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Projected Changes in S2D Hydroclimate Predictability in North America in CESM-LE

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Grant RC-2711: Developing an Experimental Predictive Framework for Climate Regime Shifts and Their Impacts Within a 2-20 Year Outlook Window

CIRES

Cooperative Institute for Research in Environmental Sciences
UNIVERSITY OF COLORADO **BOULDER** and **NOAA**

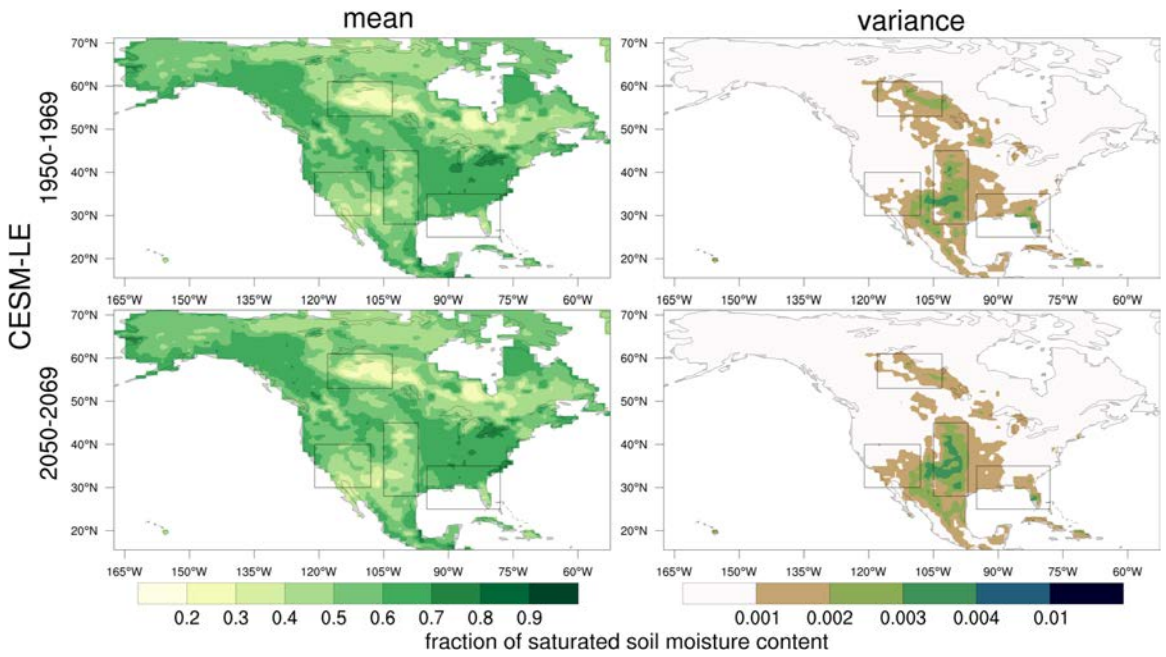
Goals

- Test a simplified linear regression model framework to uncover potential predictability of the North American hydroclimate
- Understand predictability of changes in drought characteristics between consecutive 20-year periods, in the context of long-term changes

Approach

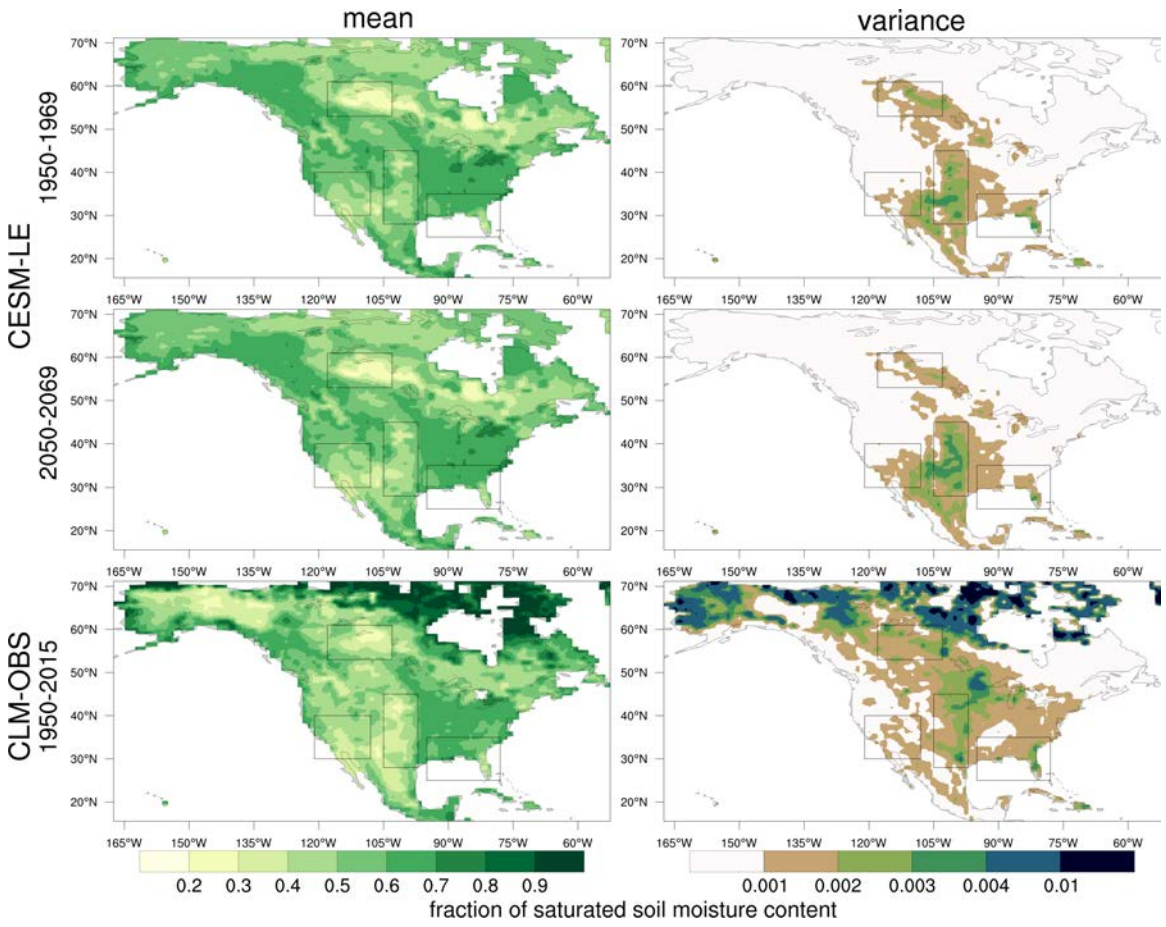
- "Perfect model" – framework is tested within the **CESM Large Ensemble** (40 members, 20th century & RCP8.5 radiative forcings)
- **Soil moisture** predictability represents the integrative response of land to atmospheric forcing
- Analyses were done on six consecutive **20-year periods** (1950-69, 1970-89,…,2050-69); results contrast the first and the last periods as they illustrate the largest shifts

