Projected changes of interannual North American hydroclimate variability and predictability

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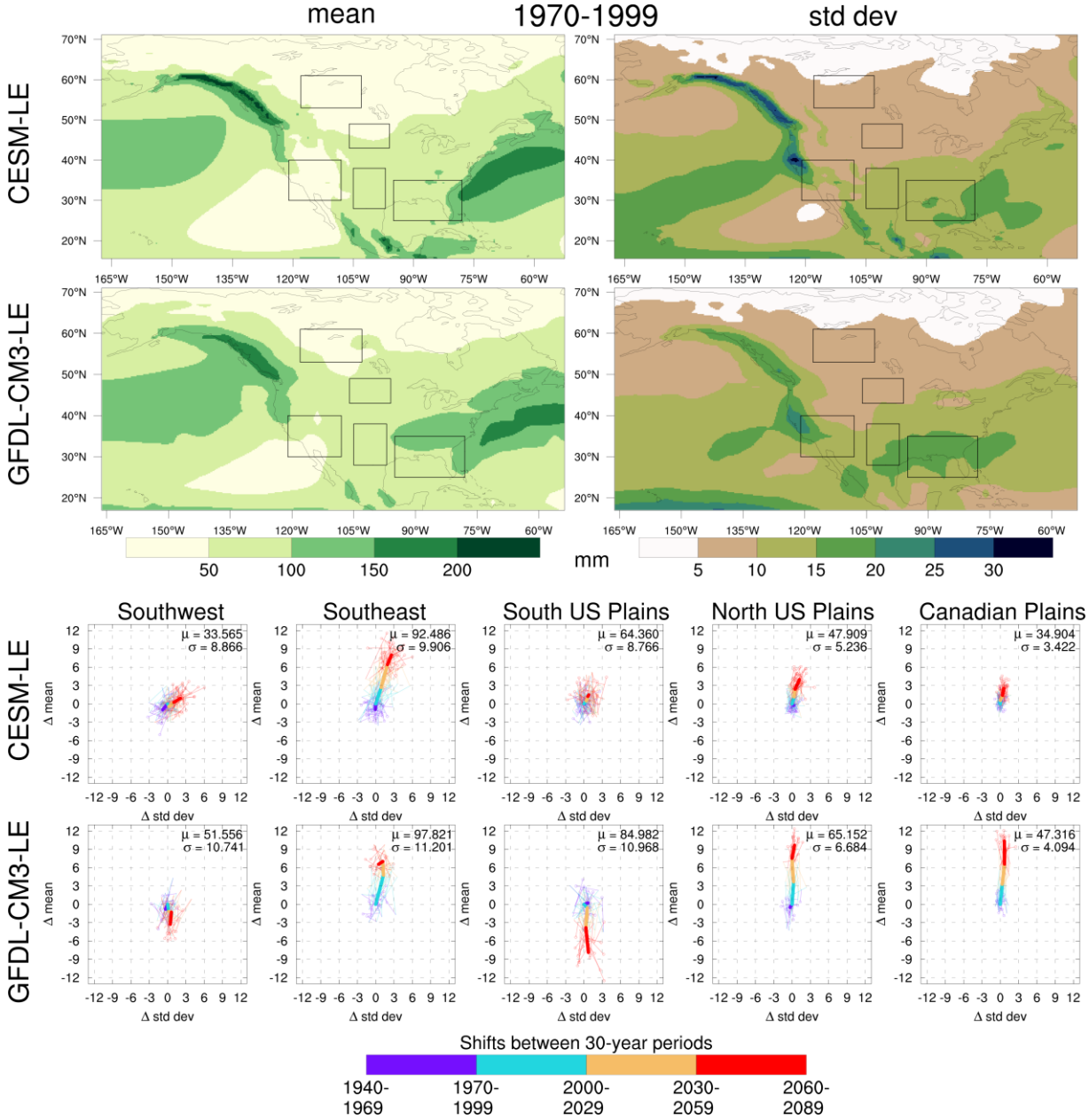
Projected changes in annual-mean **precipitation**, 1940-2089, relative to 1970-1999 base period, for

