Understanding multi-year land surface predictability

Andy Wood
National Center for Atmospheric Research -- Boulder, Colorado
Climate and Global Dynamics / Research Applications Lab

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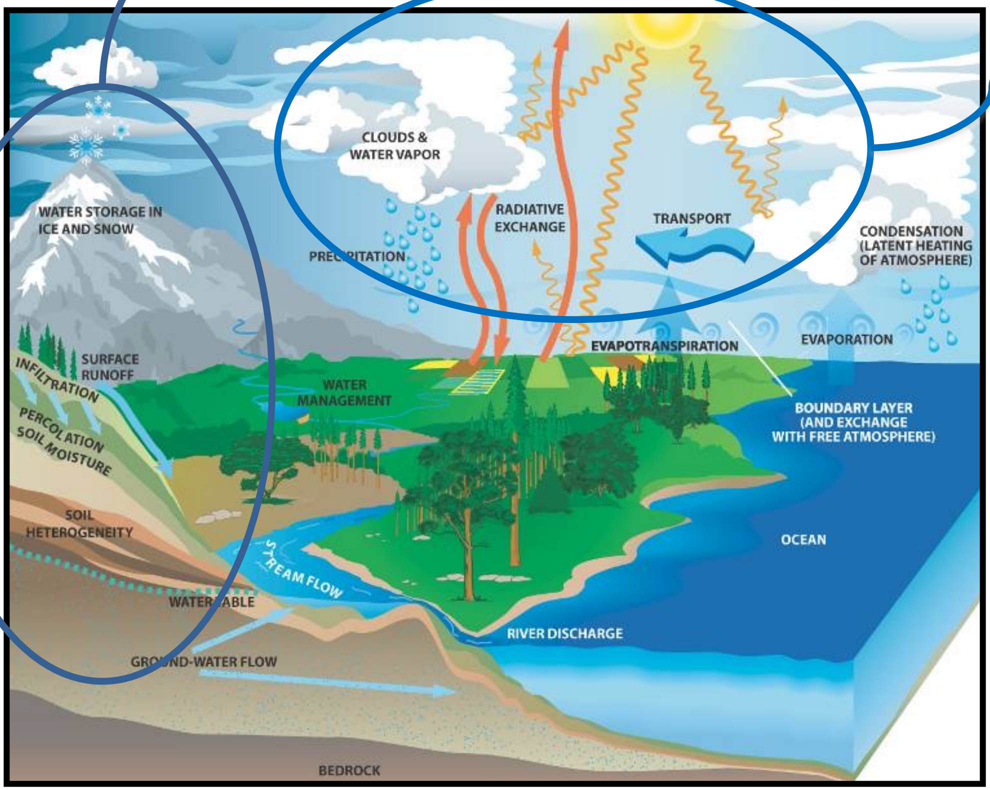
NCAR

Understanding Land Predictability

hydrological predictability (watershed)

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

Initial Hydrologic Conditions (IHCs or ICs, IV)



meteorological predictability

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

Climate Forecasts (CFs or BCs, BV)

Understanding Land Predictability

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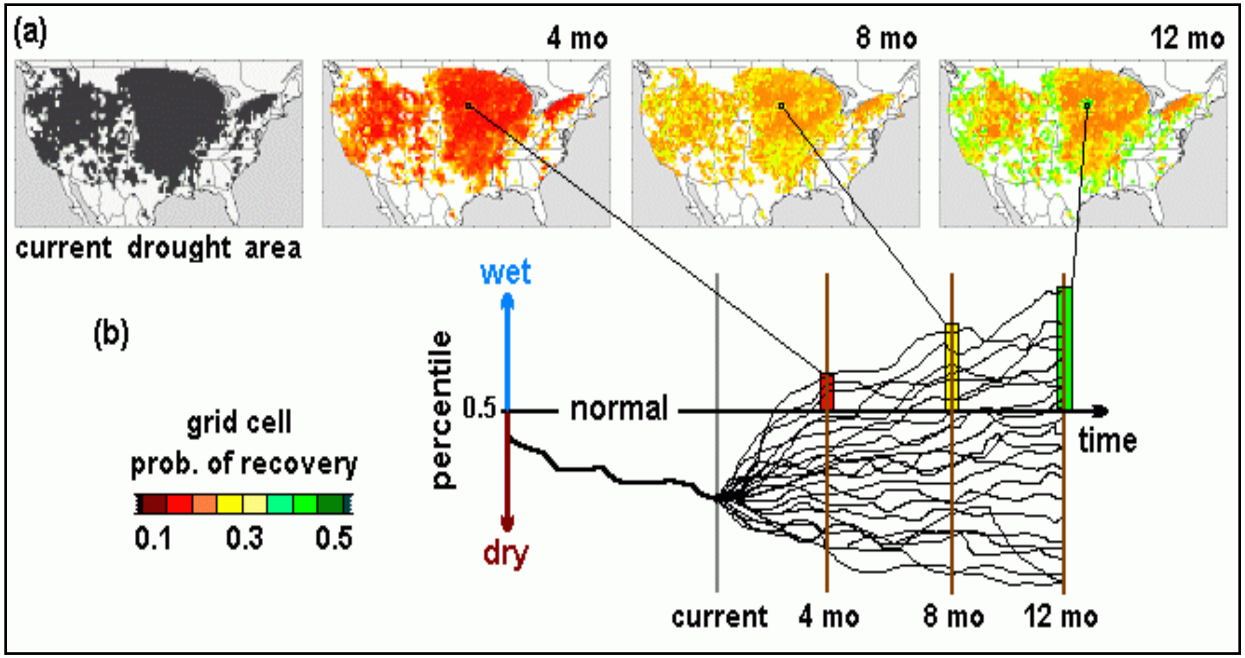
The land is a damped system, in contrast to some aspects of the atmosphere

