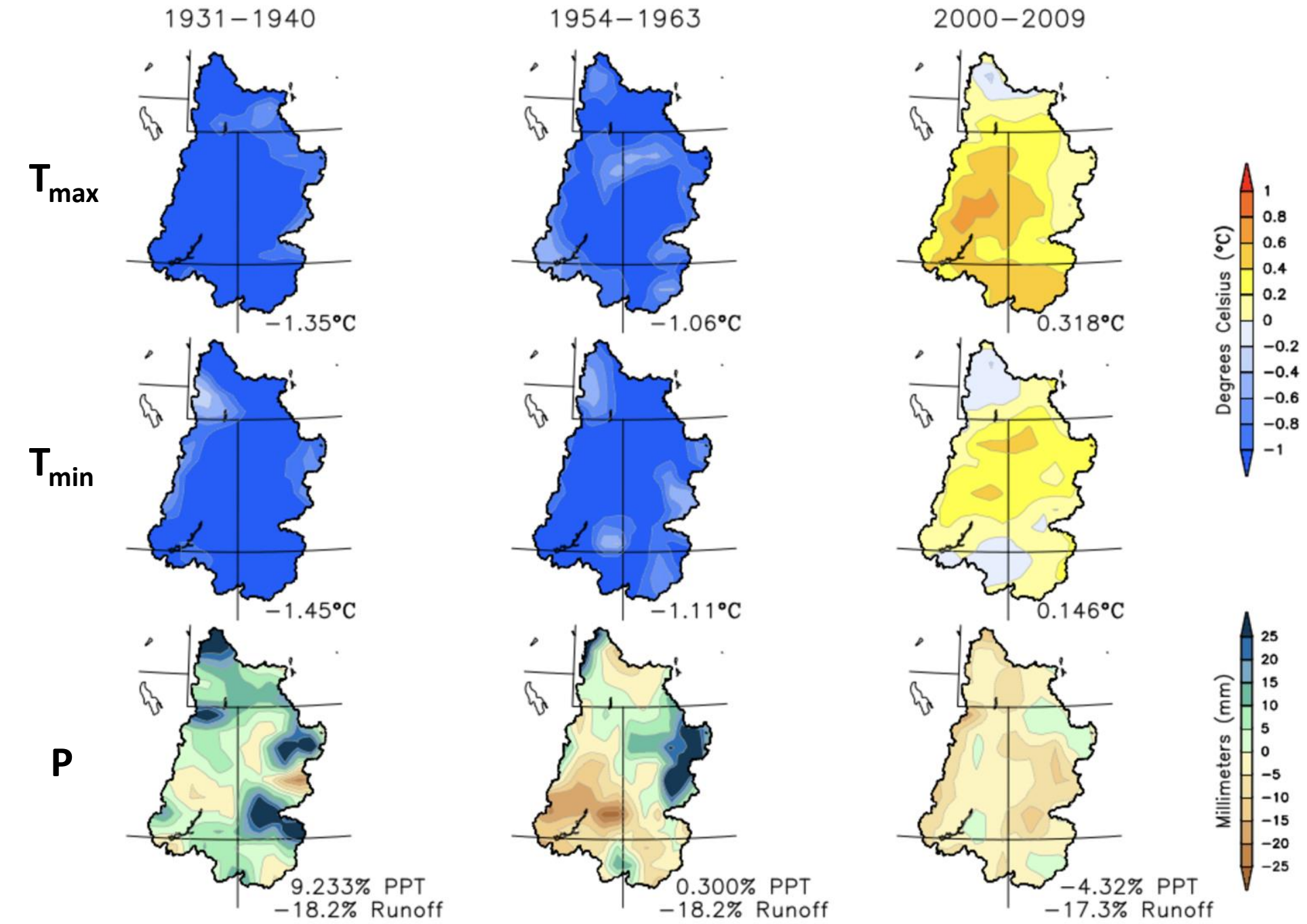


DJF



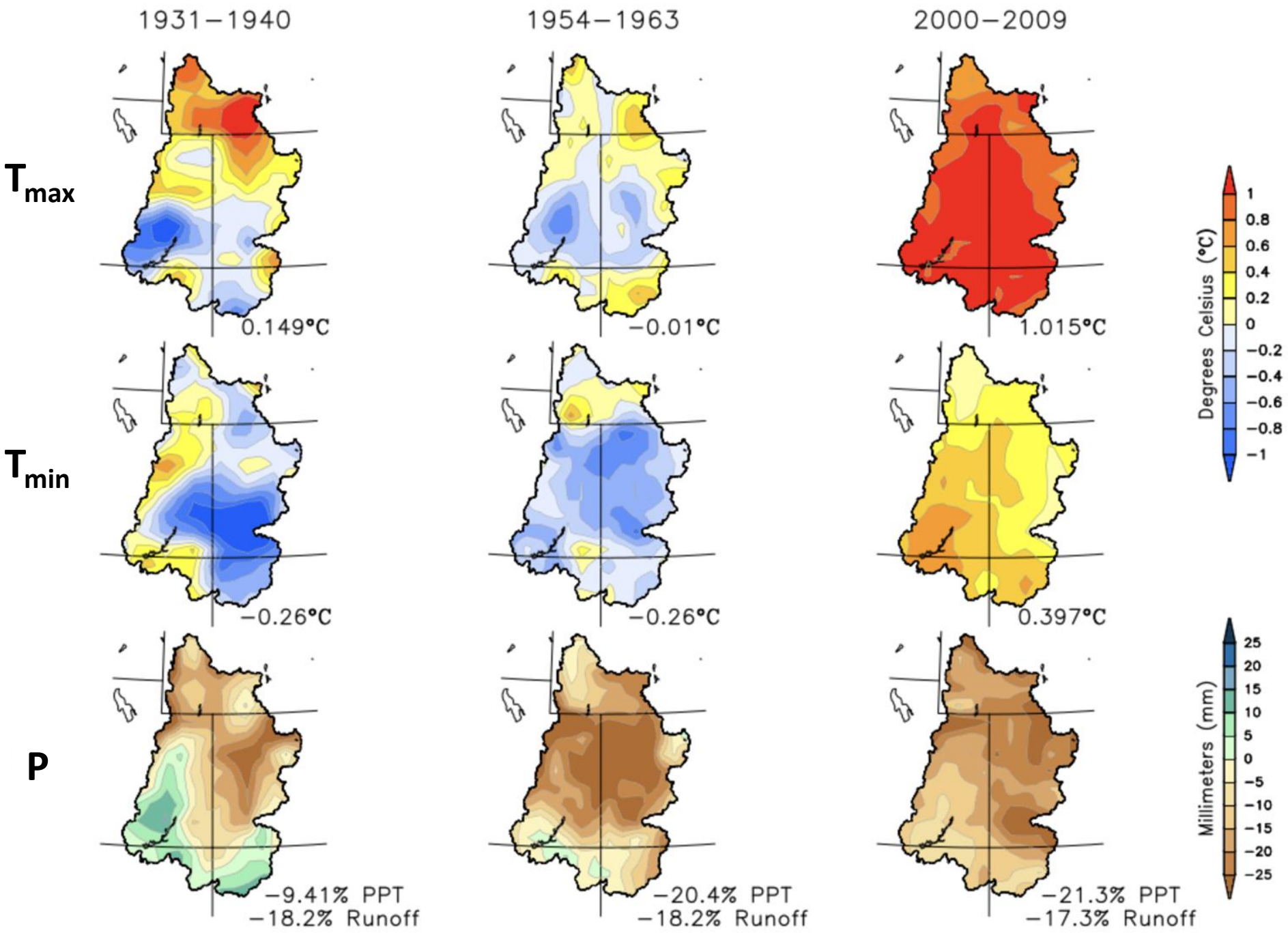
DJF NCEI Tmx/Tmn/PPT (1981–2010 Climatology)

JFM



JFM NCEI Tmx/Tmn/PPT (1981–2010 Climatology)

MJJ



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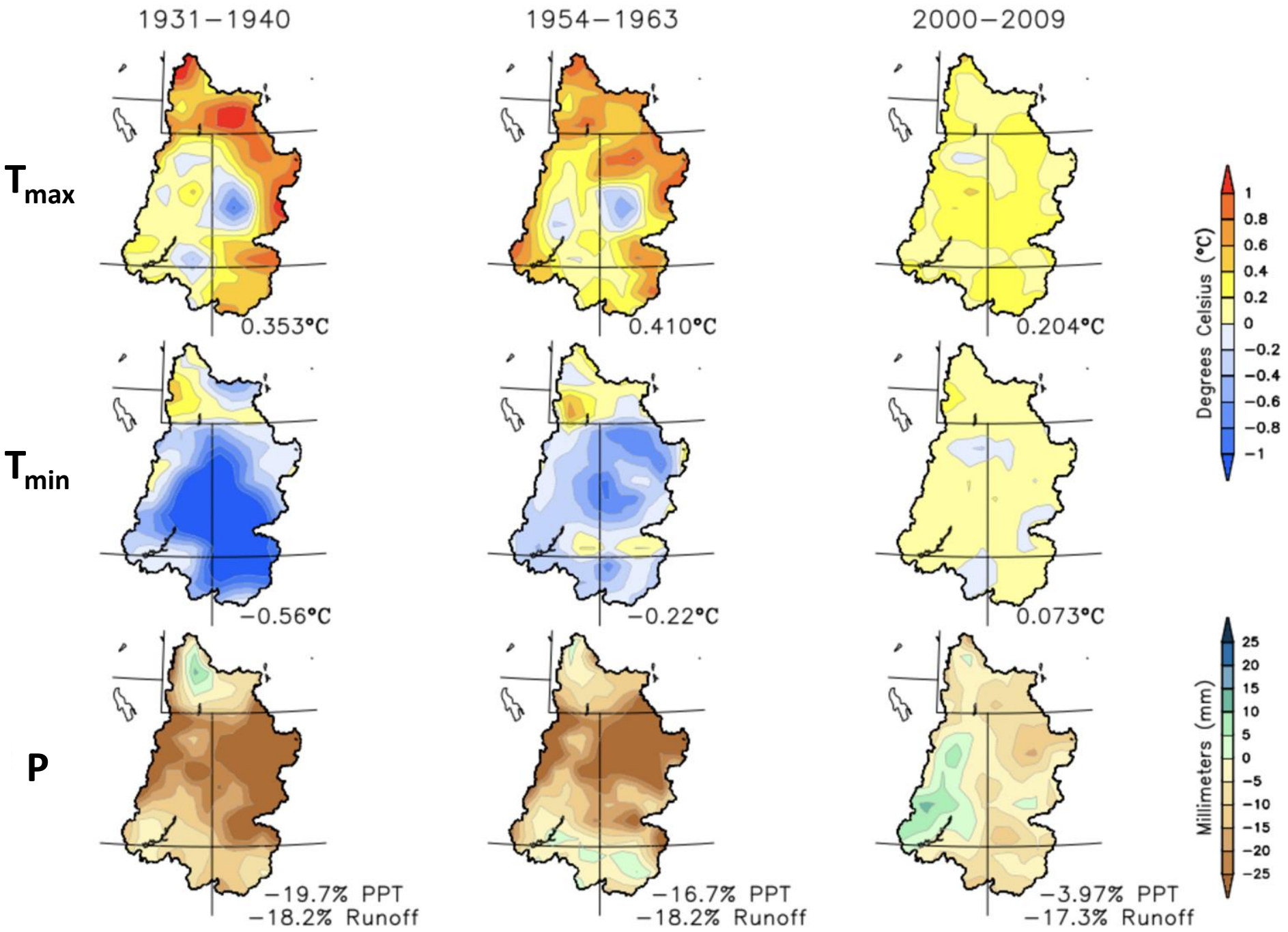
OND



OND NCEI Tmx/Tmn/PPT (1981–2010 Climatology)

Droughts: Past

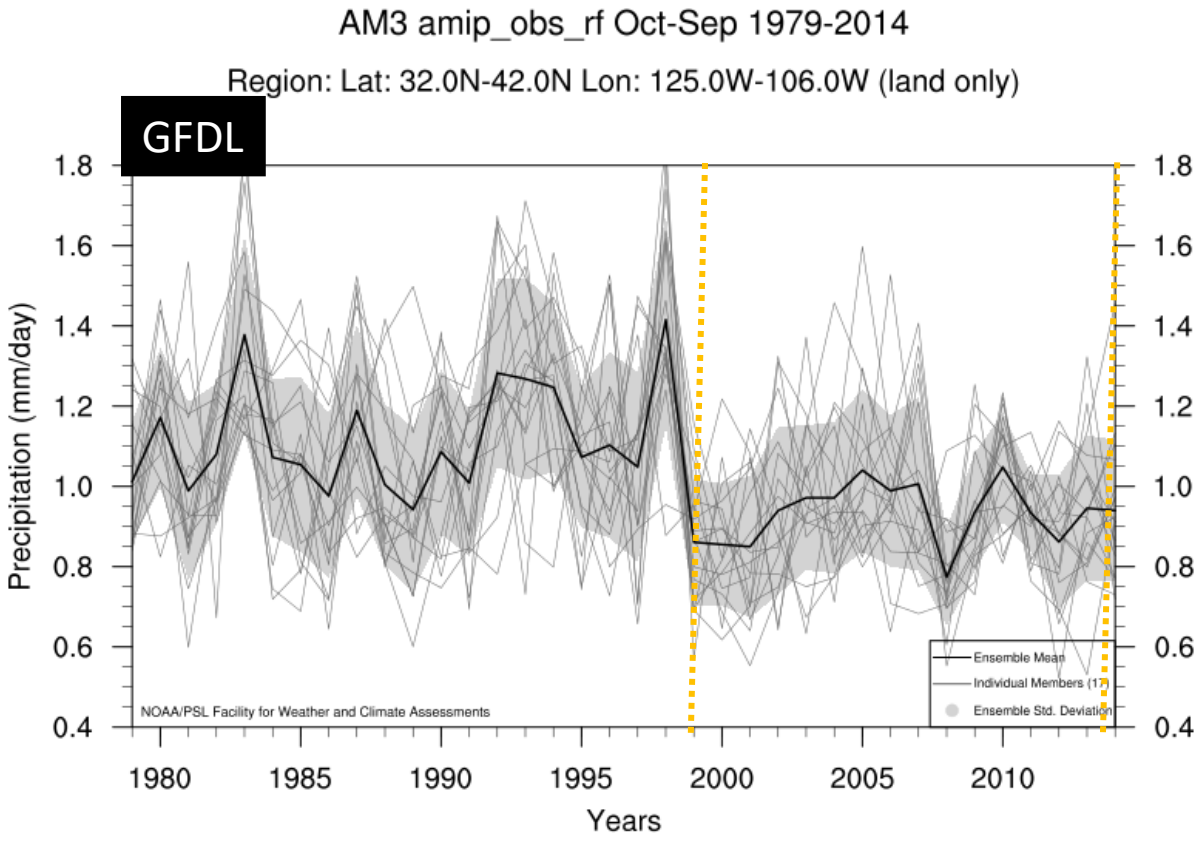
- These past decadal (hydrologic) droughts were characterized by shoulder season and warm season precipitation deficits

