Understanding multi-year land surface predictability

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Understanding Land Predictability

**hydrological predictability** *(watershed)*

How well can we estimate the water stored in a catchment or basin? (snow, soil moisture, lakes, riverbeds)

**meteorological predictability**

How well can we estimate the future weather and climate impacting a catchment or basin?

**Initial Hydrologic Conditions** *(IHCs or ICs, IV)*

**Climate Forecasts** *(CFs or BCs, BV)*
Understanding Land Predictability

The land is a damped system, in contrast to some aspects of the atmosphere

- Large anomalies tend to evolve toward normal in predictable ways
  - Wet land states (soil/snow) drain, run off, and evaporate/sublimate faster
  - Dry states drain and evaporate slower, allowing for recharge
- Such negative or restorative feedbacks can add to predictability (e.g., Hasselmann, 1976) or at least sustain it
In parts of the world, the annual cycle drives predictable land moisture fluxes.

- The climate drivers at the start of a cycle carry information about the land states at the end of it ... and sometime beyond.

Modeled water balance: precipitation (P), runoff (RO), snow water equivalent (SWE), soil moisture (SM)

Wood et al, HESS 2016
The practice of land prediction emphasized IC predictability

Traditional operational long-range (S2S) forecasts have harnessed IC predictability

- ‘Extended’ Streamflow Prediction (ESP) first used at CADWR and CNRFC in the mid 1970s
- NWS began ESP development in 1975

Ensemble hindcasts can be used to understand predictability

ESP Ensembles for Feather R, Inflow to Oroville Reservoir, CA

**S2S Hydrologic Prediction**

- Initial condition signal (given expected climate)
- Future weather/climate uncertainty
Exploring the sources of hydrologic predictability

Demonstration focus on two different watersheds

An ensemble approach for attribution of hydrologic prediction uncertainty

Andrew W. Wood¹ ² and Dennis P. Lettenmaier¹

Received 9 May 2008; revised 19 June 2008; accepted 24 June 2008; published 30 July 2008.

Wood & Lettenmaier, GRL, 2008; Lorenz (1975): first (IC) and second (BC) kinds of predictability; see also Collins & Allen (2002)
Exploring the sources of hydrologic forecast uncertainty

- Ratios of error: Error (MSE) from ESP and rev-ESP as a fraction of climatological variance
  - based on multi-year hindcasts
  - forecasts initialized 4x per year (Oct, Jan, Apr, Jul)

climate forecasts more important than initial conditions

initial condition more important than climate forecasts
Seasonally varying influence of IC and climate information

Snowmelt basin in the Western US

- Wide seasonal variations in influence of different skill sources

- Cold forecast period (Nov-Jan) -- forecast skill depends mainly on initial condition accuracy

- Warmer snowmelt forecast period (Feb-Apr) forecast skill depends strongly on meteo. forecast skill

IHC: initial Hydrologic Conditions
SCF: Seasonal Climate Forecasts

Wood et al (JHM, 2016)
Humid Basin in the Eastern US

- Few seasonal variations in streamflow skill dependence
- Forecast skill (3 months) is always a blend of IHC and SCF influence

Seasonally varying influence of IC and climate information
Describing the influence of predictability source using forecast skill elasticity

**Elasticity** = change in [variable] forecast skill with respect to changes in the estimated skill or accuracy of the predictability source

- e.g., ICs, BCs
- assessed through hindcast resampling
- a skill attribution method
- could guide investments in IC or BC capability

Total Water Storage (TWS) decadal forecast skill

See: Wood et al, HESS, 2016; Arnal et al, JHM, 2017
Recent exploration of interannual skill using two 40-member systems (DePreSys3, CESM-DPLE) reveals potentially useful skill for some regions, particularly during active ENSO seasons.

To be explored further within CESM’s Earth System Prediction Working Group: Seasonal-to-Multiyear Large Ensemble (SMYLE) Project.
Total water storage (TWS) interannual prediction skill

- Month 19 skill (detrended) can be significant in places ... (Yeager et al, 2022)
Predictability: annual precipitation versus land moisture storage

Modeled soil moisture: annual precip greater than storage $\rightarrow$ regular refill $\rightarrow$ memory loss

Results based on SUMMA watershed modeling at NCAR
In applied/operational contexts, there is some evidence of multi-year memory in SW US river basins such as the Colorado River Basin. The Colorado River Basin Operational Prediction Testbed: a tool for improving water management through benchmarking seasonal to interannual forecasts of streamflow and reservoir system projections, *J. Amer. Water Res. Assn.* (in review)

- Testbed establishes framework for testing performance of streamflow forecasts and modelled operations in the Colorado River Basin (CRB)
- Evaluate current and experimental streamflow forecasting methods

From a NOAA & Reclamation research project

‘Year-2’ inflow prediction skill for Lake Powell (Colorado R)

ESP & Clim-kNN: initialized predictions

We know enough to develop expectations for when and where we should find terrestrial/hydrologic predictability.

For example ...

<table>
<thead>
<tr>
<th>Land Storage/Annual Precipitation</th>
<th>Climate Predictability</th>
</tr>
</thead>
<tbody>
<tr>
<td>• excursions from normal are driven by climate, rapid recovery possible</td>
<td>• can have prolonged excursions from normal are driven by climate and sustained by land</td>
</tr>
<tr>
<td>• most predictability from climate forecasts</td>
<td>• predictability from both ICs and climate forecasts</td>
</tr>
<tr>
<td>• excursions from normal are driven by climate, rapid recovery possible</td>
<td>• can have prolonged excursions from normal are driven by climate and sustained by land</td>
</tr>
<tr>
<td>• little predictability</td>
<td>• most predictability related to ICs</td>
</tr>
</tbody>
</table>

Wood et al, 2022 (in prep)
Take-aways

• It is helpful to understand the components of land surface predictability
  — Initial condition, boundary forcing, internal land process feedbacks (damping)
  — Starting with an expectation of predictability can help us identify whether our prediction skill makes sense (or doesn’t)

• S2S to decadal hydrologic predictability varies in time, by season, by climate system mode, and by (hydroclimate) location.

• Multi-year semi-skillful forecasts for the land surface are possible but not everywhere and always
  — governed by conditionally skillful climate forecasts
  — in locations where the land hydroclimate is conducive
  — ‘forecasts of opportunity’

• Multi-year Earth System knowledge and science is still developing, with more focus initially on climate system aspects such as ENSO, SSTs) – but such predictability is degraded in translation to continental or regional climate, and associated hydrology
  — conversations with potential stakeholders should be clear about progress
  — e.g., at present we’re comfortable with multi-year to decadal temperature forecasts and some temperature-impacted hydrology