(top) NCAR CESM-LE
(bottom) GFDL-CM3-LE

Each line shows ensemble member, solid line shows ensemble mean

Changes in the mean are much larger than changes in variability

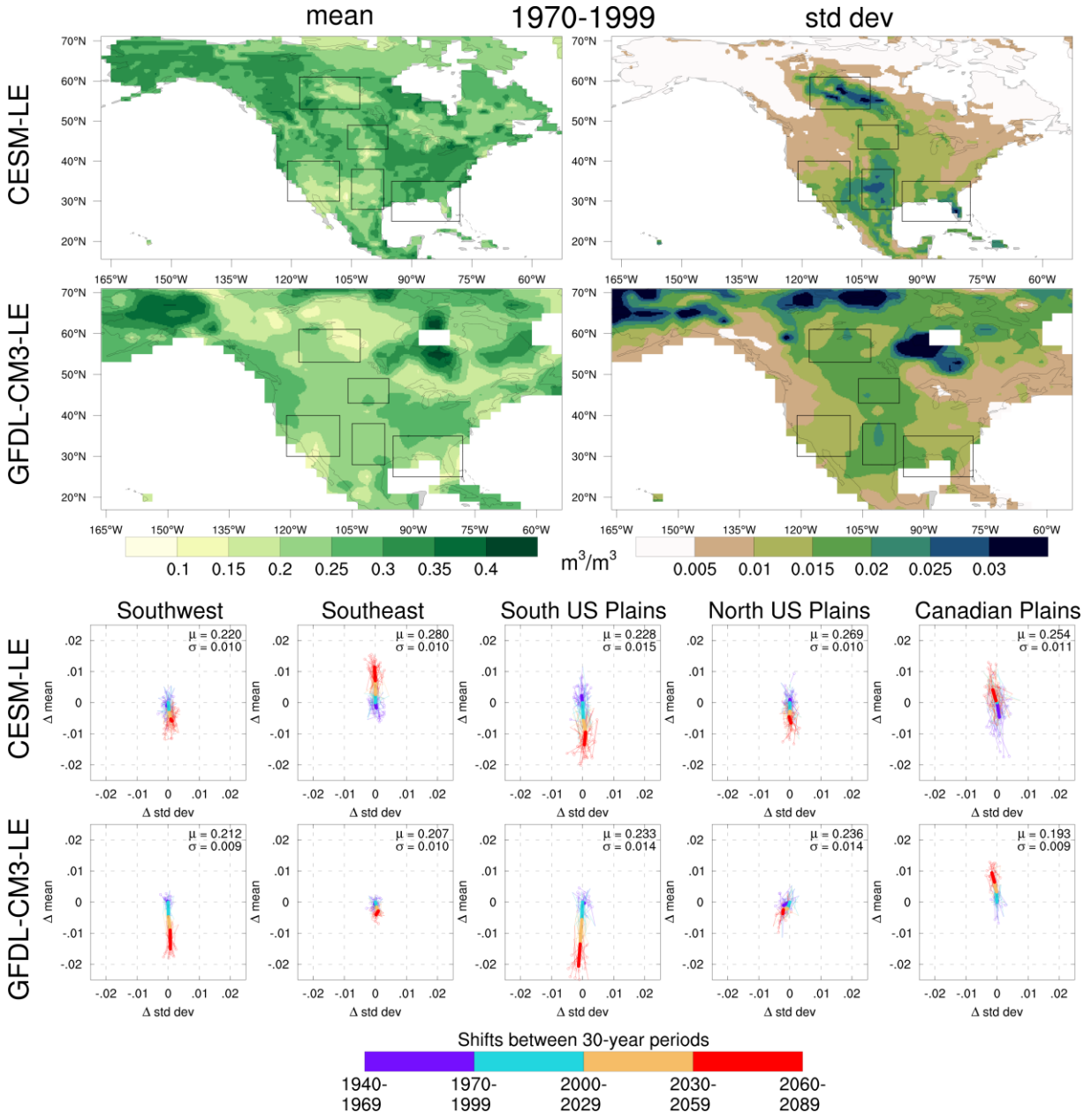


Projected changes in annual-mean **root zone soil moisture (top 1m)**, 1940-2089, relative to 1970-1999 base period, for