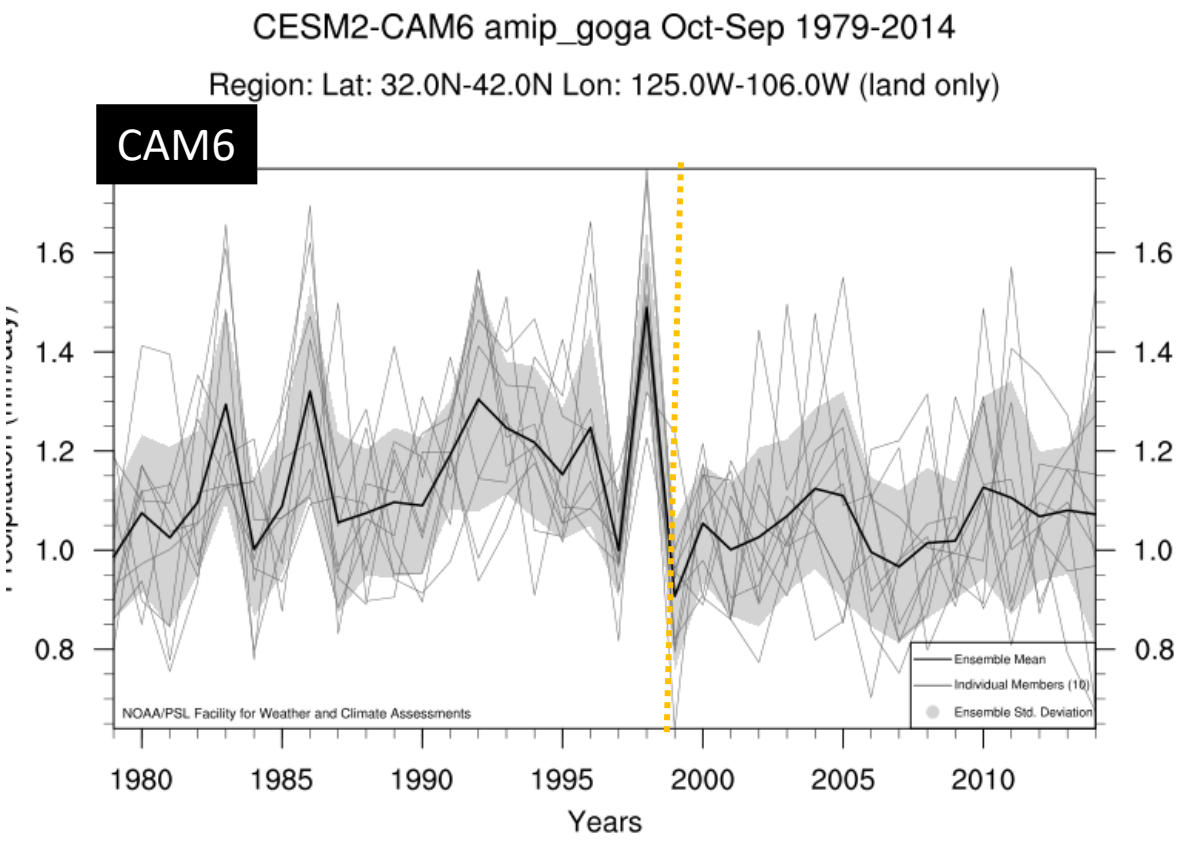
- We are pretty sure that the 1930's and 1950's droughts were driven mainly by a precipitation deficit (there was little "forced" temperature anomaly), but what about the 2000's drought?

Drought: present

- Post 2000 drought
- “Southwest” perspective: 32N – 42N, Pacific Coast to 106W
- Use Atmosphere models forced by “boundary conditions” of the historical SSTs, Sea Ice, GHGs, other drivers* (AMIP)
- Use “Large Ensembles” to separate the forced signal from intrinsic atmospheric variability

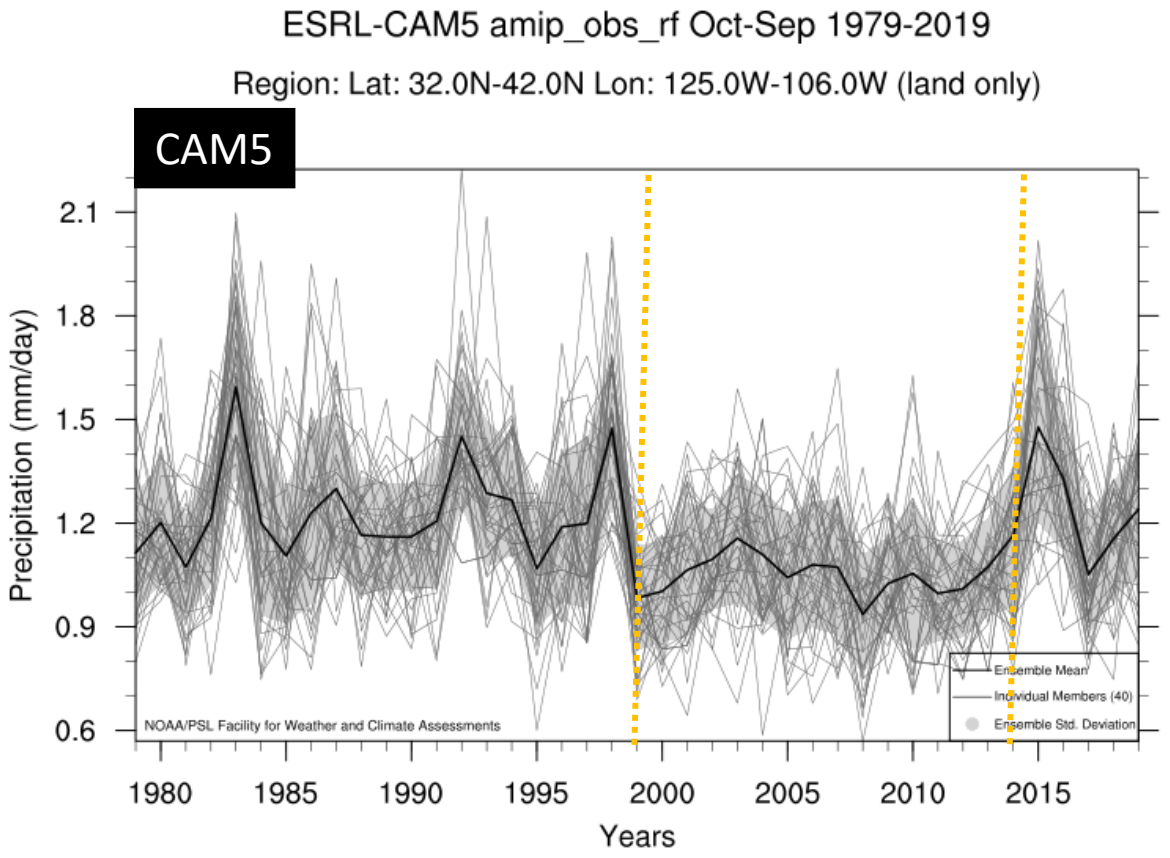
AMIP Simulated Western US Water-Yr Pcpn Time Series 1979-2014

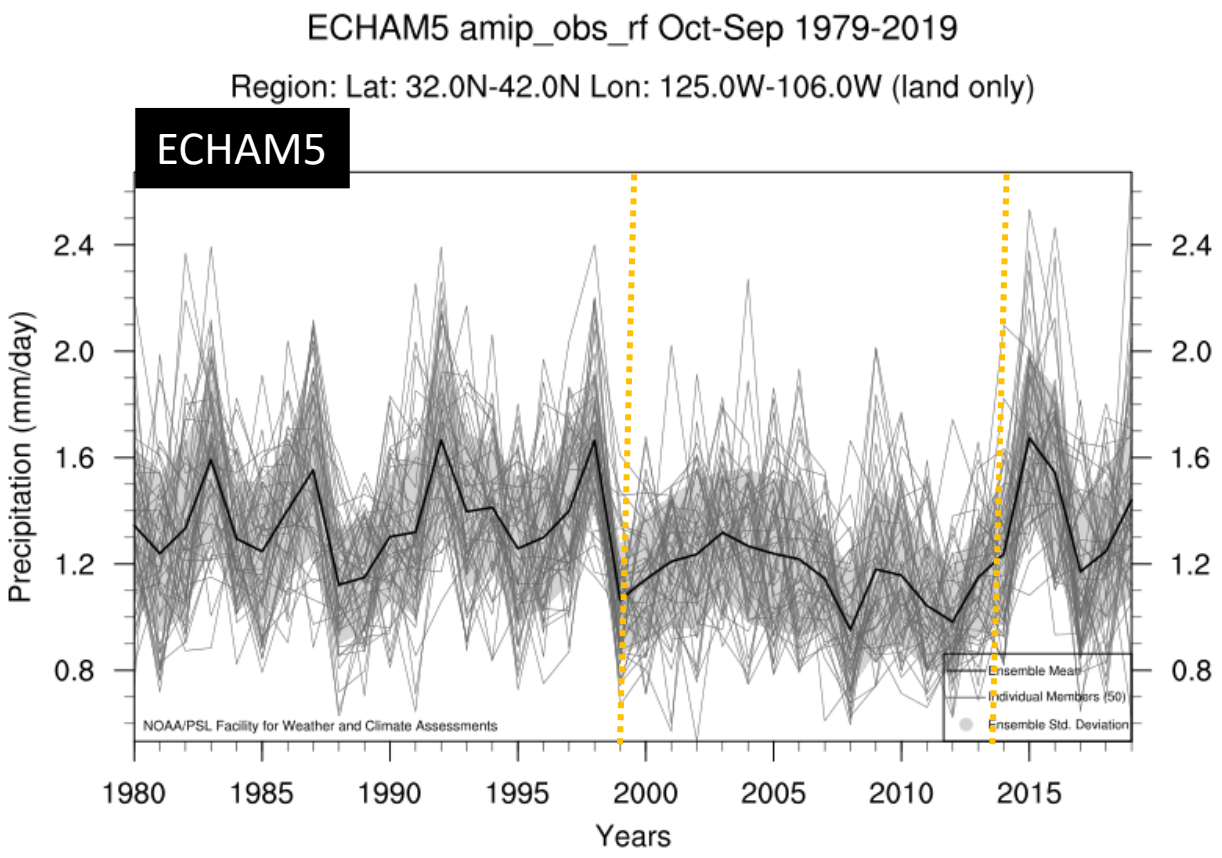




Historical AMIP (1979-2014) simulated pcpn time series clearly indicate a forced period of sustained low pcpn over the Western U.S. beginning suddenly in 1999

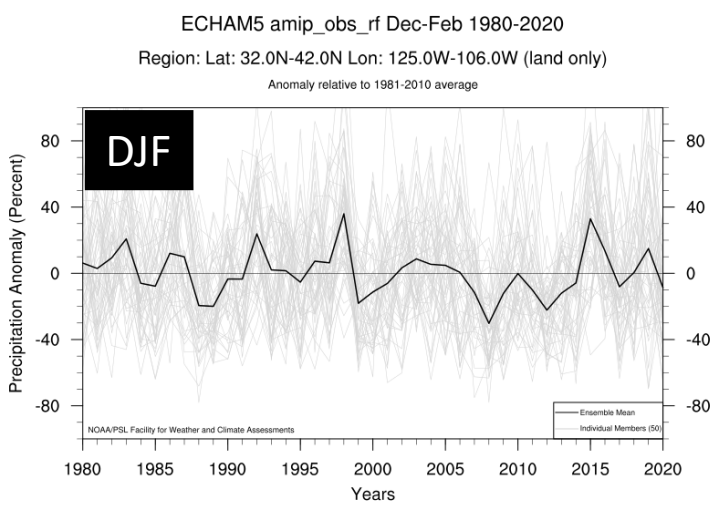
AMIP Simulated Western US Water-Yr Pcpn Time Series 1979-2019