Changes in soil moisture mean and variance



- 12-month running means of root zone (1 m) soil moisture
- Means and variances computed over 20-year periods
- Means computed before detrending
- Variances computed on (detrended) anomalies to the ensemble mean

Changes in soil moisture mean and variance



- 12-month running means of root zone (1 m) soil moisture
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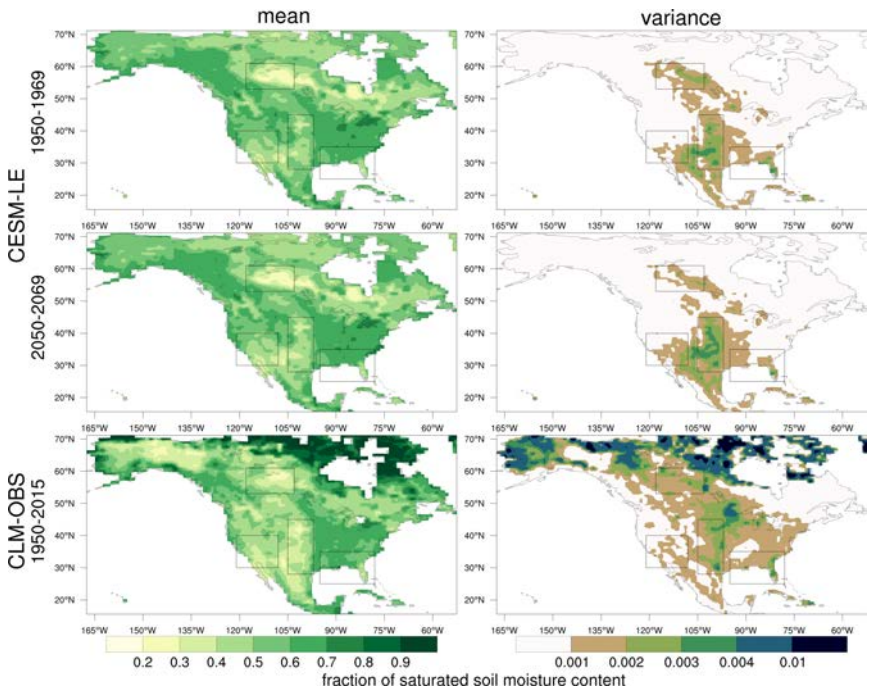
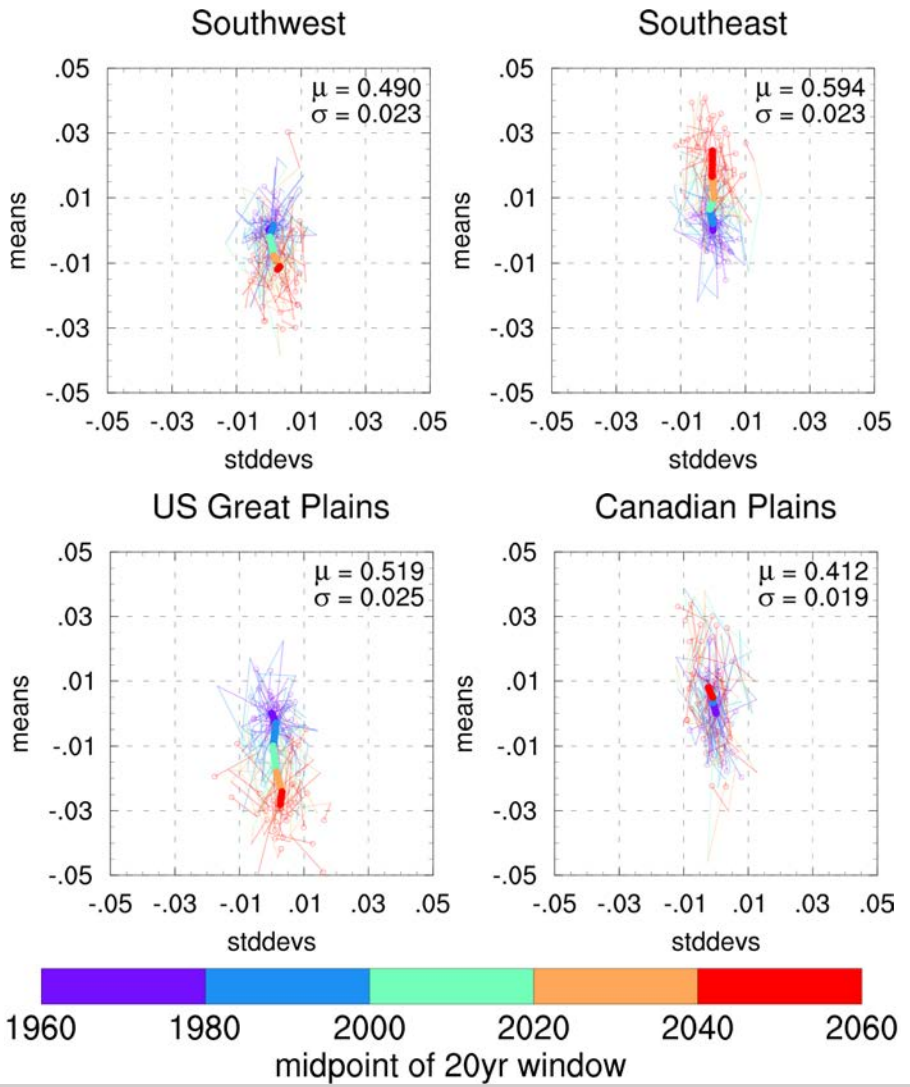
"observational reference"
(not a direct comparison)