(top) NCAR CESM-LE
(bottom) GFDL-CM3-LE

Each line shows ensemble member, solid line shows ensemble mean

Changes in the mean are much larger than changes in variability

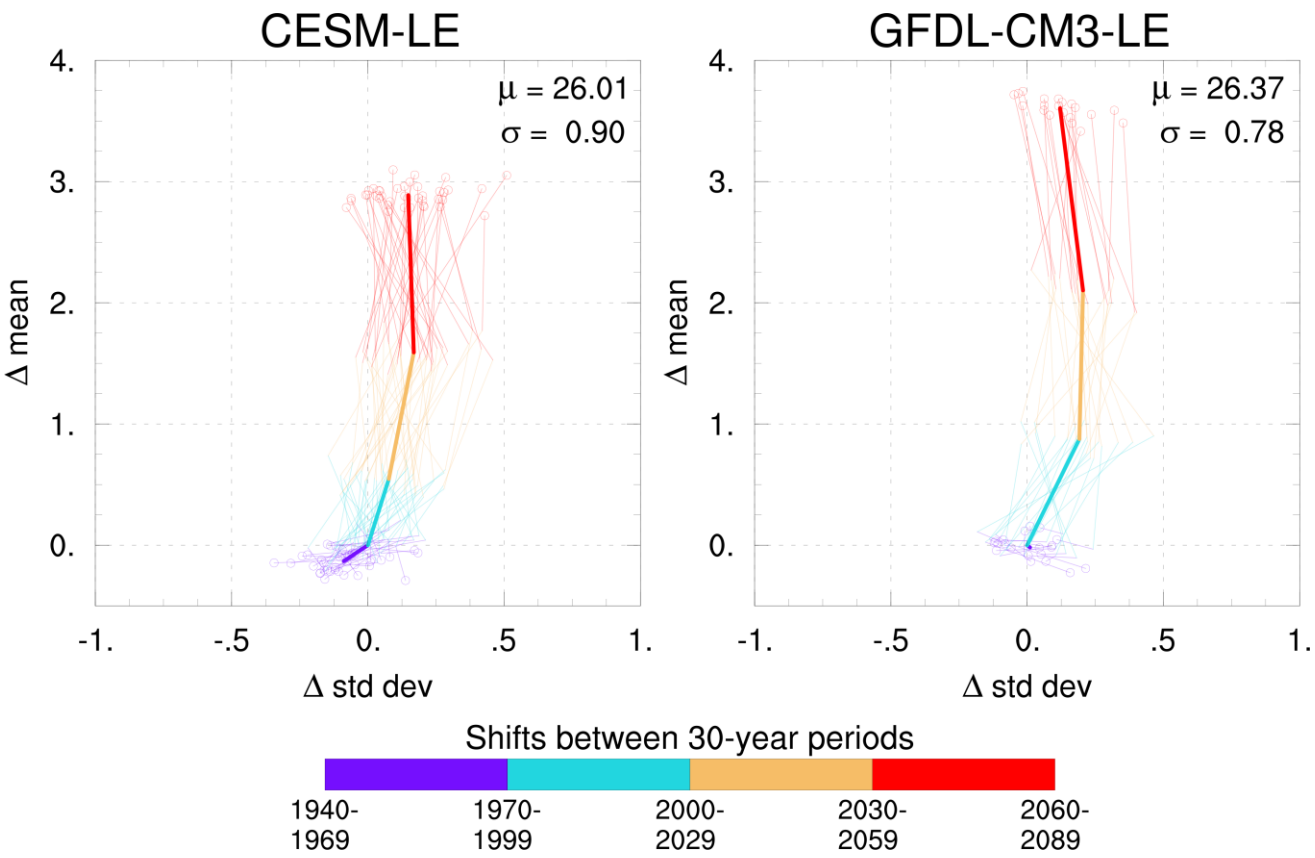


Projected changes in annual-mean **Niño3.4**, 1940-2089, relative to 1970-1999 base period, for

(top) NCAR CESM-LE
(bottom) GFDL-CM3-LE

Each line shows ensemble member, solid line shows ensemble mean

Changes in the mean are much larger than changes in variability



Simple model of root zone soil moisture