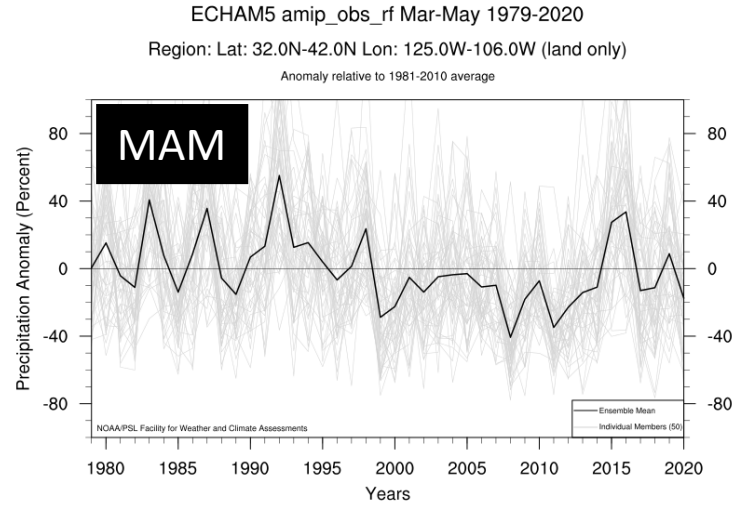


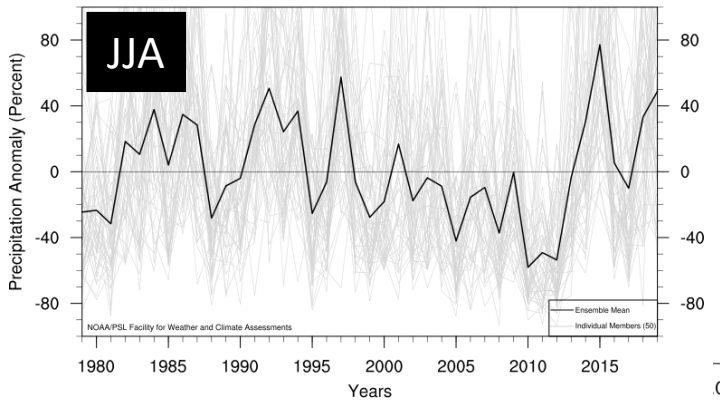


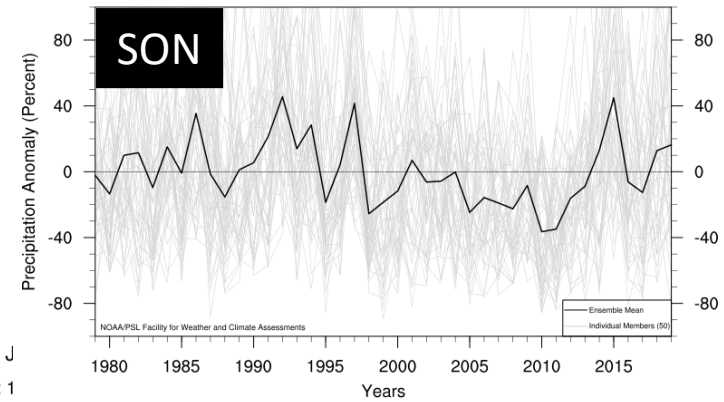
Historical AMIP simulated pcpn time series that extend to 2019 clearly indicate a forced period of sustained low pcpn over the Western U.S. continued to WY2014.

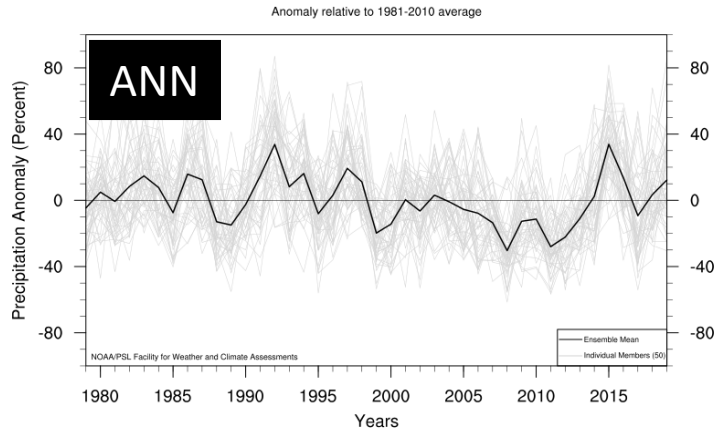
Forcing of low precipitation suddenly ended in WY2015 (Oct 2014-Sept 2015)







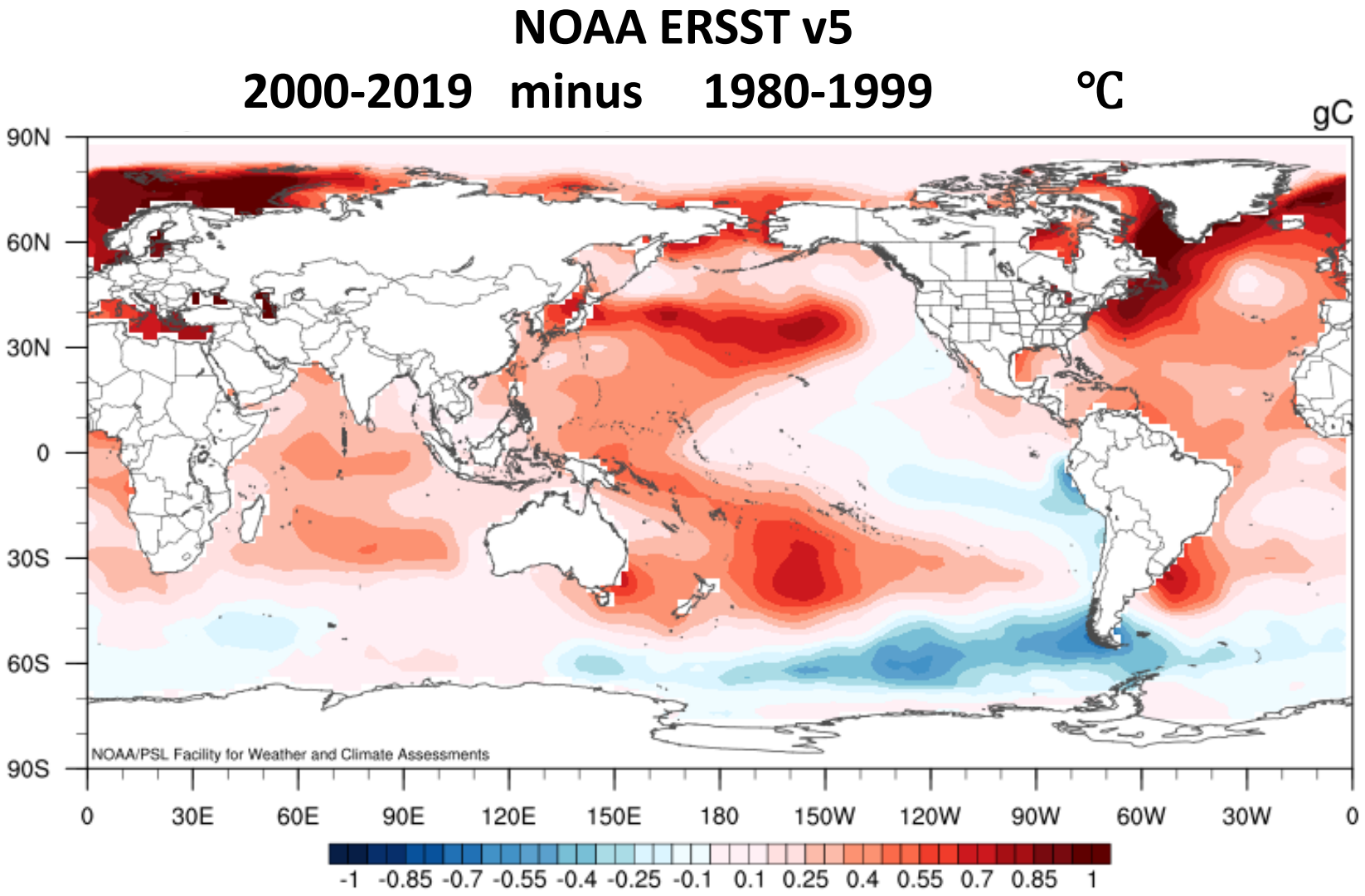




ECHAM - AMIP

The forced component is present in all seasons.

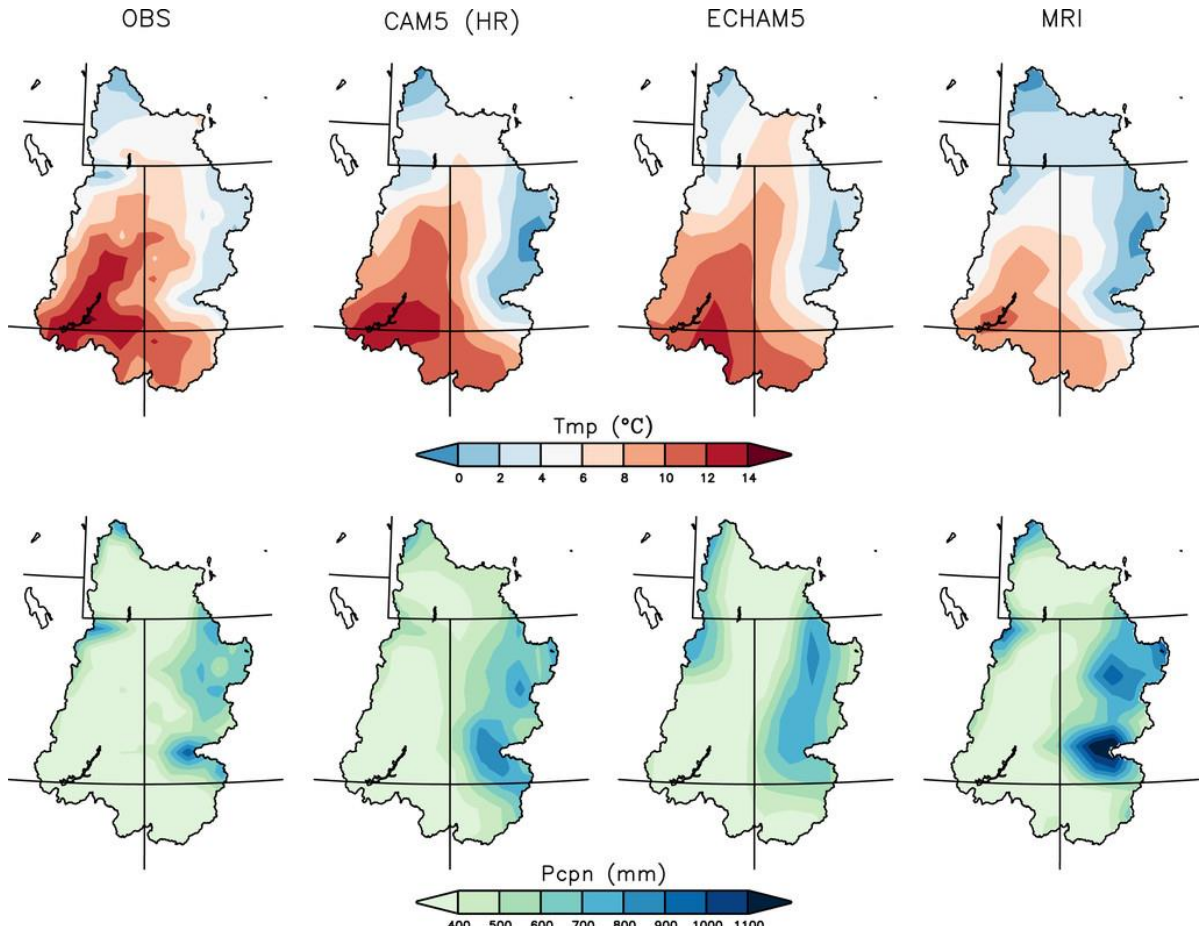
What did the shift in SST's look like?



Causes for the Century-Long Decline in Colorado River Flow, 2019
M. Hoerling, J. Barsugli, B. Livneh, J. Eischeid, X. Quan, and A. Badger

Model	Resolution	Land model	Ensemble size
CAM5	0.45° × 0.6°	Biophysical/CLM4	10
ECHAM5	T157	SiB/bucket	30
MRI3.2	60 km	SiB, three layers	100

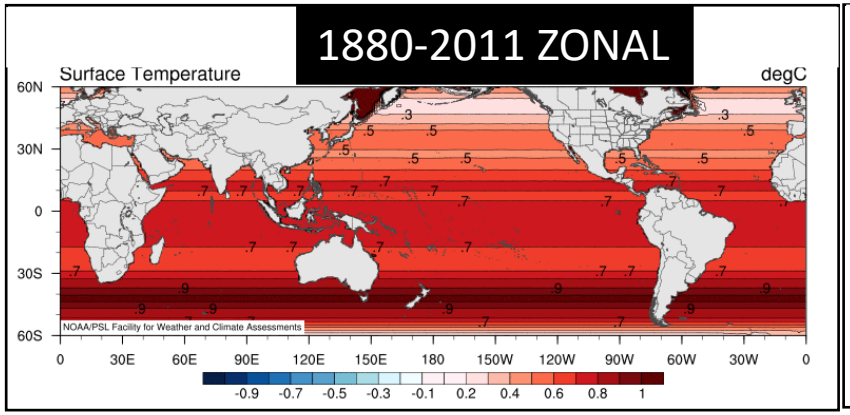
Model	Temperature (°C)	Precipitation (mm)	Streamflow (mm)
CAM5	7.0	465	67
ECHAM5	7.1	457	80
MRI3.2	5.0	478	74
Obs	7.4	391	63



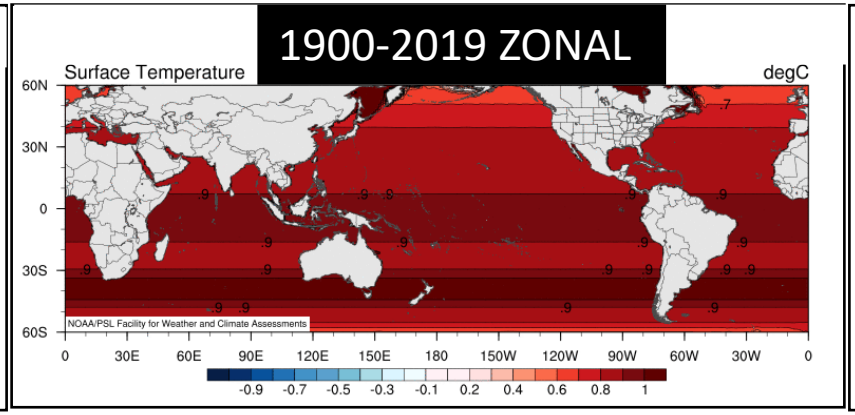
AMIP Factual/Counterfactual to estimate the impact of long-term changes in SST, GHGs and other forcings