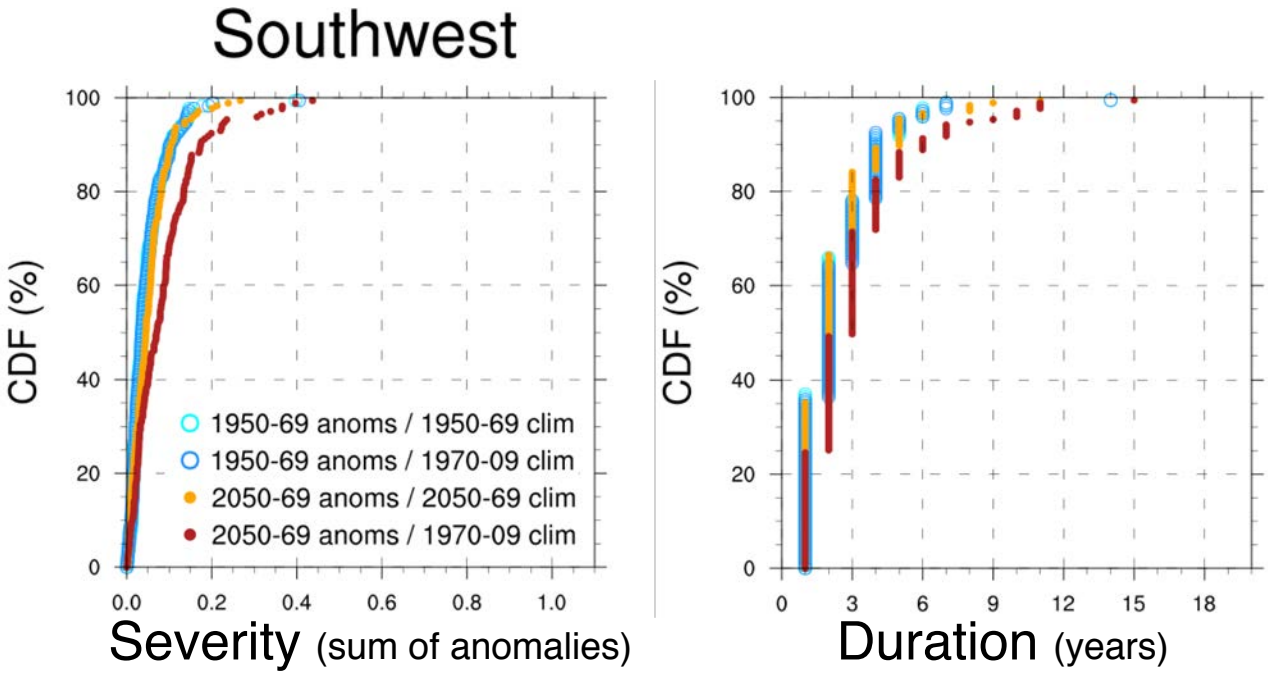
Changes in soil moisture mean and variance



- Externally-forced soil moisture mean changes are small but significant over the entire period, relative to changes in variability



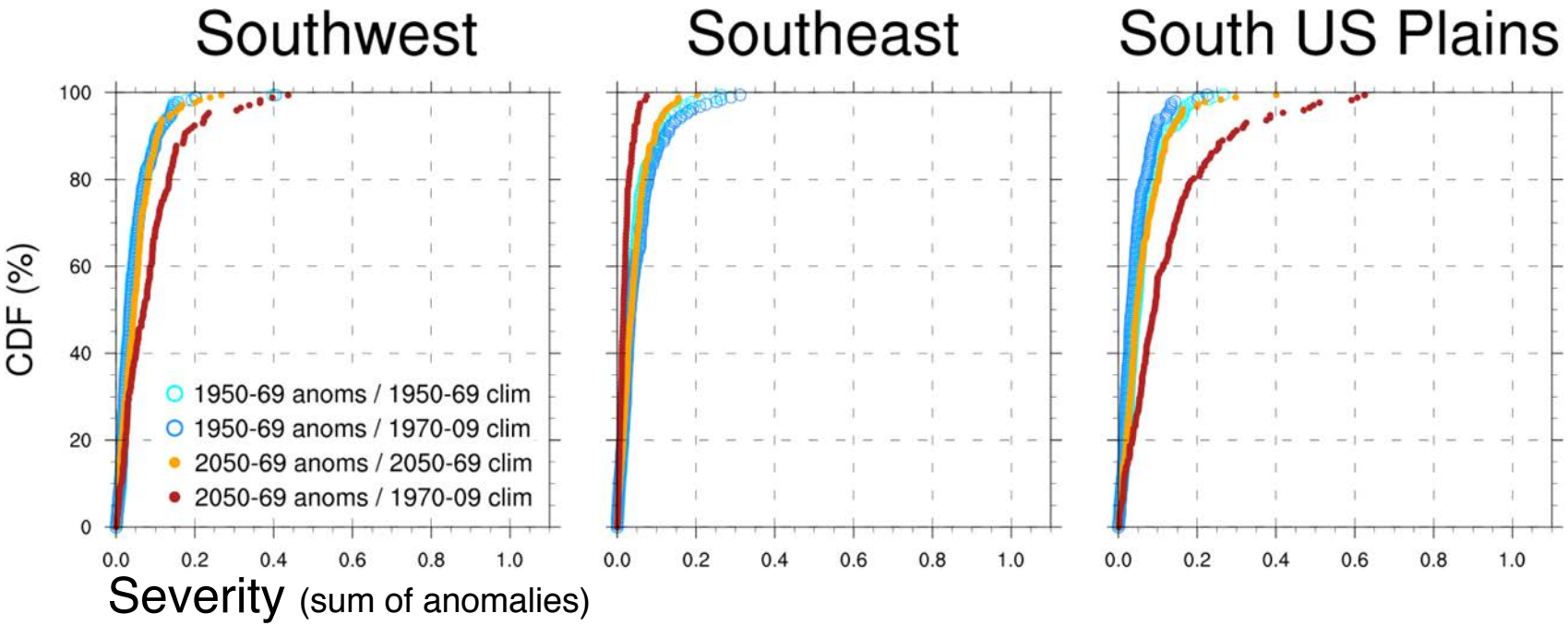
Changes in drought events in CESM-LE



- Oct-Sep annual mean soil moisture
- Any annual mean below the climatology was considered "drought"

- "detrended anomalies" are anomalies relative to the respective 20-year climatology
- "total anomalies" are anomalies relative to 1970-2009 climatology, and include the externally-forced changes in mean soil moisture
- Changes in drought events appear to be mostly driven by changes in the mean

Changes in drought events in CESM-LE



Potential sources of predictability of soil moisture anomalies

Land surface memory

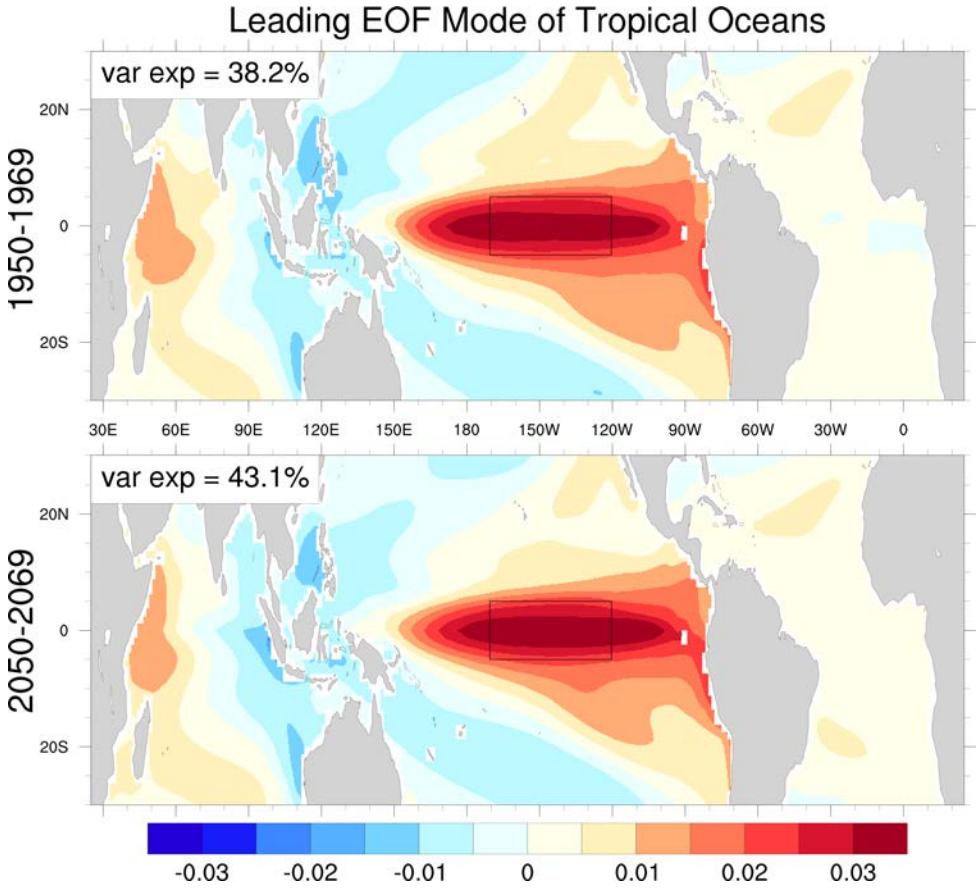
- Local forcing
- Integrates land-atmosphere feedbacks