12-month running mean soil moisture anomalies can be modeled as a **memory (AR1) process forced by ENSO & weather noise**:

$$P_{(t)} = \alpha\, P_{(t-12)} + \beta\, E_{(t)} + \varepsilon$$

$P_{(t)}$ = soil moisture this year
$P_{(t-12)}$= soil moisture last year
$E_{(t)}$ = ENSO this year
ε = noise (unpredictable weather)

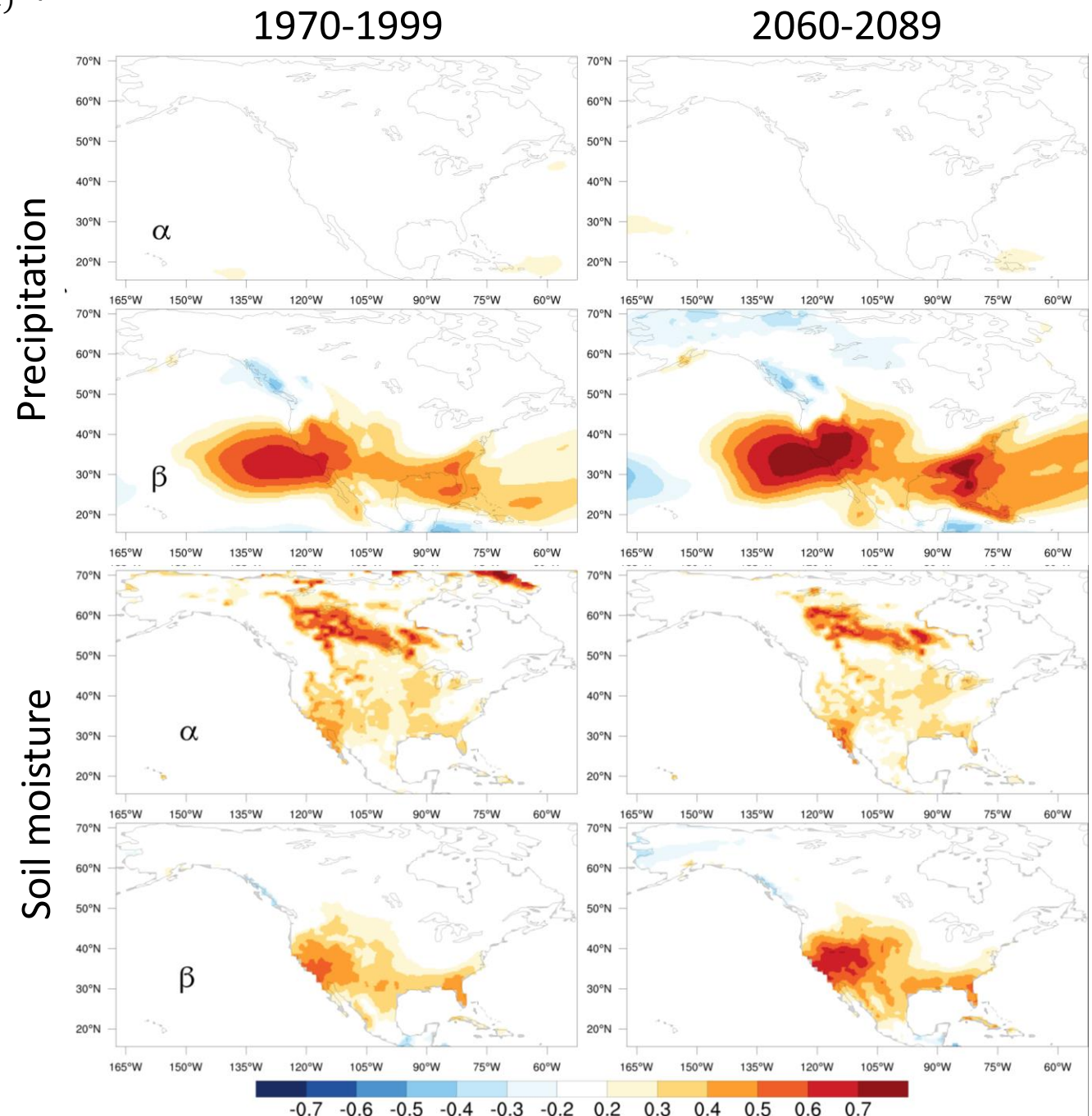
- Same as Newman et al. (2003) model of PDO
- Forecasts are then $\hat{P}_{(t)} = \alpha\, P_{(t-12)} + \beta\, E_{(t)}$
- $P_{(t)}$ can also represent precipitation