Empirical Estimate of SST Change from Observations

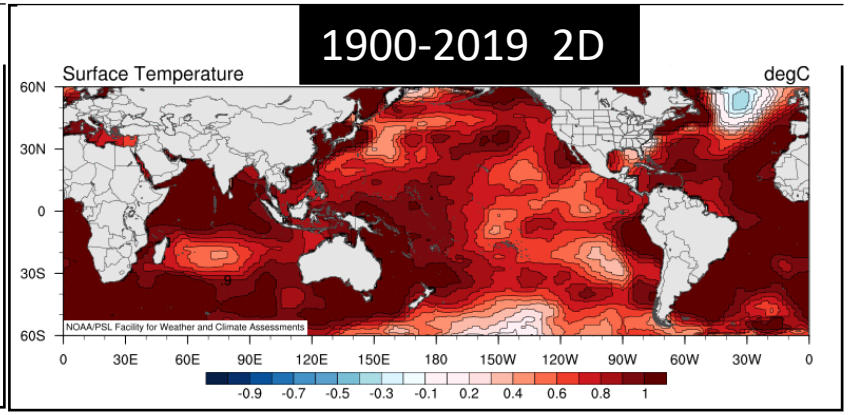
1880-2011 ZONAL



1900-2019 ZONAL



1900-2019 2D



Factual minus Counterfactual-v1

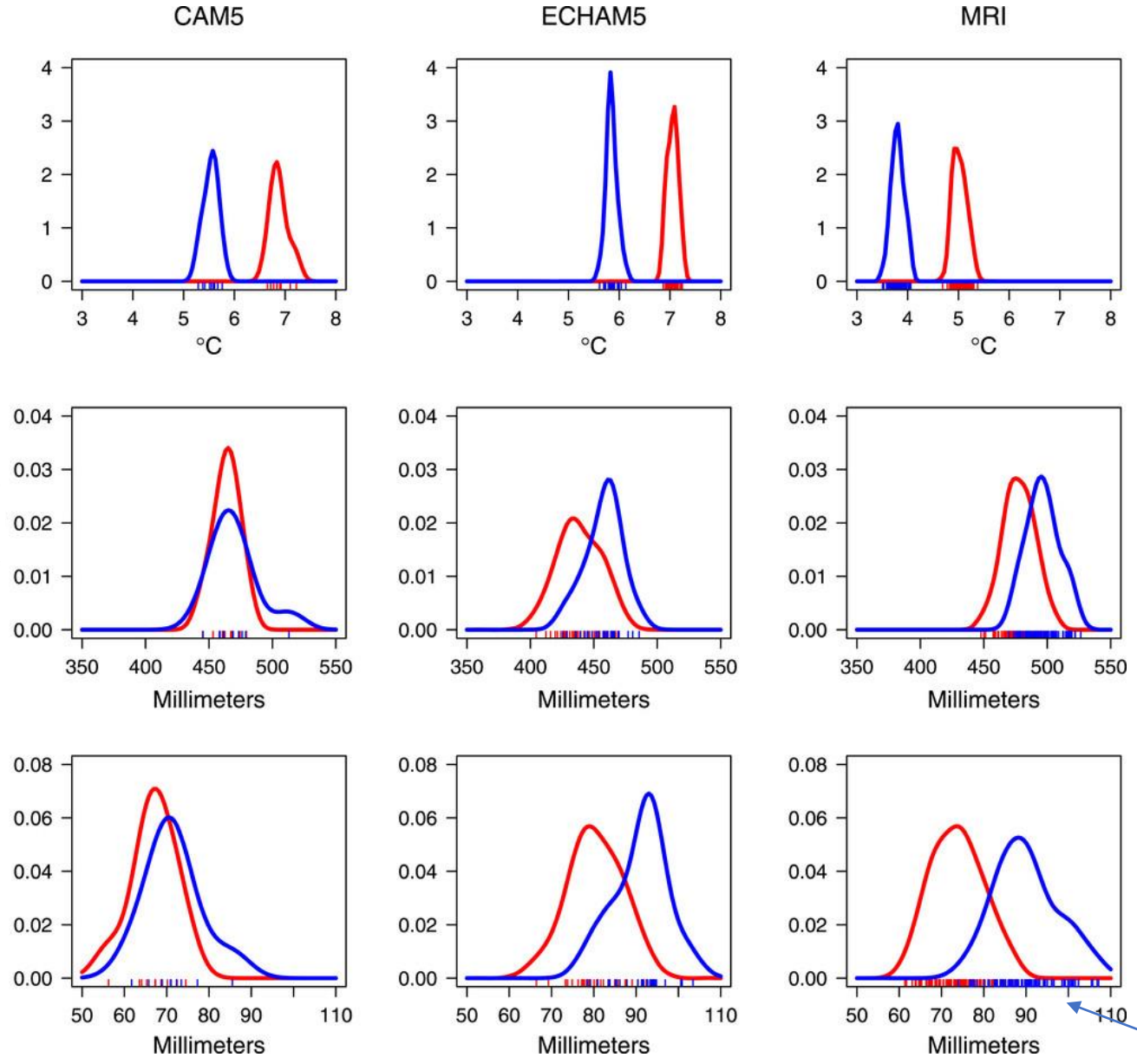
Factual minus Counterfactual-v2

Factual minus Counterfactual-v3

Counterfactual AMIP – “what if” the present-day SST variability occurred but with …. GHGs and other radiative forcing fixed at ~1900, centennial-scale SST and sea ice cover trend removed.

SST trends consistent with observations (by construction) – so “empirically constrained” attribution, conditional on SSTs

Using AMIP models to show effect of long-term change



FACTUAL

AMIP with all forcings

COUNTERFACTUAL

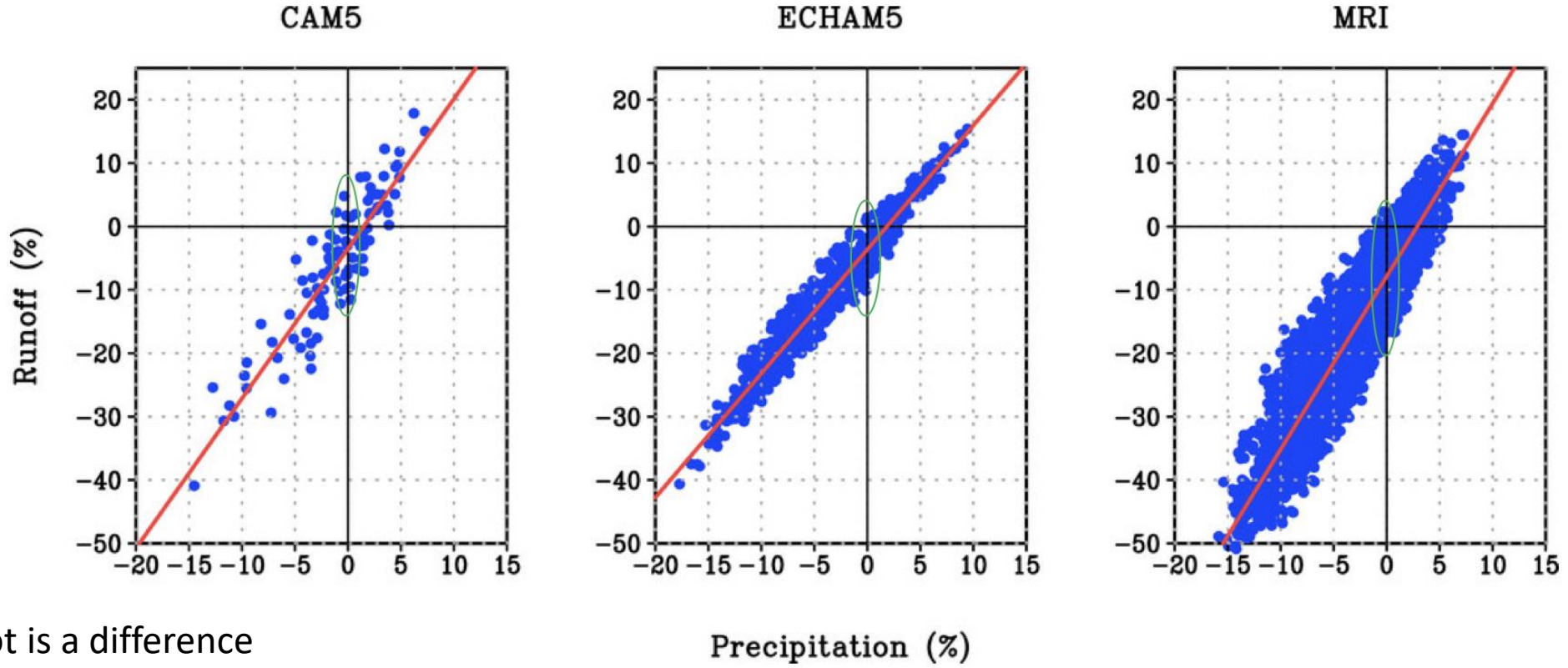
Zonal SST Trend removed

GHGs and other drivers set to ~1880-1900 values

PDF of ensemble members for UCRB

Each tickmark is a model run

Fig. 8.



Slope tells us precipitation elasticity

Y- Intercept tells us the temperature effect

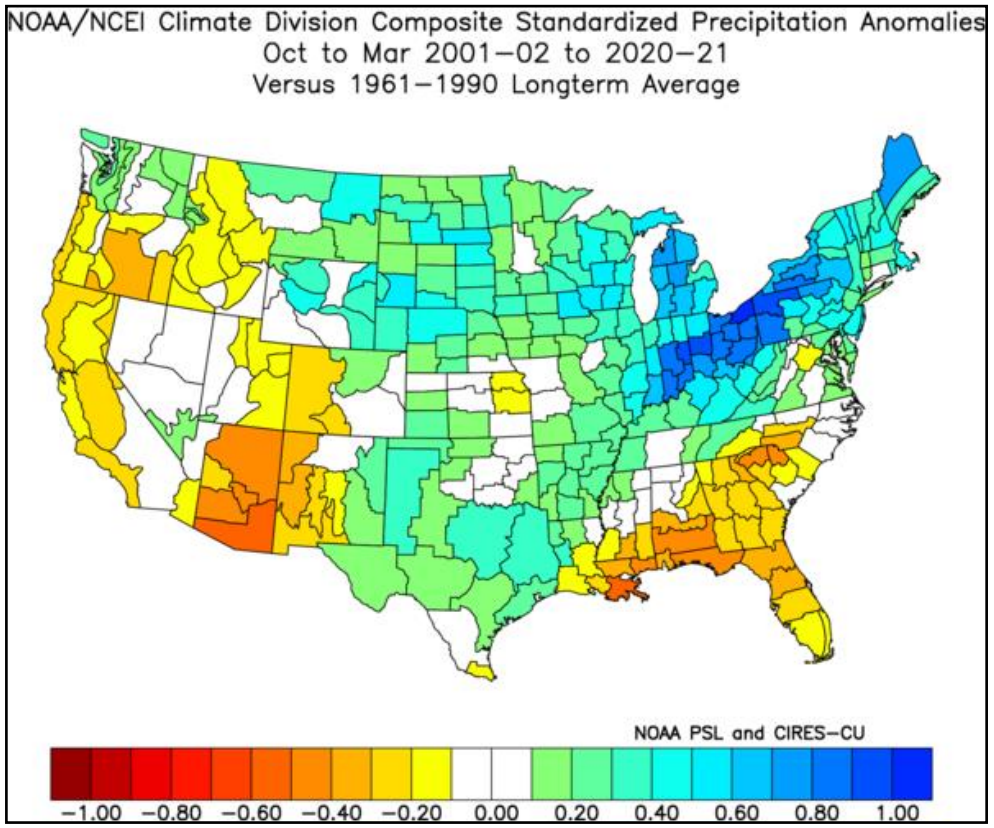
Each dot is a difference between a FACTUAL model run and a COUNERFACTUAL model run

Model	T sensitivity (% °C^{-1})	P elasticity	Correlation δQ vs δP
CAM5	−2.5	2.4	0.91
ECHAM5	−3.0	2.0	0.97
MRI3.2	−6.5	2.7	0.93

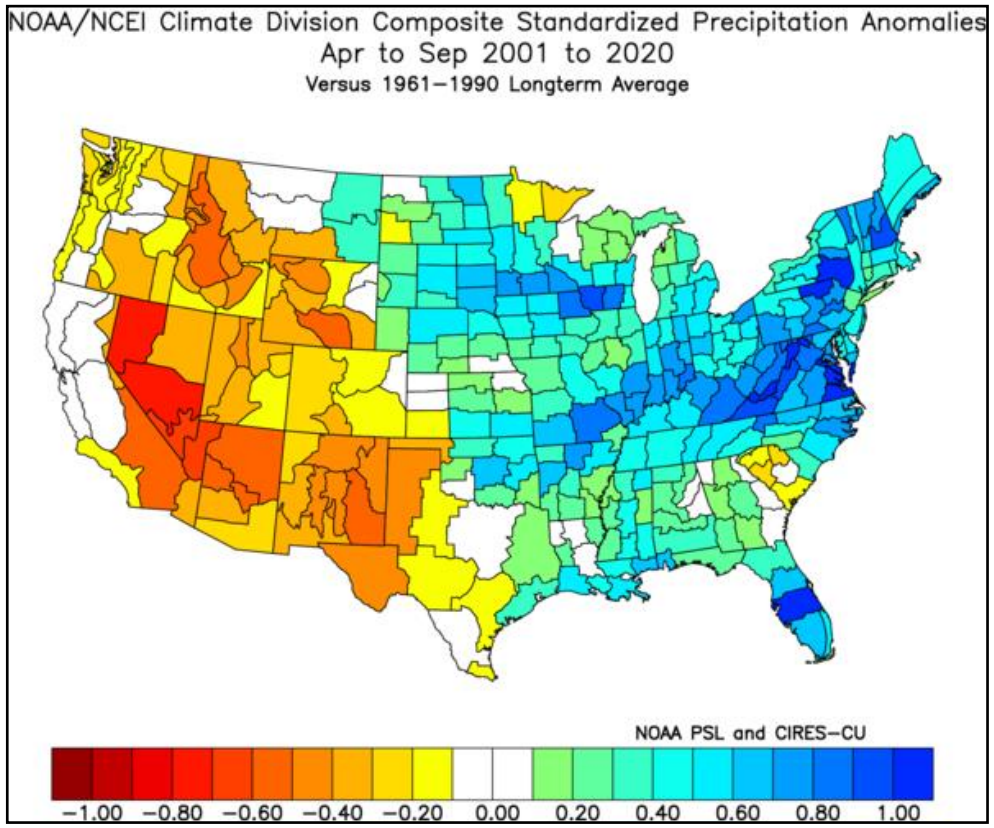
Scatter relationship between UCRB runoff (y axis) vs UCRB precipitation differences of the 1981–2010 factual minus counterfactual experiments of (left) CAM5, (center) ECHAM5, and (right) MRI3.2. All values are averages for the entire UCRB. The precipitation and runoff anomalies are expressed as percentage departures relative to the counterfactual 1981–2010 climatology.

