Decadal potential predictability of soil water, vegetation, and wildfire frequency over North America

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Mega-droughts in US historical records

Woodhouse and Overpeck (1998)
Total water storage is predictable on decadal timescales even though precipitation is less predictable beyond 1 year.
Model experiment

- Low-resolution version of CESM 1.0.3 (Shields et al. 2012)
  - ATM & LND: T31 L26
  - OCN & SEA ICE: 3 x 3 L60

- A 900-year-long pre-industrial control simulation (+100-yr spinup)

- Hindcast experiment for 200-yr CTL run.

100-yr spin-up → 900-yr CTL → 200-yr Hindcast

- 10-yr prediction
- 10-member (ATM perturbed)
- Every 5-yr
- 39 initial cases
EOF1 for prec. and soil water

Annual Prec.
(a) Pattern
Cl: 0.05 mm/day

EOF1 for Precipitation (17.2%)
(b) White noise

Total Water
(g) Pattern
Cl: 20 mm

EOF1 for Total water storage (13.5%)
(h) Red noise

(c) Power spectrum

(i) Power spectrum
Water budget in soil layer

\[
\frac{\partial W}{\partial t} = P - E - R + S \\
\approx -\lambda W + P(t)
\]

Delworth and Manabe (1988)

AR1 process

\[
W_{i+1} = \alpha W_i + \varepsilon_i \\
= \varepsilon_i + \alpha \varepsilon_{i-1} + \alpha^2 \varepsilon_{i-2} + \alpha^3 \varepsilon_{i-3} + \cdots
\]

Soil layer acts as an integrator of precipitation: the filtering effect
\[ W_{i+1} = \alpha W_i + \varepsilon_i \]

\( \alpha \): Auto-correlation with 1-yr lag

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**AR1 process estimated from precip.**
Soil acts as a natural low-pass filter.

Annual Prec.:
- EOF1 for Precipitation (17.2%)
- Principal component
- Power spectrum

10-yr Prec.:
- EOF1 for Low-frequency precipitation (17.1%)
- Principal component
- Power spectrum

Total Water:
- EOF1 for Total water storage (13.5%)
- Principal component
- Power spectrum

White noise
Red noise

Ar1 process estimated from precip.
Relationship between the land hydrology and the westerly jet

Downstream jet activity is a main driver for land hydrological variations
Can we really predict the total water variations on decadal timescales?
Hindcast exp. for total water storage

Hindcast of total water storage

(a) Northern US

Total water storage (mm)

Predictable year

(b) Northern US

Soil depth

Predictable year

(c) Southern US/Mexico

Total water storage (mm)

Predictable year

(d) Southern US/Mexico

Soil depth

Predictable year

CTL run

Hindcast
Decadal land predictability: ACC skill

100 105 110 115 CTL run

HCST run (39 cases)

Soil water

Vegetation

Fire

Vegetation carbon

Fire frequency

Total water storage

(a) 1 year lead time

(b) 1 year lead time

(c) 1 year lead time

(d) 2-5 year lead time

(e) 2-5 year lead time

(f) 2-5 year lead time

(g) 5-9 year lead time

(h) 5-9 year lead time

(i) 5-9 year lead time

Legend:

- 0.21
- 0.27
- 0.37
- 0.48

0°N 20°N 40°N 60°N

120°W 100°W 80°W
Vegetation regime

Lag correlation coefficients

- Fire $\Rightarrow$ Veg
- Veg $\Rightarrow$ Fire
- Veg $\Rightarrow$ Soil

Soil water

Fire

Vegetation

<table>
<thead>
<tr>
<th>Lag (year)</th>
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<tbody>
<tr>
<td>-20</td>
</tr>
<tr>
<td>-10</td>
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<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
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<tr>
<td>20</td>
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</tbody>
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R = -0.04

R = -0.40
Soil water regime

Lag correlation coefficients

(a) Fire (line) & Soil water (color) \( R = -0.52 \)

(b) Fire (line) & Vegetation (color) \( R = -0.34 \)

Soil water \( \rightarrow \) Vegetation

Fire \( \rightarrow \) Vegetation
Schematic view of droughts in CESM

- Precipitation
- Soil water
- Moisture constrain
- Evapotranspiration
- Photosynthesis
- Vegetation
- Fuel
- Fire
- Mortality
- Low skill
- Decadal Predictability
- C/N Cycle
- Westerly Jet

Decadal Predictability

Evapotranspiration

Photosynthesis

Vegetation

Soil water

Fire

Low skill

Westerly Jet
Conclusion

- Annual mean precipitation is less predictable beyond 1-year.

- Changes in total water storage are potentially predictable on decadal timescales due to the long-term persistent memory of soil and aquifer water.

- Skillful decadal predictions of soil water storage, carbon stock, and wildfire frequency are feasible with proper initialization of soil conditions.


Impact of ocean variability on downstream jet activity is still an open question.
Possible climate forcing to the westerly jet activity

**ENSO**

- Higher pressure (cold water)
- Warm counter current
- Wet conditions
- Lower pressure (warm water)
- South America

**ENSO flavor**

![Graphs showing ACC predictive skill over lead time](image)
Multi-year memory of the tropical climate

Trans-Basin Variability