Predictability = *f (S)* , where S^2 = forecast variance/error variance

$$P_{(t)} = \alpha\, P_{(t-12)} + \beta\, E_{(t)} + \varepsilon$$

Both precipitation and soil moisture are strongly teleconnected to ENSO but soil moisture also has substantial year-to-year memory

[That is, memory not just due to annual-averaging]

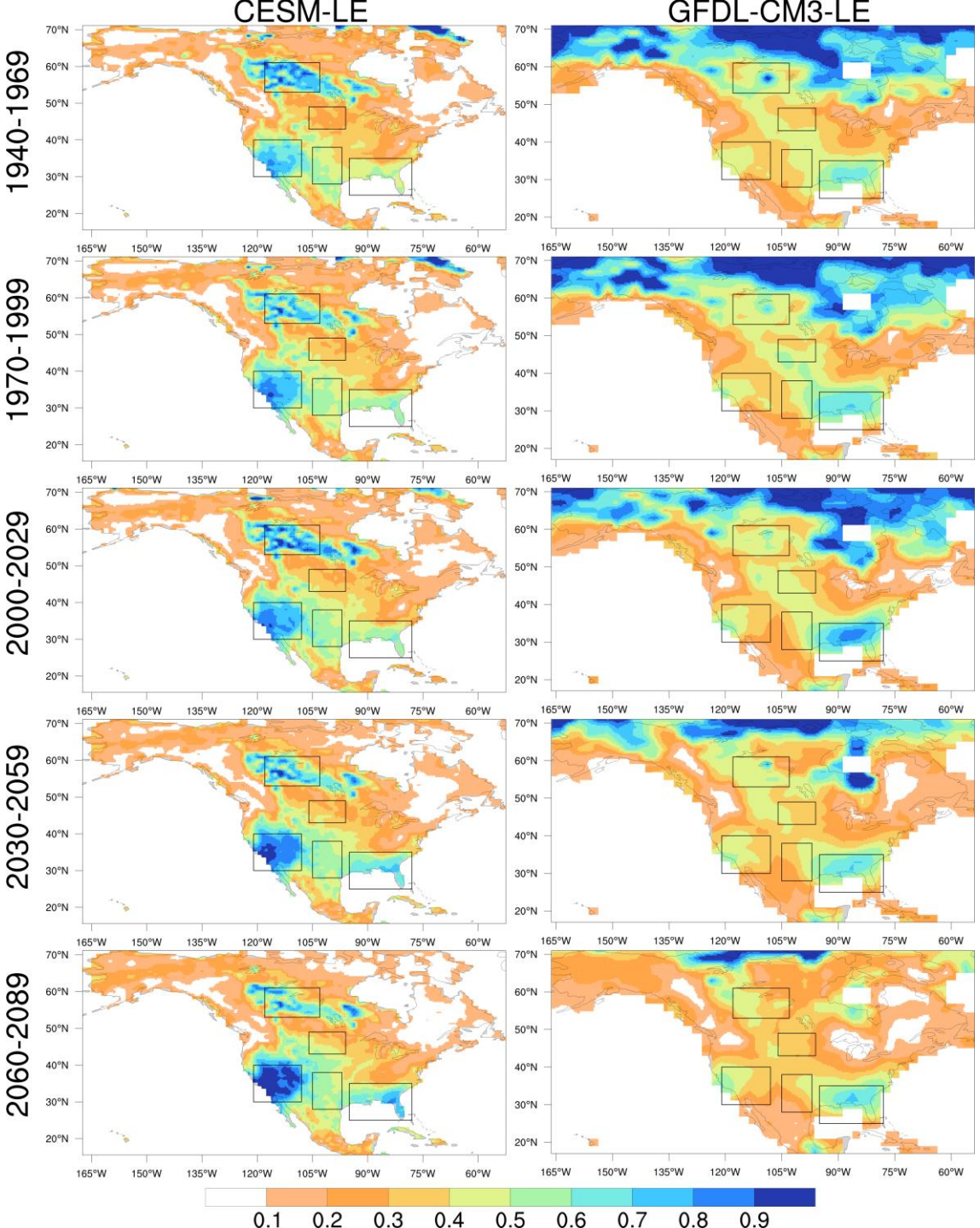


Projected changes in soil moisture predictability

(left) NCAR CESM-LE
(right) GFDL-CM3-LE

Predictability strongly increases even as variability does not

This increase is much stronger for CESM1 than CM3, consistent with ENSO change in each model