Observed Anomalies In Seasonal Precipitation

2001-2020



Winter

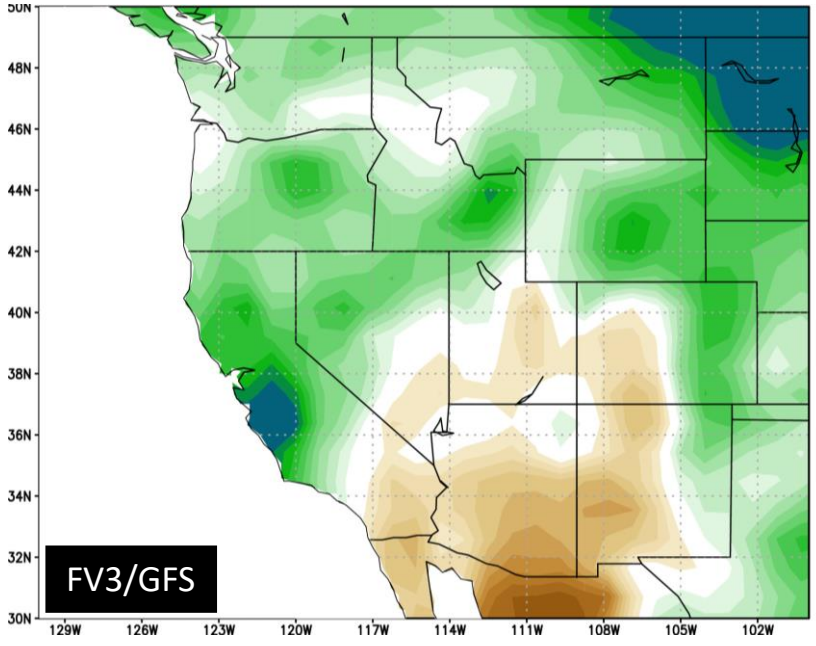


Summer

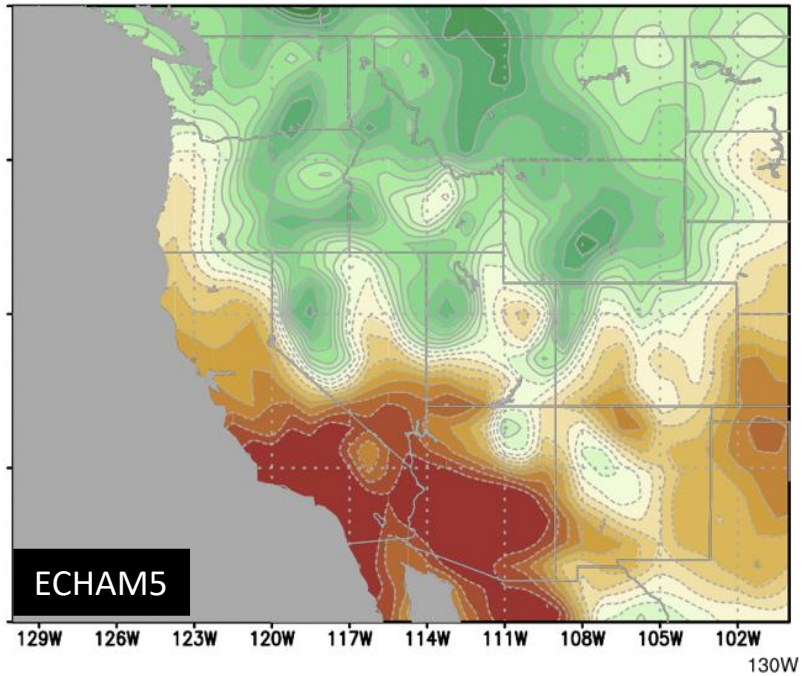
Anomalies are standardized departures, relative to 1961-90

Climate Change Forced Precipitation

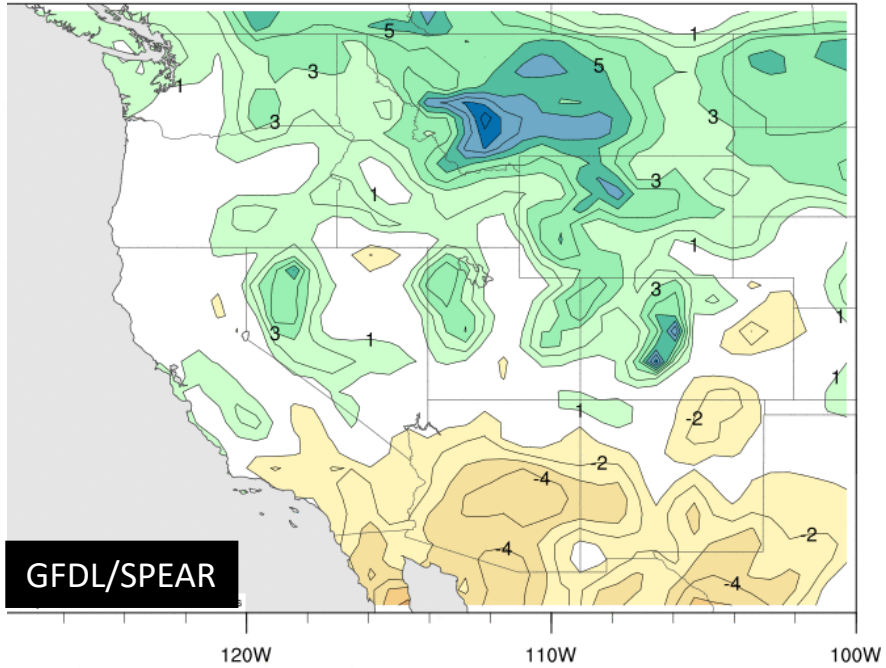
Winter: *October thru March*



AMIP – AMIP CF (zonal v2)

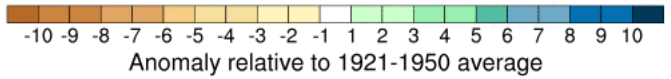


AMIP-AMIP CF (zonal v2)



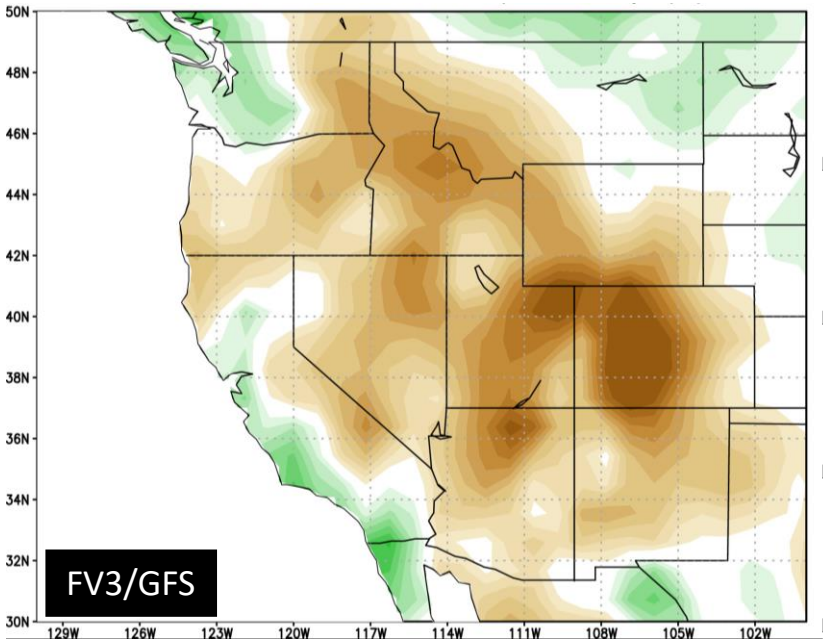
COUPLED

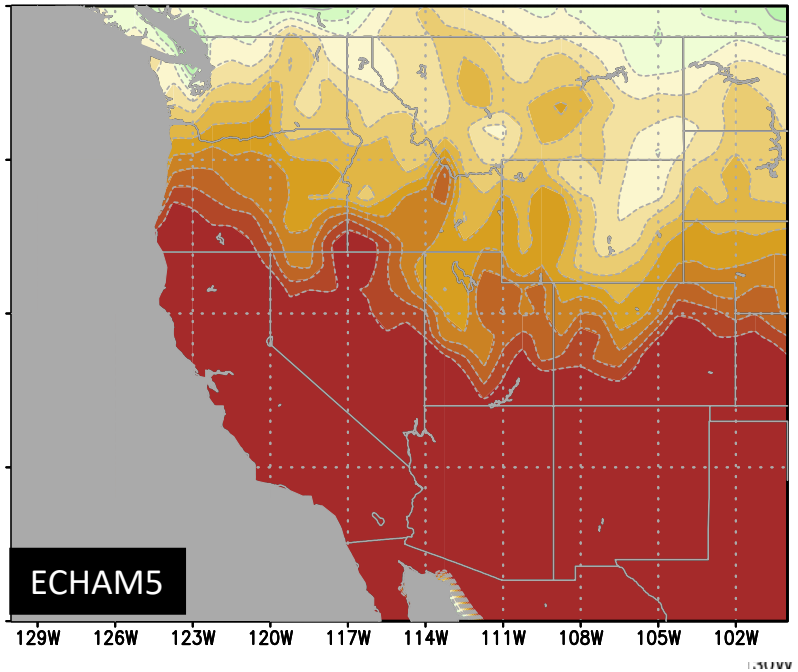
% change; 2001-2020 relative to early 20th Century