SST variability

- Remote forcing

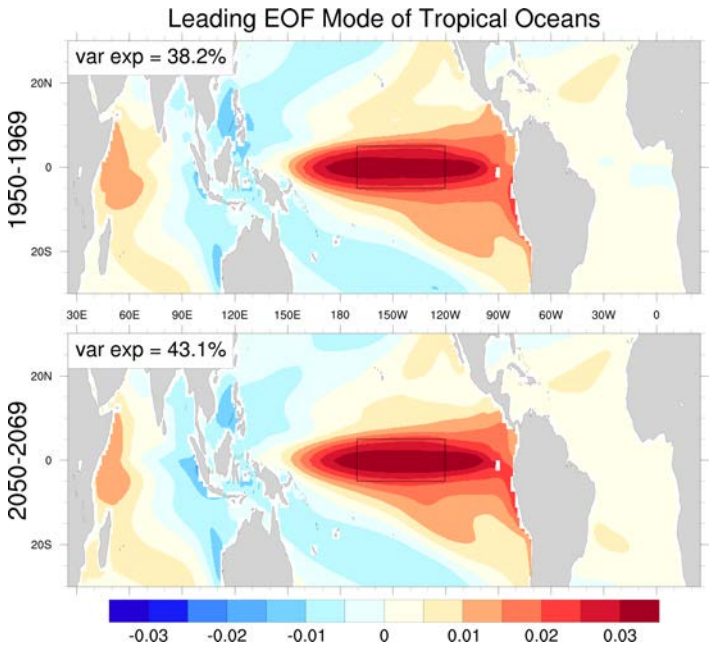
What is the impact of Pacific SSTs on soil moisture predictability?

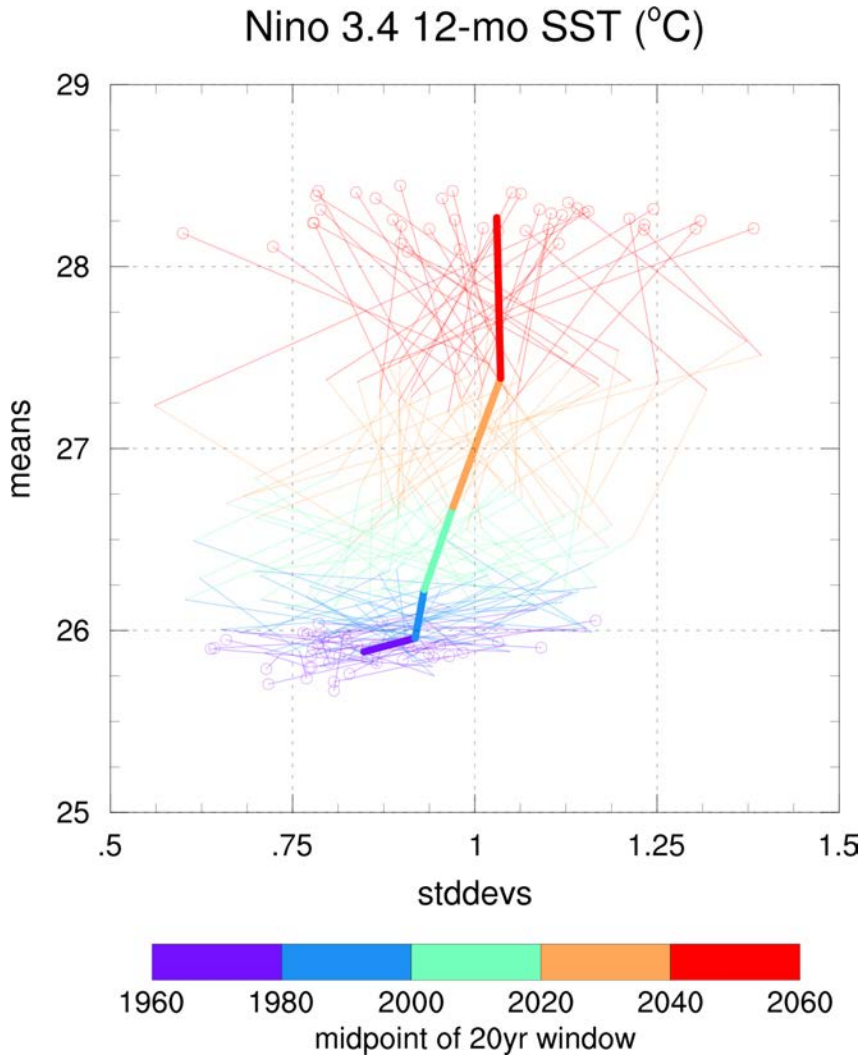
Changes in Tropical SST variability in CESM-LE



- Subtle increase in variance in tropical Pacific SST
- Increase in variance explained by the leading mode (ENSO)

Changes in Tropical SST variability in CESM-LE





- Significant increase (2.5 ˚C) in mean SST of Niño 3.4 region
- Modest increase (< .25 ˚C) in Niño 3.4 standard deviation, with larger spread of changes across ensemble members