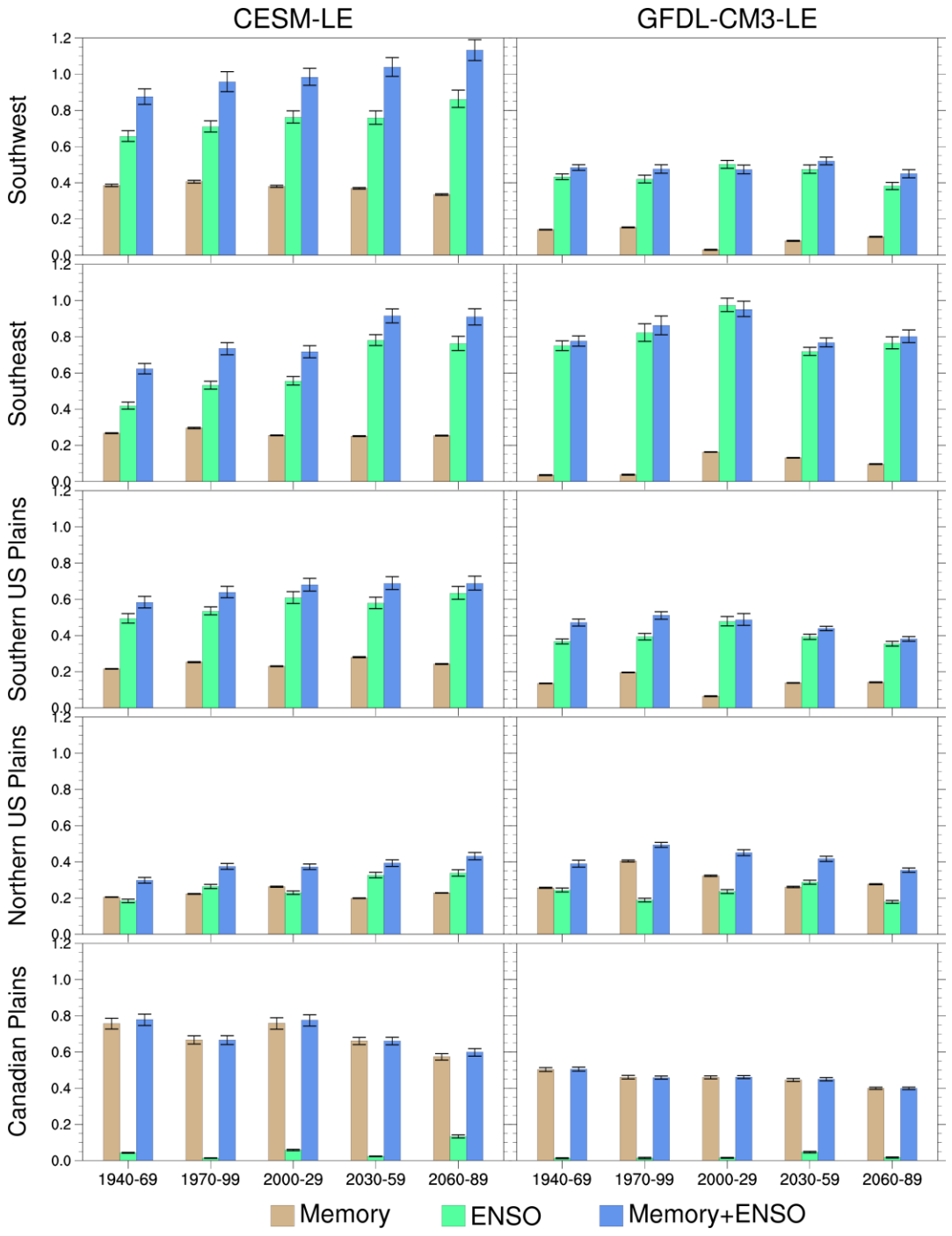
Projected changes in soil moisture predictability in selected regions due to memory and ENSO terms