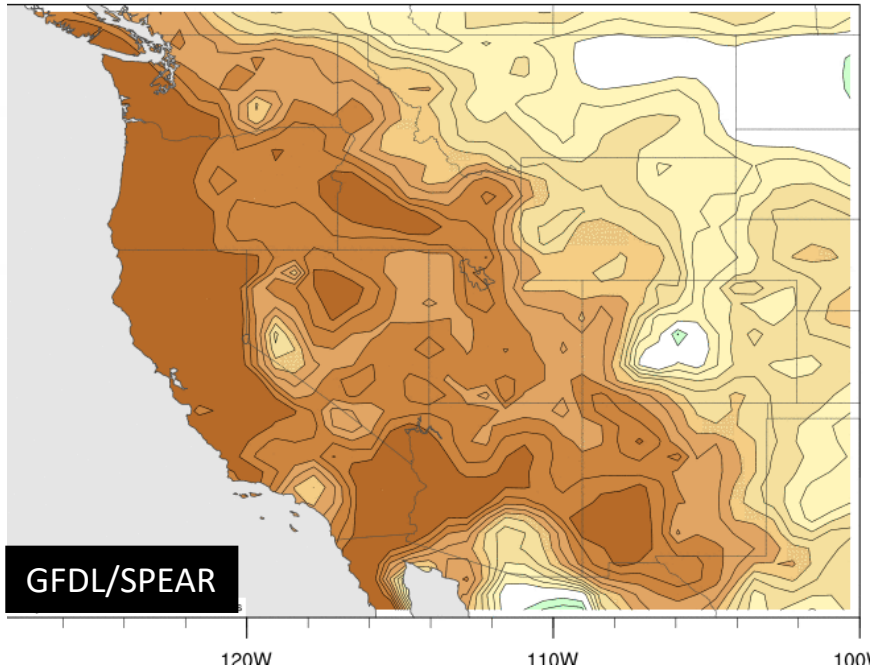


Climate Change Forced Precipitation

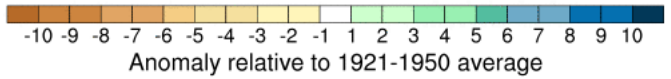
Summer: *April thru September*



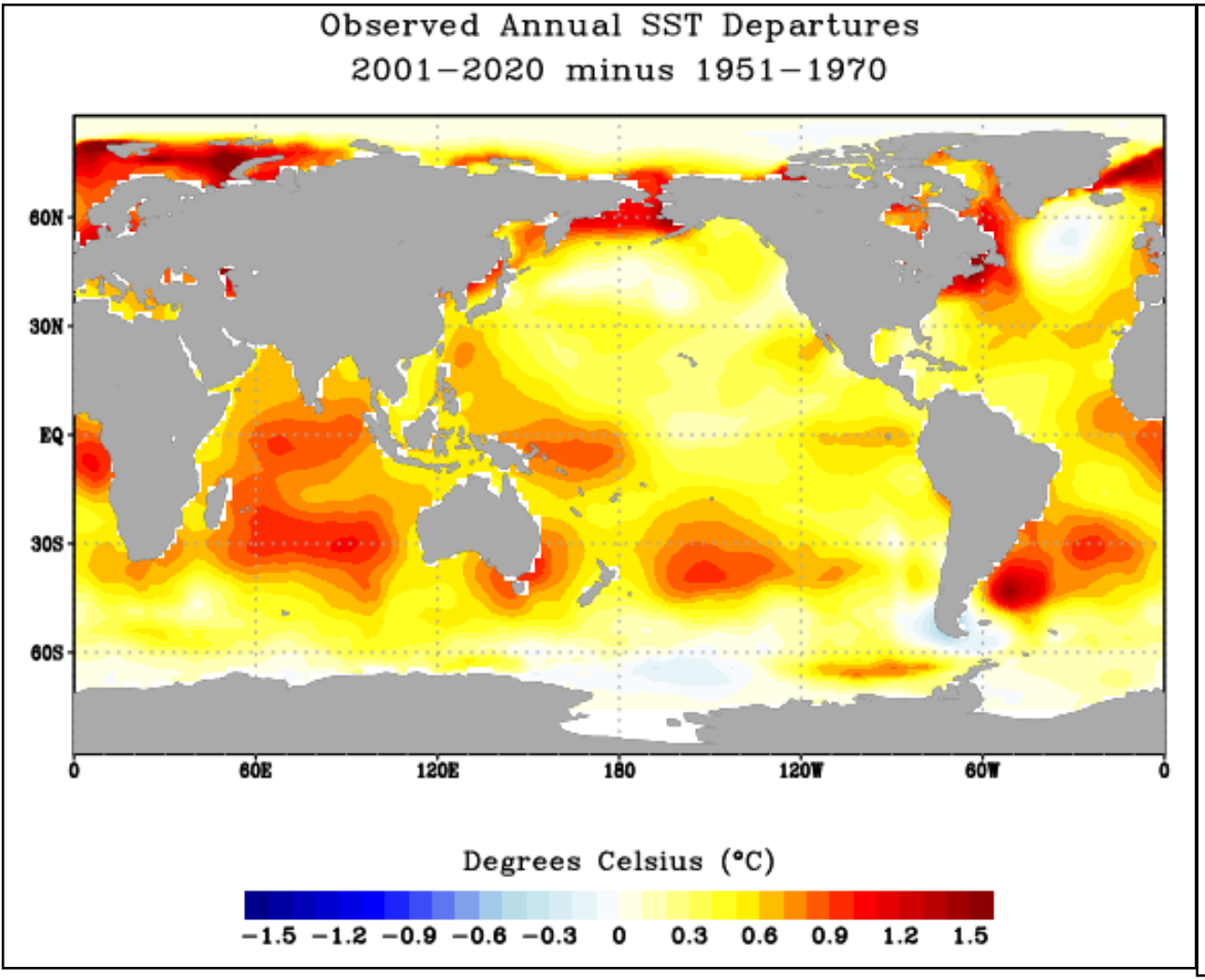


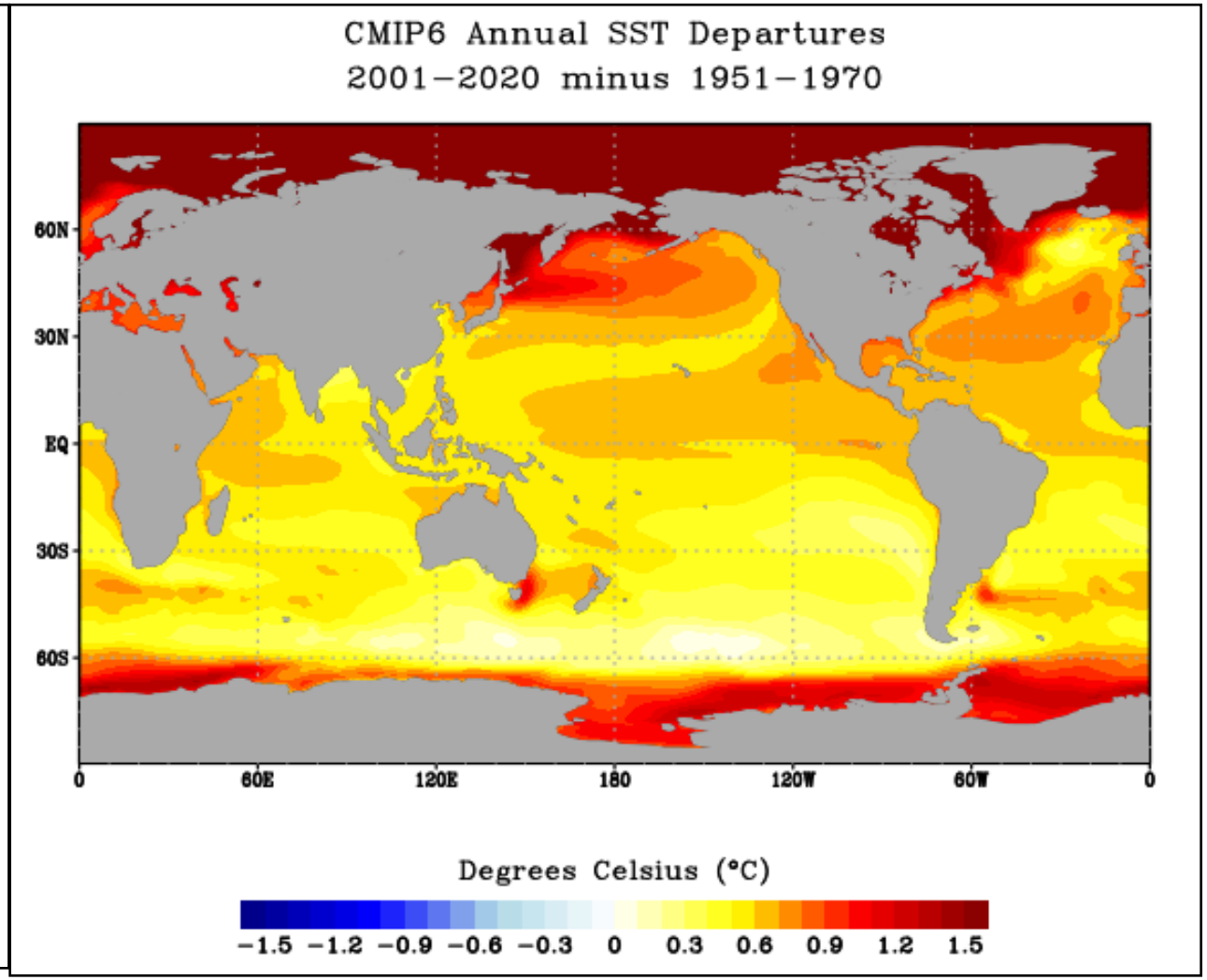


% change ; 2001-2020 relative to early 20th Century

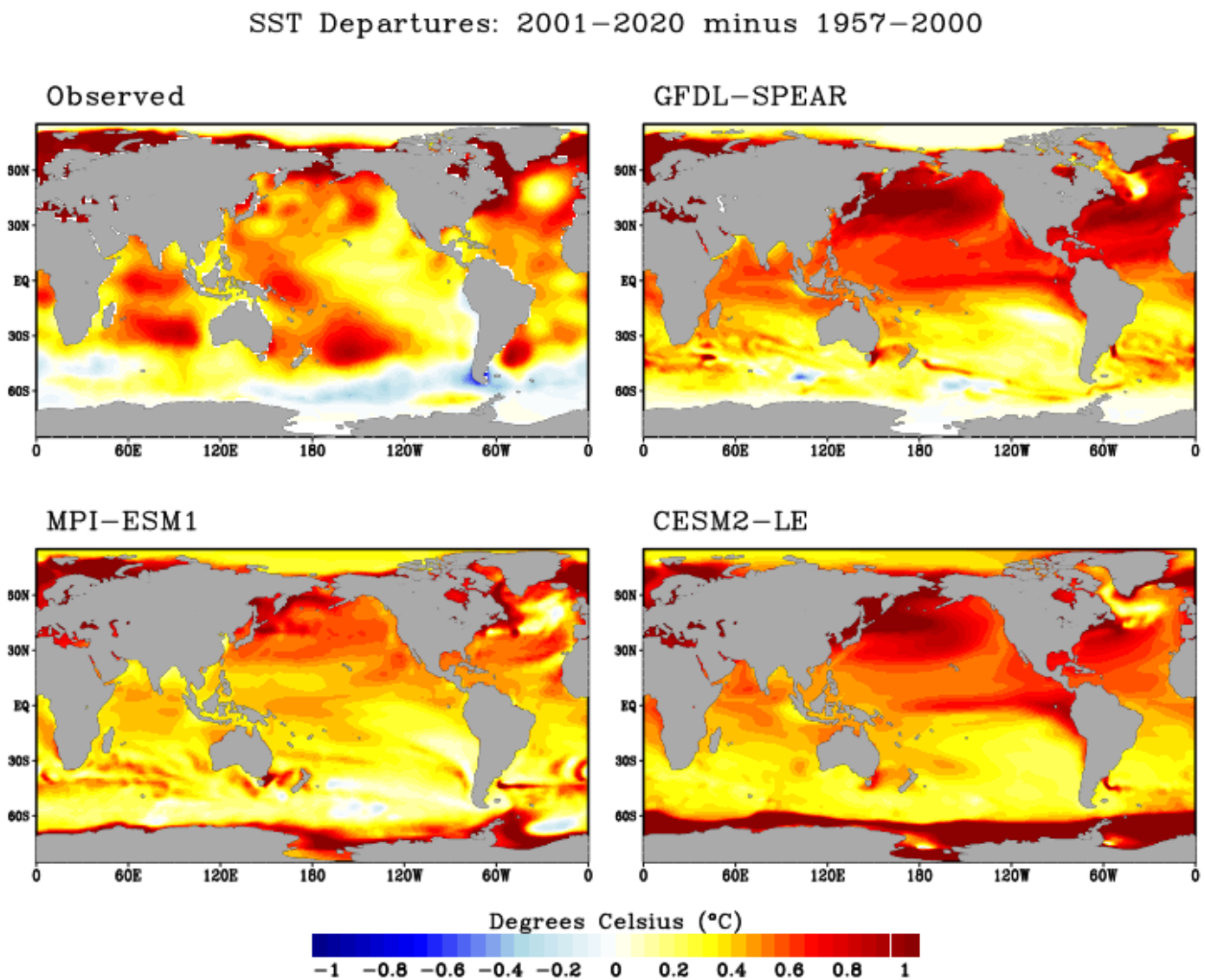


Observed vs CMIP6 SST Change : [2001-2020 minus 1951-1970]