Three Simple Linear Models

- "Memory": single predictor of soil moisture anomaly is the anomaly observed 12 months prior

$$S_{(t)} = a\, S_{(t-12)} + \varepsilon_a$$

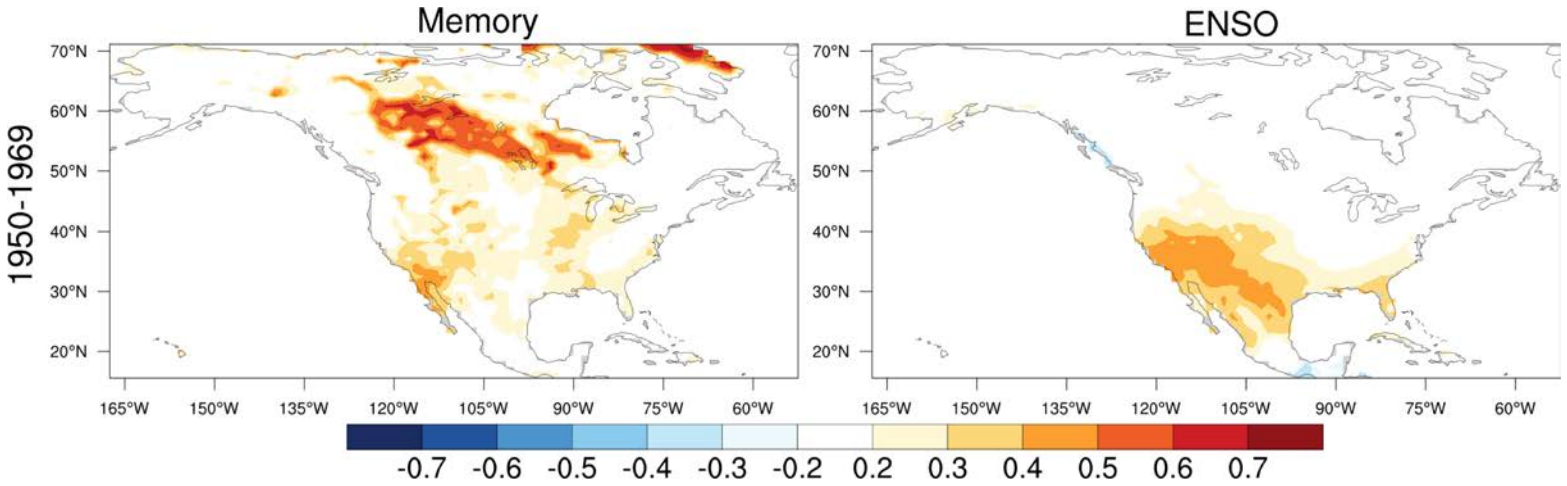
- "ENSO": single predictor of soil moisture anomaly is the ENSO PC value for same month (assumes perfect knowledge of ENSO)

$$S_{(t)} = b\, E_{(t)} + \varepsilon_b$$

- "Memory + ENSO": both soil moisture memory and ENSO are predictors of a soil moisture anomaly

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

Spatial pattern of regression coefficients

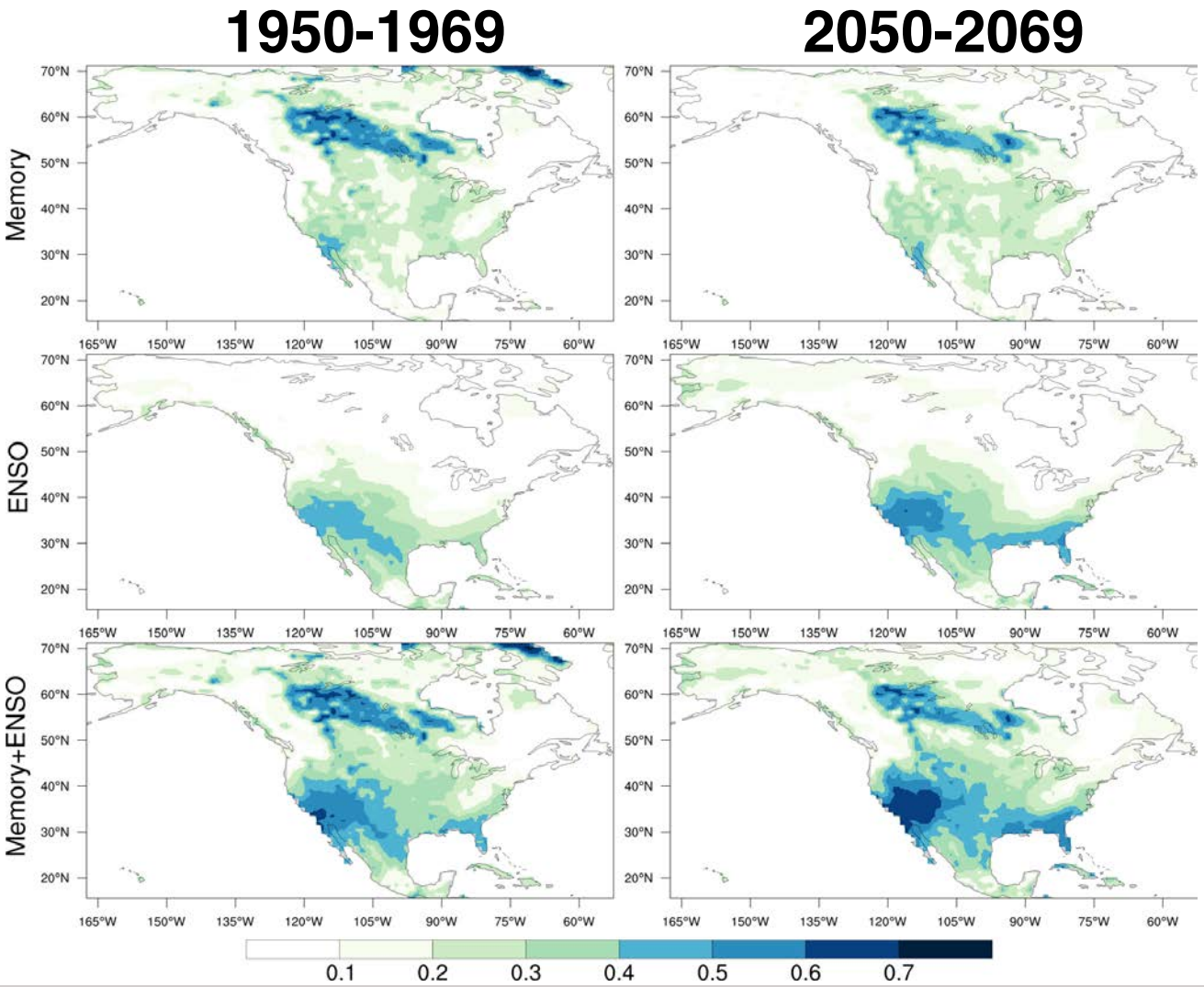


- Land surface memory is a strong predictor of soil moisture anomalies across the Canadian Plains; much weaker throughout rest of North America
- ENSO is relatively strong predictor across south-central and southeastern US
- Memory and ENSO coefficients obtained in the bivariate model were nearly identical in spatial pattern and magnitude