(left) NCAR CESM-LE
(right) GFDL-CM3-LE

Predictability increases where ENSO-forced component gets stronger

Memory weakens slightly as mean soil moisture gets drier

Uncertainty estimates from bootstrapped ensembles

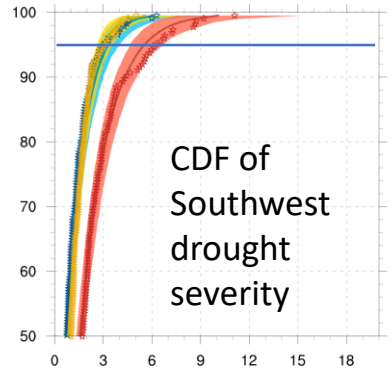


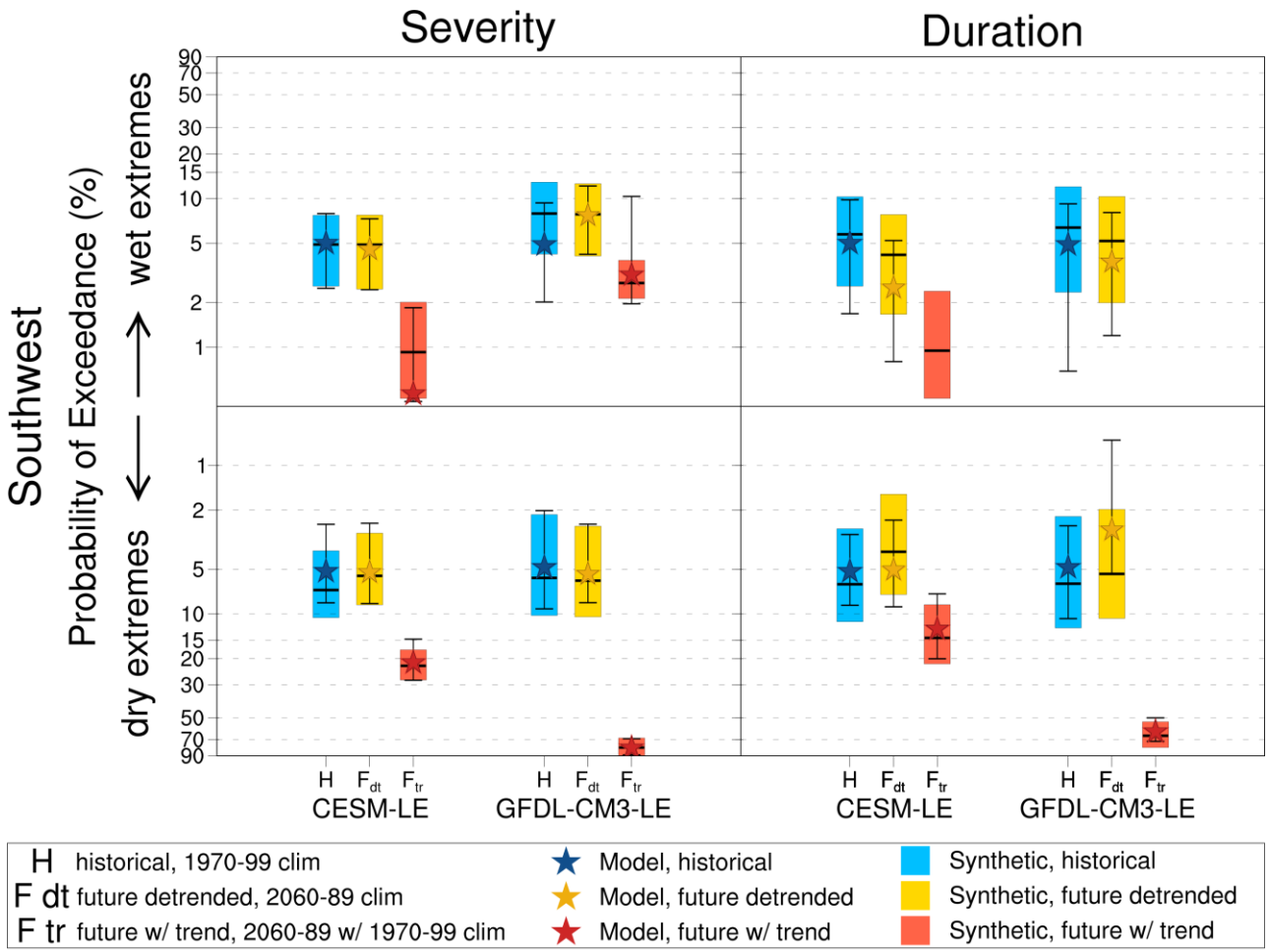
Forced changes in extreme drought/pluvials are due to the mean shift in climate but not to change in variability

Projected changes in probability of exceedance of wet and dry extremes in US Southwest

Threshold defined by 95th percentile based on statistics from:

blue: 1970-99
yellow: 2060-89
red: 2060-89 *but relative to 1970-89 climate*





Duration: length of event (one sign)
Severity: integrated anomaly over the event

Conclusions* (*in these models)

- Annual mean soil moisture variability can be modeled as a **reddened ENSO response**
  - Just like the PDO!
- Soil moisture memory slightly decreases as mean soil moisture is reduced
- So, stronger ENSO teleconnections make soil moisture more predictable but do not increase variability
  - Just like the PDO!
  - Compare with precipitation/temperature variability (e.g. Fasullo et al. 2018)
- Changes in hydroclimate extremes (drought/pluvial) are due almost entirely to changes in the mean and not to changes in variability

PDSI-root zone soil moisture relationship