SST change in Coupled Large Ensembles (CMIP6-class of models) ---

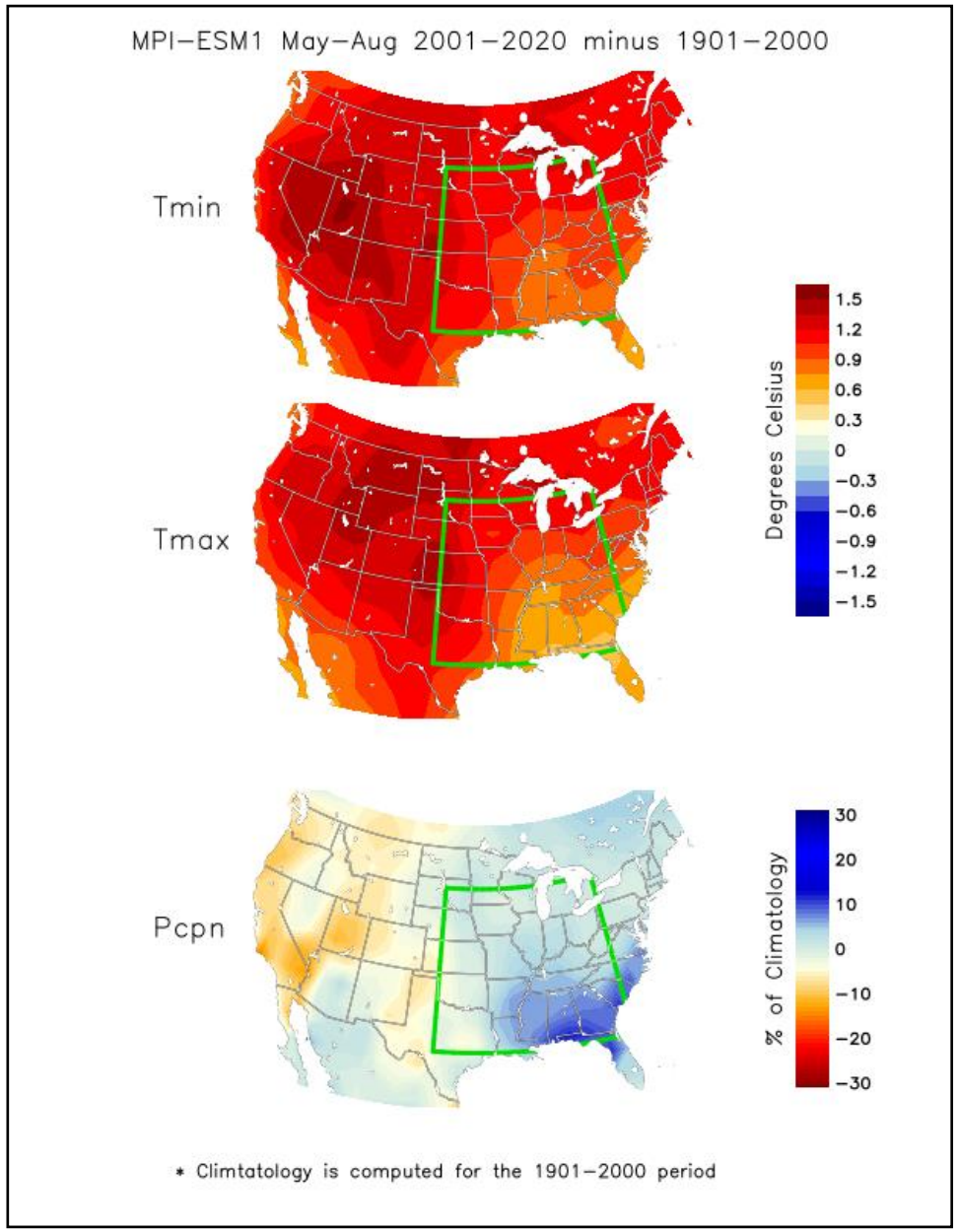


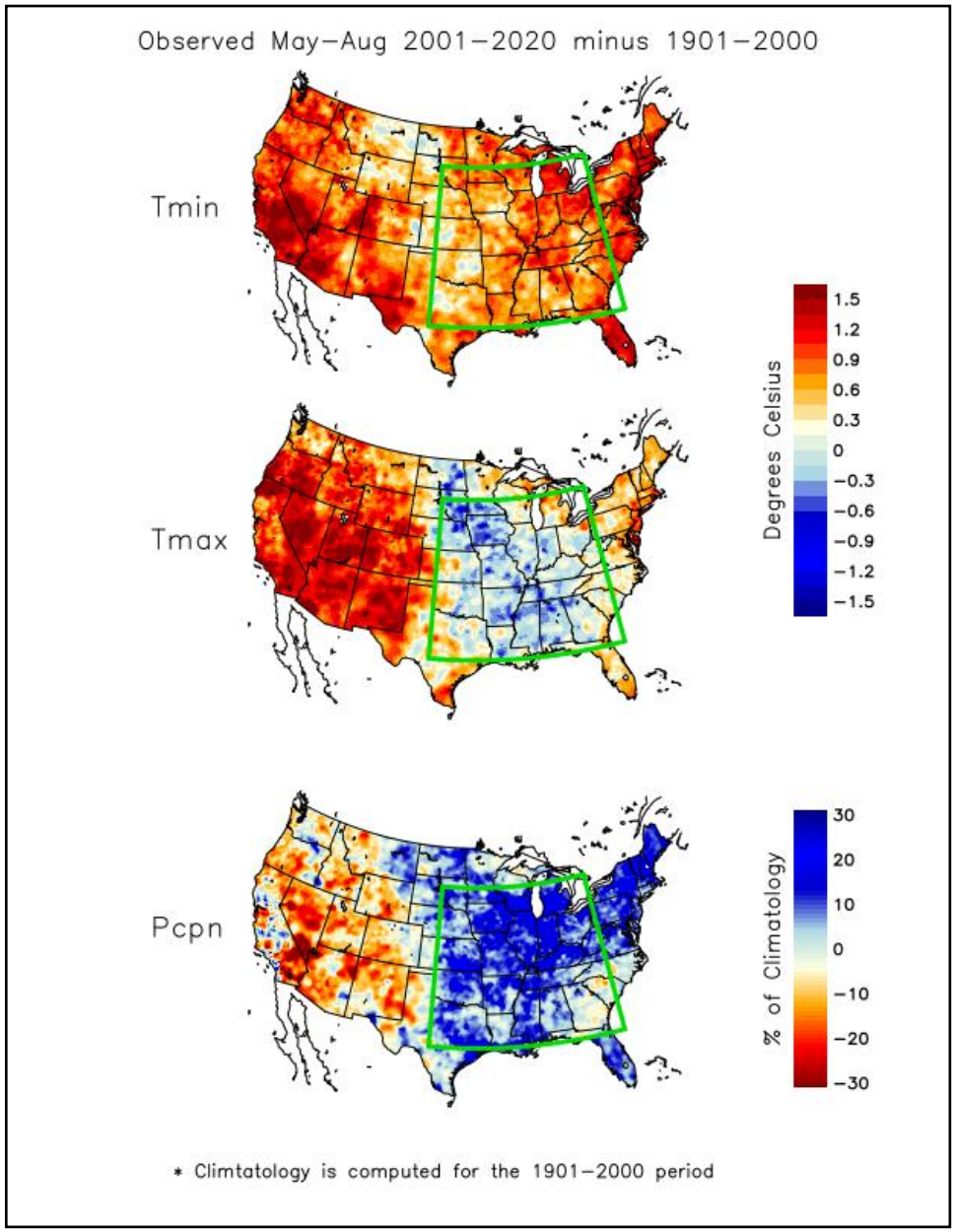
Too strong warming in N. Pacific

El Nino-Like Warming in Tropics

Pretty good!

So what does the MPI model say about Summer? (analysis is ongoing)





- ”Conditional Attribution” using AMIP/Counterfactual methodology finds that long term changes in SSTs (along with GHGs, other drivers) likely made the recent drought worse.

- We find that even the Zonal Mean trend in SSTs , along with the other changes, leads to a decline in annual UCRB precipitation in many large ensembles.

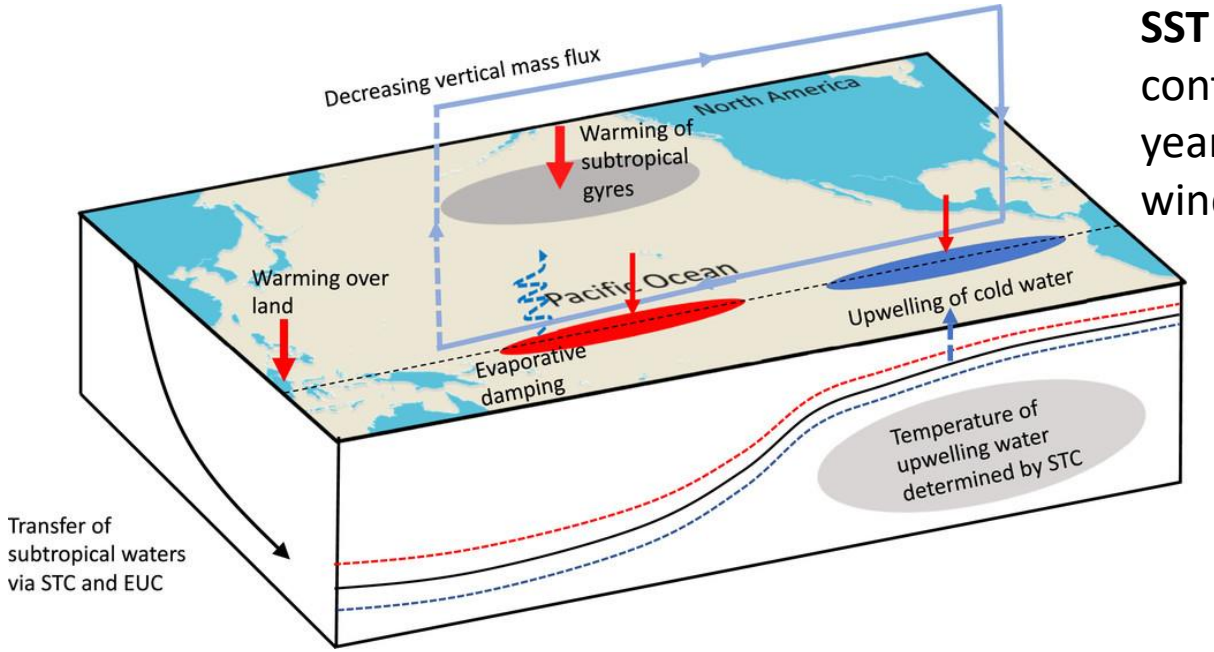
- The temperature “sensitivity” is on the lower end compared to off-line hydrologic models and other estimates (note that experiments with hydrologic models show that higher resolution tends to lead to *decreased* temperature sensitivity, so these GCMs are likely overestimating this quantity)

- Isn’t this just the PDO and won’t it just go away?

Time Scales and Mechanisms for the Tropical Pacific Response to Global Warming: A Tug of War between the Ocean Thermostat and Weaker Walker

Ulla K. Heede[1], Alexey V. Fedorov[2], and Natalie J. Burls[3]

We find a robust transient response to CO_2 forcing across all simulations, lasting between 20 and 100 years, depending on how abruptly the system is perturbed. **This initial response is characterized by the strengthening of the Indo-Pacific zonal SST gradient** and a westward shift of the Walker cell. In contrast, the equilibrium response, emerging after 50–100 years, is characterized by a warmer cold tongue, reduced zonal winds, and a weaker Walker cell.



Conclusions – so far:

- Shoulder and warm season precipitation important for historic droughts (antecedent soil moisture is a factor in reduced runoff yield from SWE)

- Sudden onset of 2000's drought was largely driven by SST-forced precipitation variability.

- Centennial scale SST changes have made the precipitation less than it would otherwise be – whether we take into account only the zonally averaged SST change or the full spatial pattern of change.

- Most (but not all) CMIP6 models do not have a change pattern that comports with the observed pattern.

- Recent hypothesis (building on past theory) is that the "La Nina-ish" SST gradient (less warming in the East Tropical Pacific than the West) could be a transient response to anthropogenic climate change that is not well captured by the CMIP6 models.

- This transient tendency for La Nina-ish conditions could last decades, but this is not known.

- Consider this a "what if…" possibility.

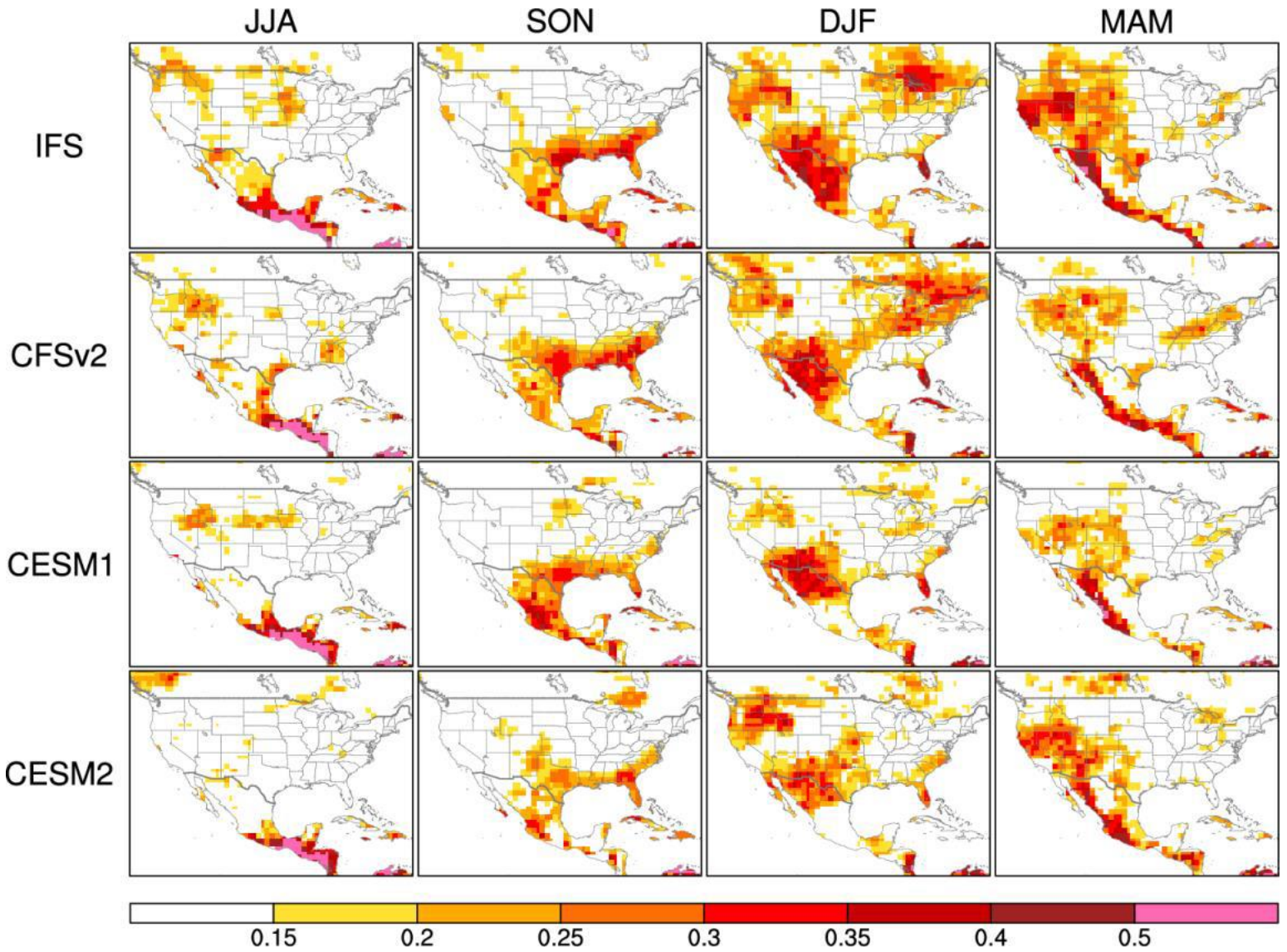
Attribution of North American Subseasonal Precipitation Prediction Skill

Lantao Sun, Martin P. Hoerling, Jadwiga H. Richter Andrew Hoell Arun Kumar James W. Hurrella

Submitted to *Weather and Forecasting*

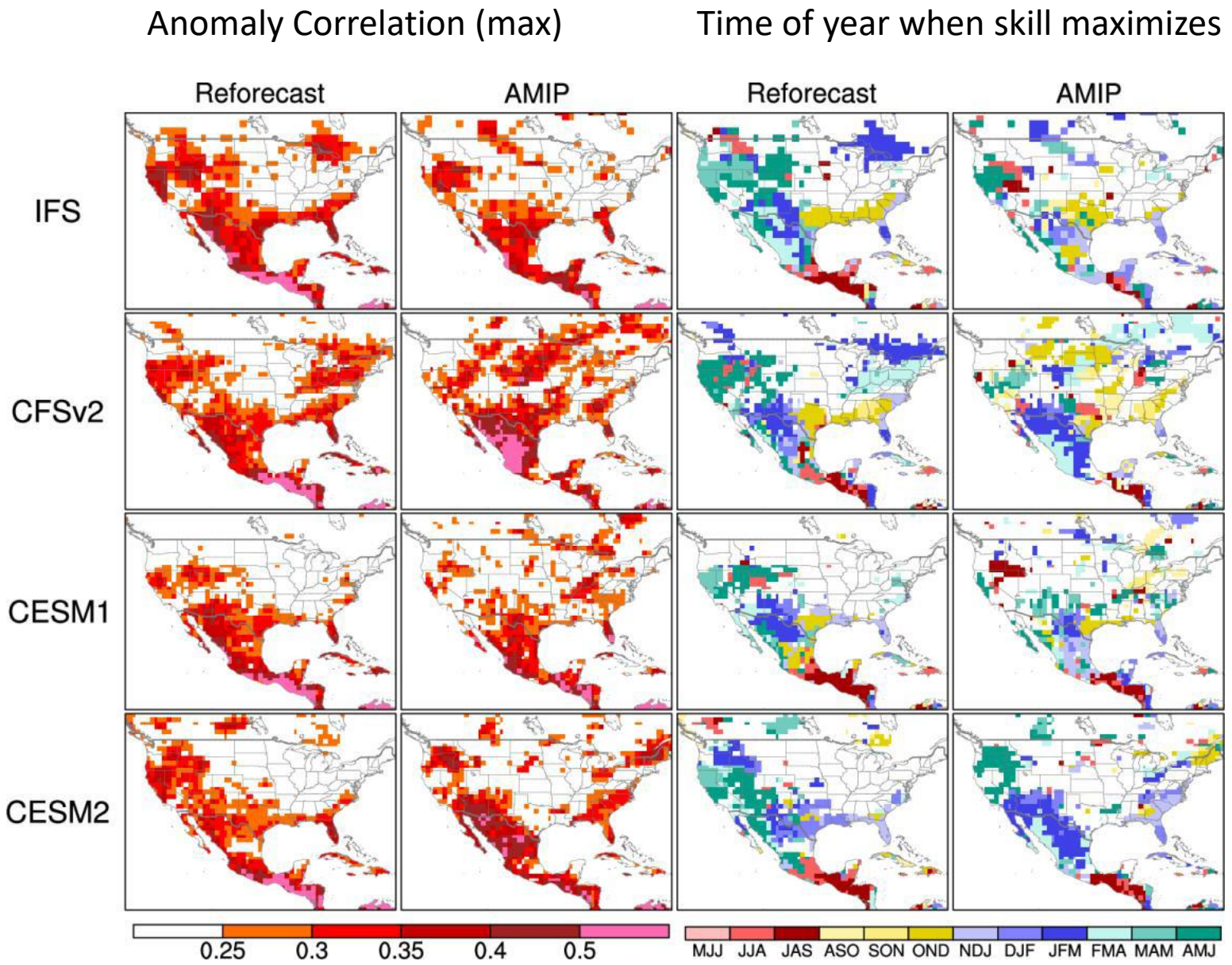
Hindcasts from 1999 – 2014 from four initialized coupled forecast systems were compared AMIP runs with the atmosphere component of the coupled models

Here we show the initialized model skill for weeks 3-6 z(the ~1 month forecast with 2 weeks lead time).