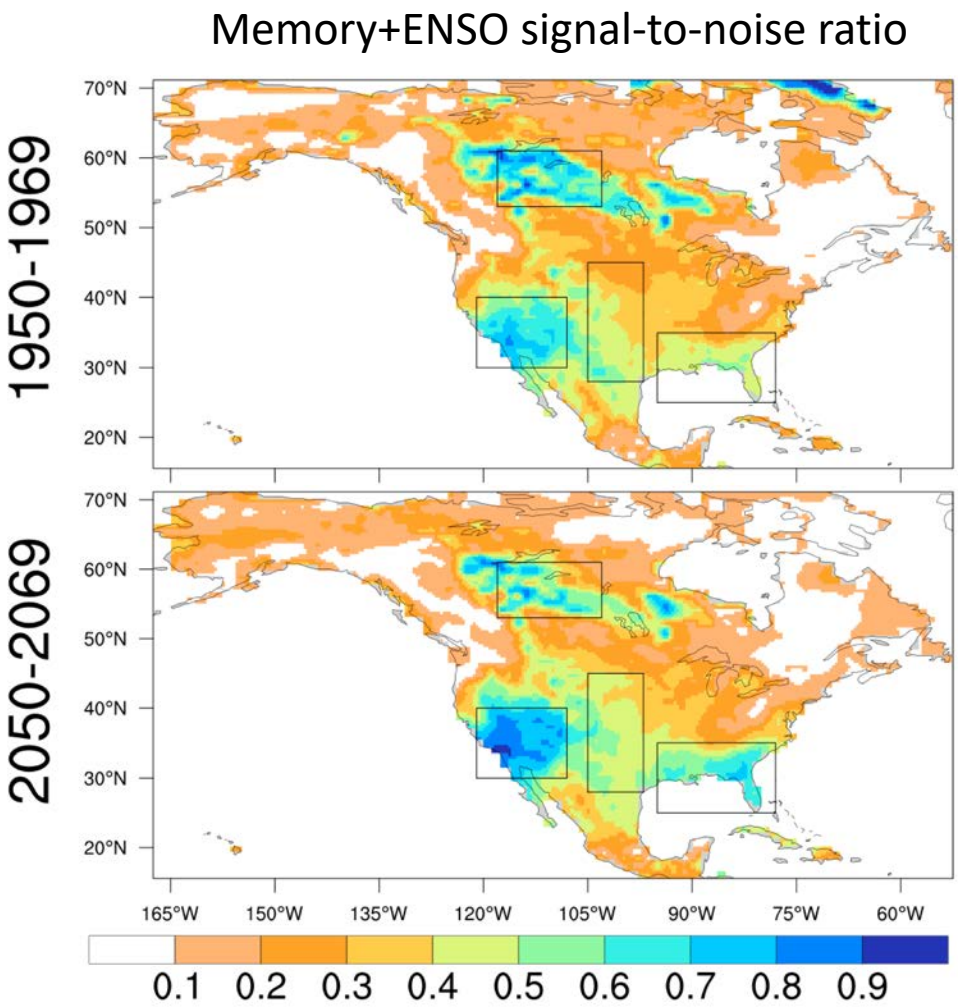
Skill of regression models changes over time

Skill = corr($S_{(t)}, \hat{S}_{(t)}$)

- Matches pattern and absolute magnitude of regression coefficients
- Skill of ENSO predictor increases, while Memory slightly decreases



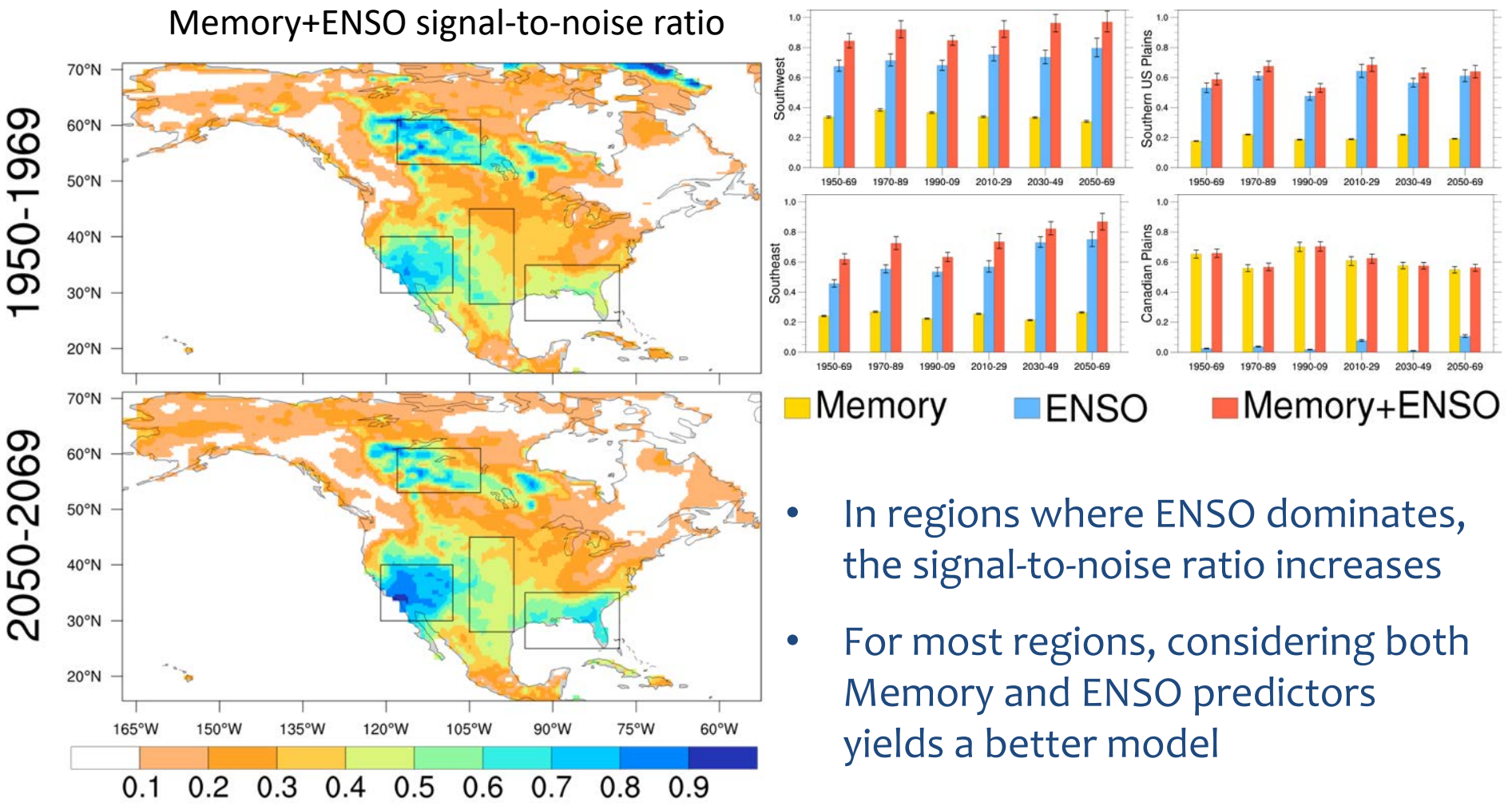
Projected changes in signal-to-noise ratio



$$S2N = \sqrt{\frac{var(\hat{S}_{(t)})}{var(\varepsilon)}}$$

- Mostly increases over southern US
- Decreases over Canadian Plains

Projected changes in signal-to-noise ratio



- In regions where ENSO dominates, the signal-to-noise ratio increases
- For most regions, considering both Memory and ENSO predictors yields a better model

