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

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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, 20\textsuperscript{th} 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

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- Means and variances computed over 20-year periods
- Variances computed on (detrended) anomalies to the ensemble mean

“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

Severity (sum of anomalies)

Southwest | Southeast | South US Plains

CDF (%)
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

\[ S(t) = \alpha S(t-12) + \beta E(t) + \varepsilon \]
• 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 = \text{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

Memory+ENSO signal-to-noise ratio

\[ S2N = \sqrt{\frac{\text{var}(\hat{s}_t)}{\text{var}(e)}} \]

- 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)

\[ \dot{S}(t) = \alpha S(t-1) + \beta E(t) + \varepsilon \]

- Coefficients determined with CESM-LE
- 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
Comparing synthetic drought events to CESM-LE

Southwest

Southeast

South US Plains

Severity (sum of anomalies)

CESM-LE

Synthetic

CDF (%)
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
CLM-OBS (1958-2007) estimating soil moisture with the “Memory + ENSO” model (using Hadisst v.5 for ENSO PC)