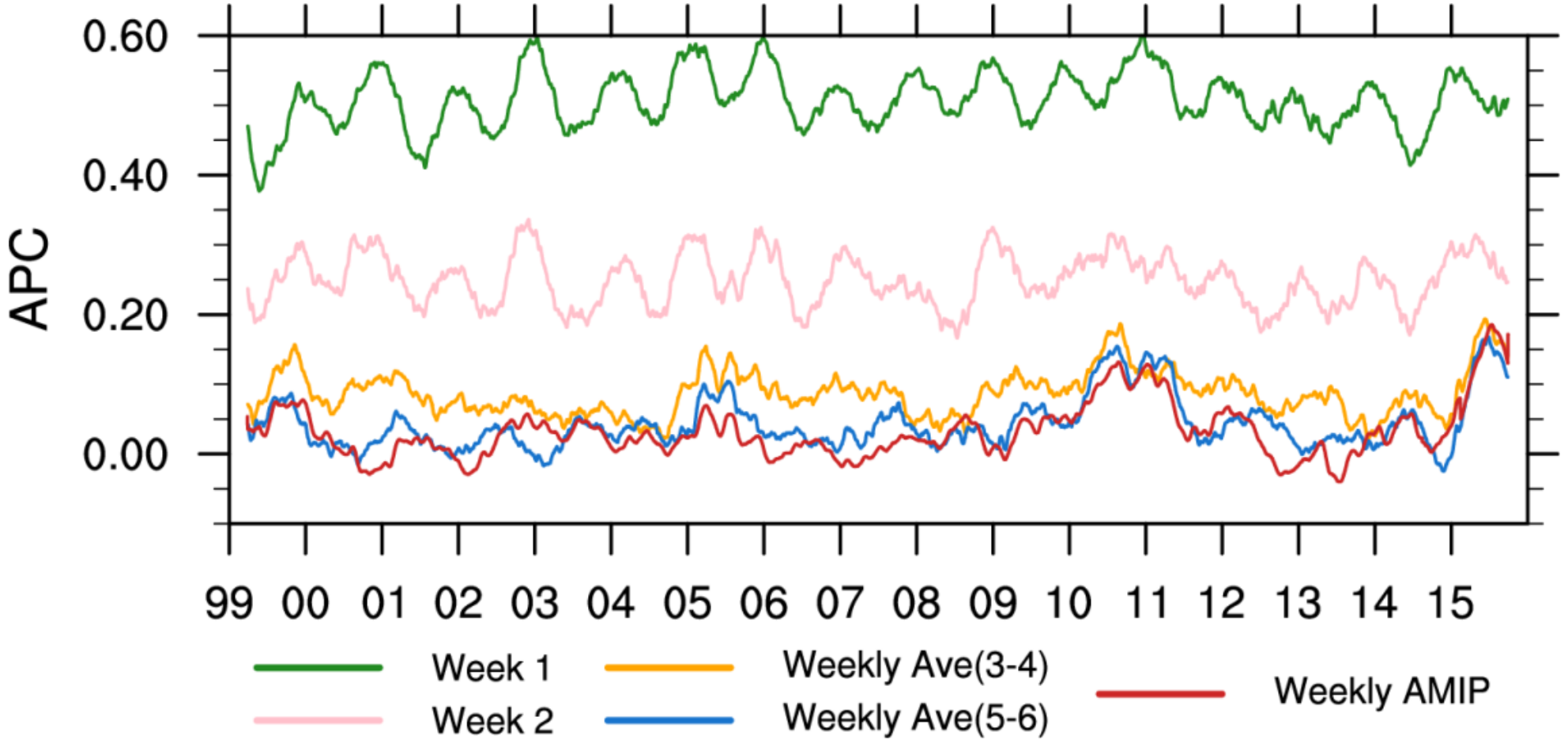


Comparing the maximum 3-month skill
Shows that much of the skill comes from the boundary forcing

Though northern CA and vicinity has a significant component of skill at these lead times from the initial conditions.

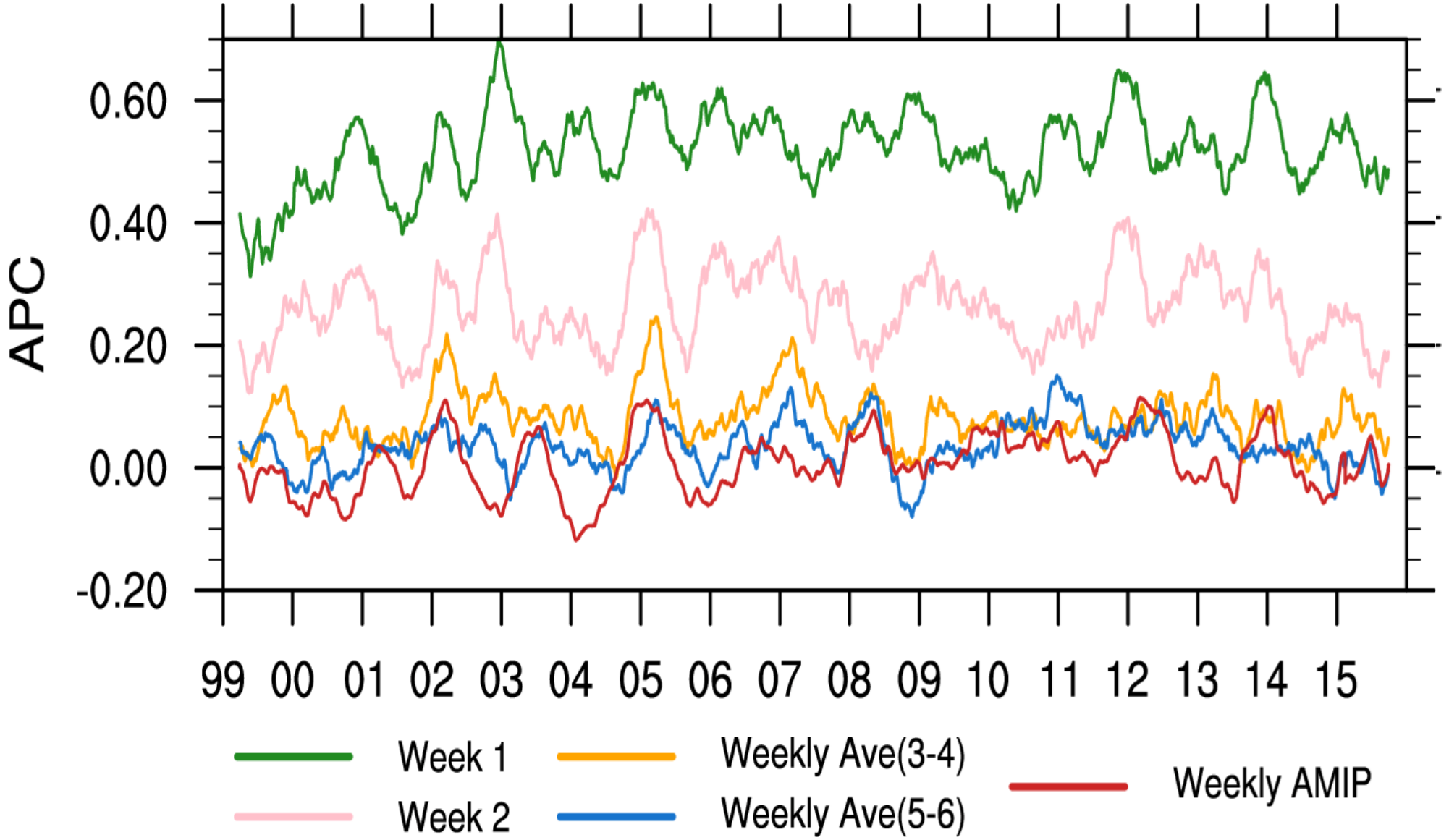


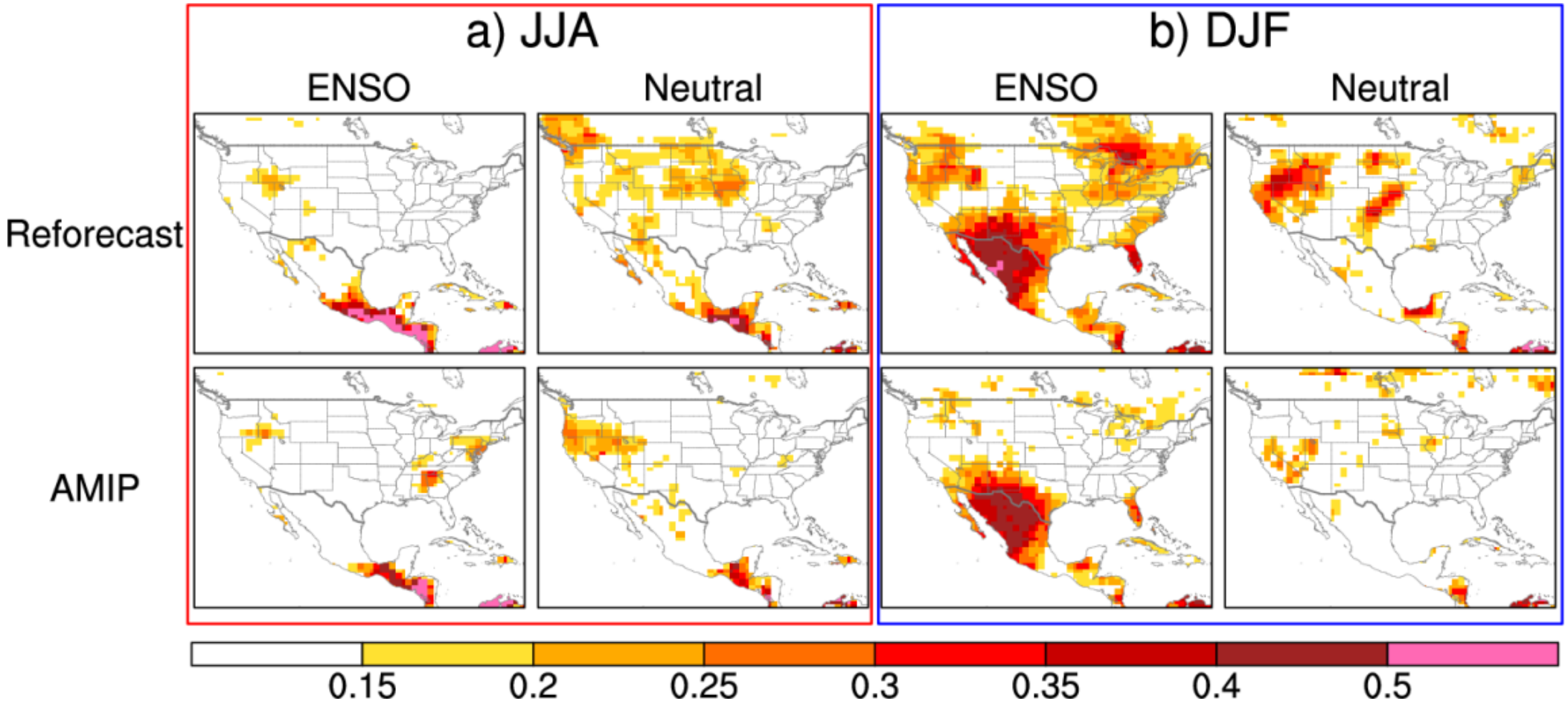
Anomaly Correlation Skill (CONUS)
Multi-model initialized forecast ensemble, Initialized forecasts vs AMIP(red)



Weeks 3-4 skill approaches AMIP!

Anomaly Correlation Skill – Western US (CONUS west of 104W)
Multi-model initialized forecast hindcast ensemble, Initialized forecasts vs AMIP(red)




a) JJA
b) DJF
ENSO
Neutral
ENSO
Neutral
Reforecast
AMIP
0.15
0.2
0.25
0.3
0.35
0.4
0.5

Conclusions:

Climate is Changing, drivers of precipitation for the western US are changing

Currently:

We can interpret this change as the response to a a multi-decadal pattern that favors La-Nina-ish SST patterns and hence drought in the southwest.

Subseasonal (and seasonal) forecasts are sensitive to SST boundary conditions

Empirical prediction models should take into account this non-stationarity

Empirical prediction models can be tested in the ”idealized” setting of one of the GCMs that ”get” the SST patterns closer to observations.