Using the "Memory+Enso" model to generate synthetic soil moisture anomalies (Oct-Sep annual means)

Coefficients determined with CESM-LE

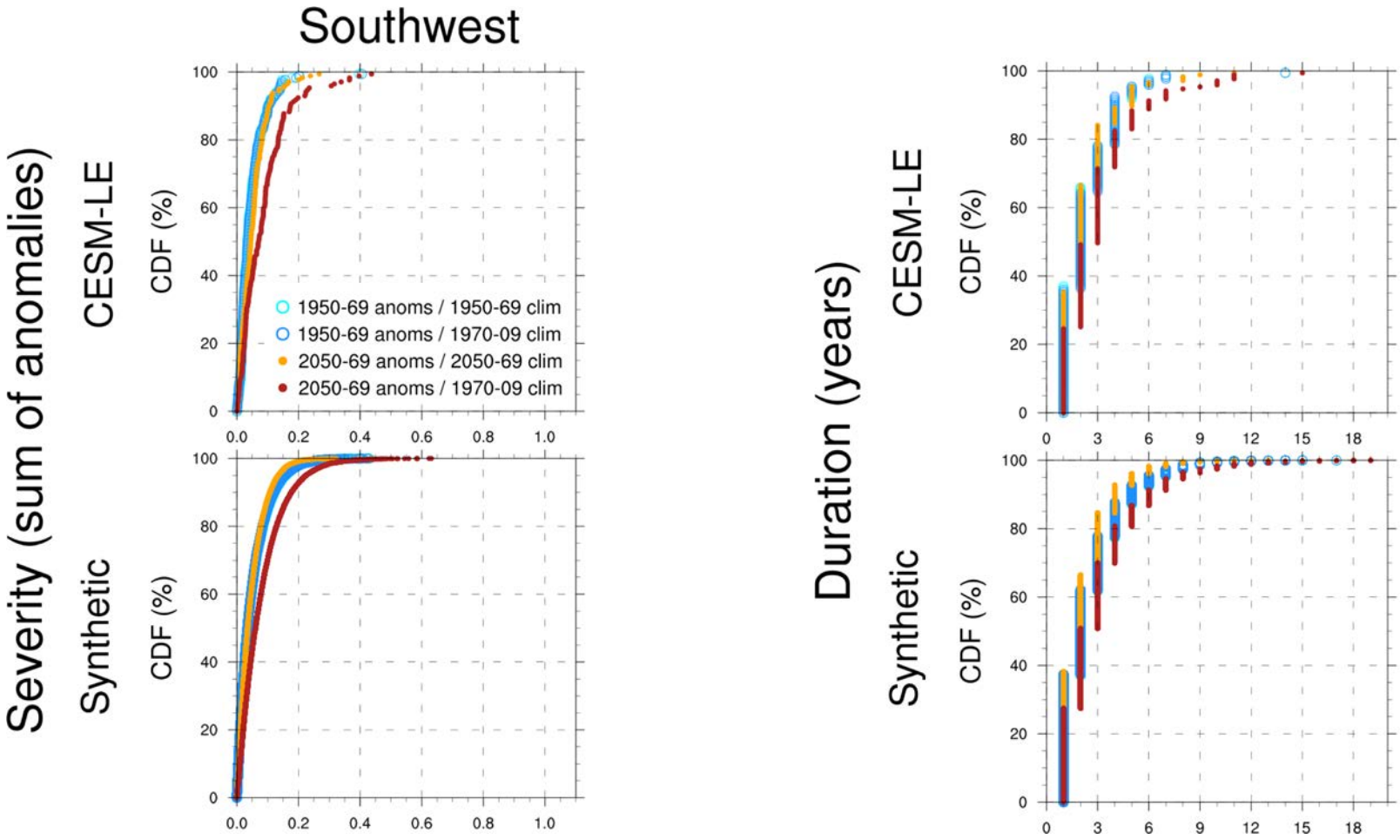
$$\dot{S}_{(t)} = \alpha S_{(t-1)} + \beta E_{(t)} + \varepsilon$$

Randomized initial soil moisture condition (i.e. $S_{(-1)}$)

$E_{(t)}$ 20-yr sequences taken from CESM-LE; bootstrapped to generate 100 x 40 realizations

Randomized error

Comparing synthetic drought events to CESM-LE



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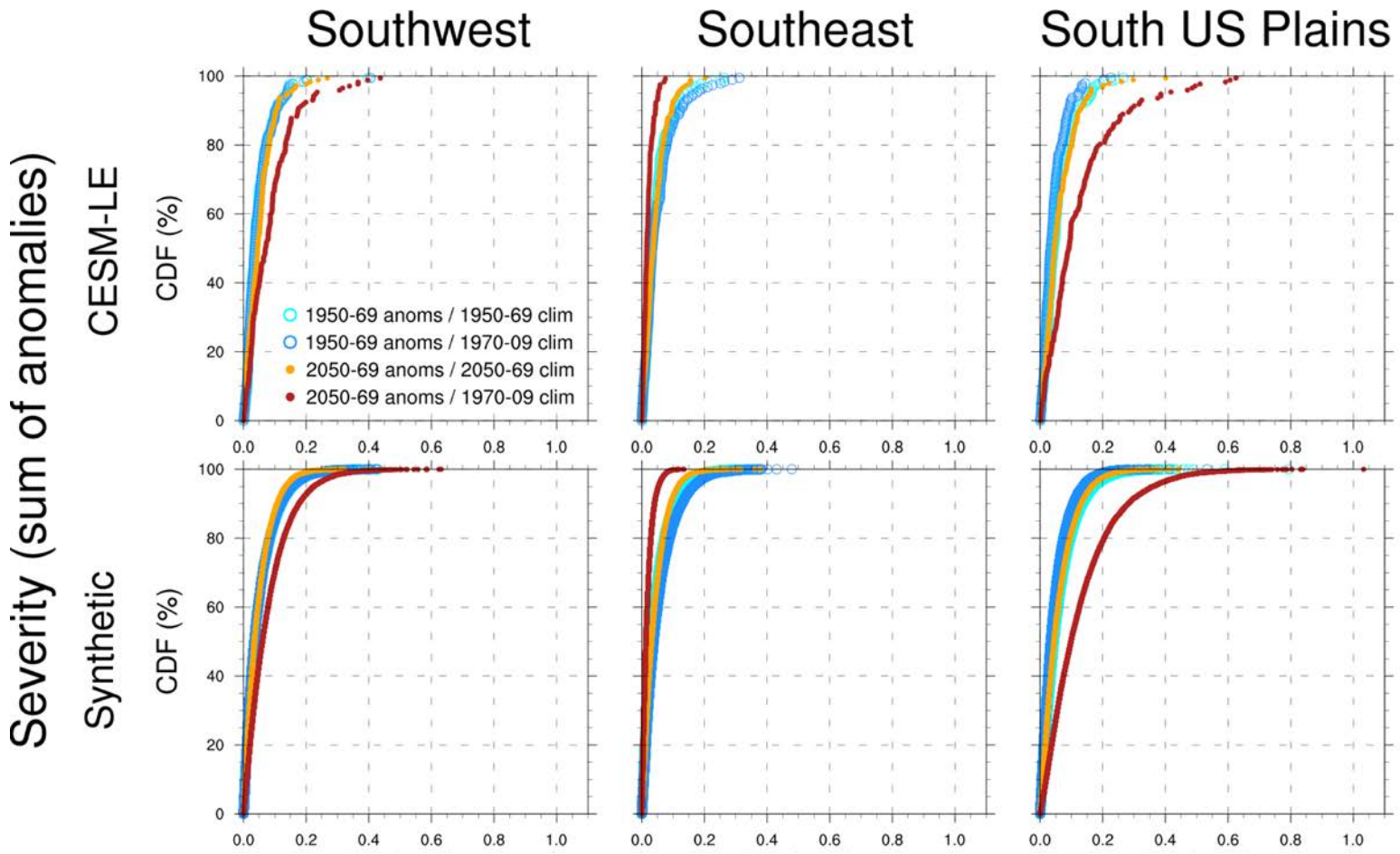

Concluding Remarks

- For most of North America, CESM-LE projects increased hydroclimate predictability in the warmer climate, even though no significant change in overall hydroclimate variability is projected.
- This is due primarily to a strengthening of the ENSO-related predictable component, which coincides with a pronounced increase in the mean and slight increase in the variance of tropical Pacific SSTs.
- Predictability due to land surface memory remains the same or slightly decreases.

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- For some regions (e.g. SW and Great Plains), CESM-LE projects overall drying that will increase the duration and severity of drought defined relative to late 20th century climate normal. However, drought variability itself is not projected to change significantly.
- The implication for decadal drought forecasts (in the CESM-LE world, at least) is that they will need to consider the mean change over the forecast period; changes in higher moments may not need to be considered.
- A linear model considering land surface memory and ENSO as predictors of annual soil moisture anomalies satisfactorily reproduces CDFs of drought severity and duration in CESM-LE, as well as their increased predictability.

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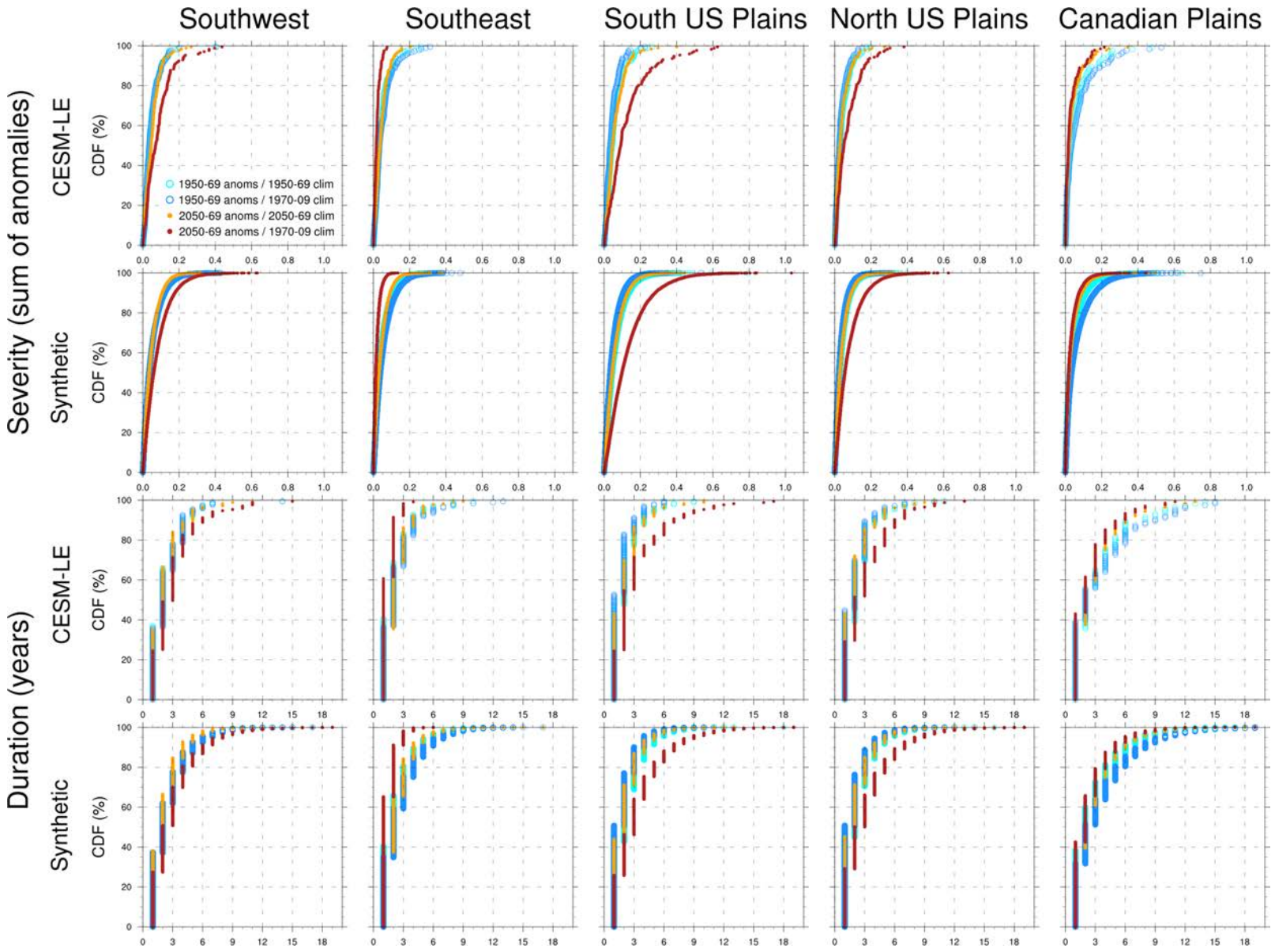
Thank you! Qs?

Extra slides


Southwest
Southeast
South US Plains
North US Plains
Canadian Plains
Severity (sum of anomalies)
Duration (years)
CESM-LE
Synthetic
CDF (%)
1950-69 anoms / 1950-69 clim
1950-69 anoms / 1970-09 clim
2050-69 anoms / 2050-69 clim
2050-69 anoms / 1970-09 clim

CLM-OBS (1958-2007)

estimating soil moisture with the "Memory + ENSO" model (using **Hadisst v.5** for ENSO PC)