- 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



Wood, AW (AMS, 2008): UW Surface Water Monitor

Understanding Land Predictability

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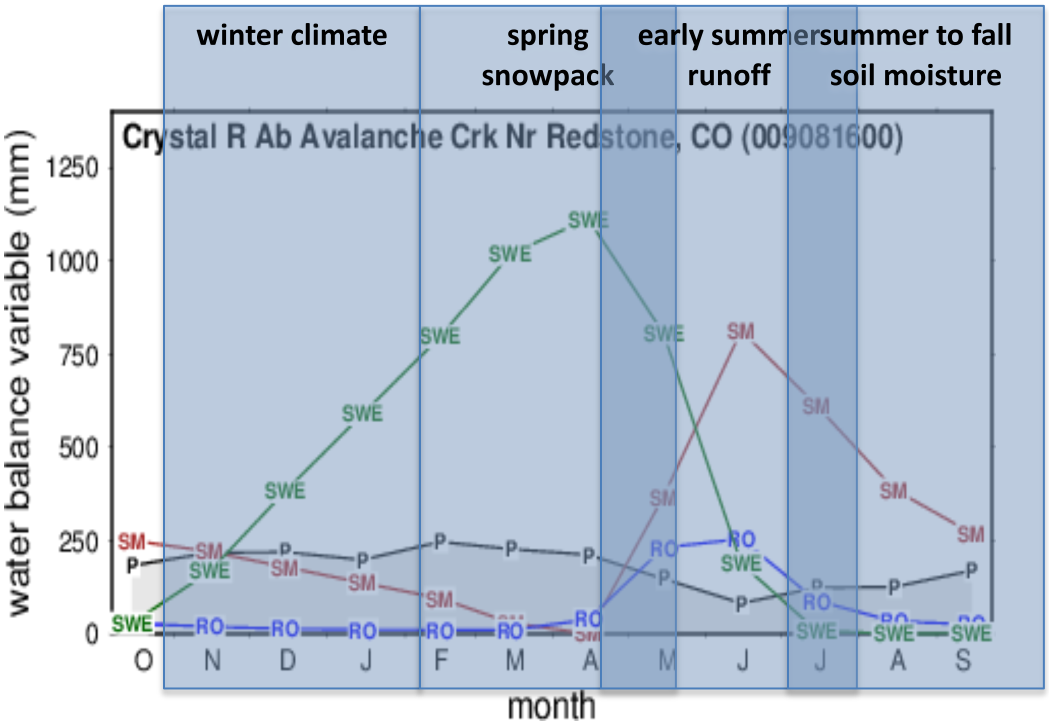
In parts of the world, the annual cycle drives predictable land moisture fluxes

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



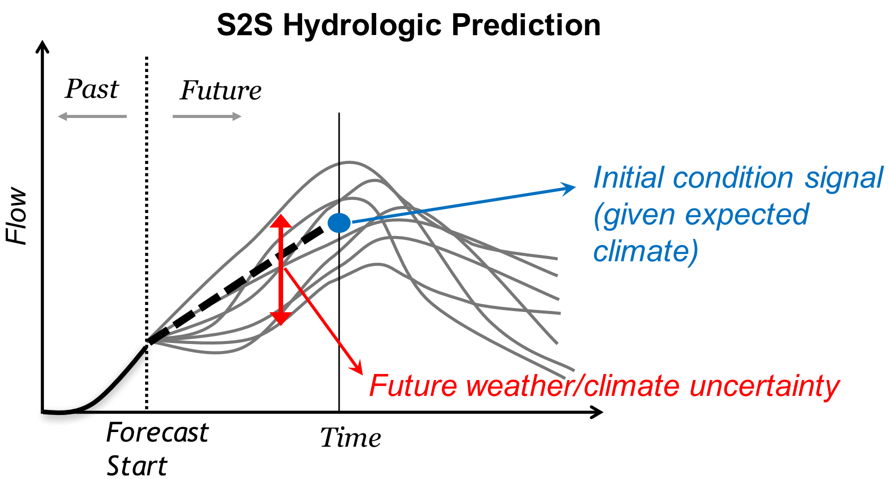
Modeled water balance: precipitation (P), runoff (RO), snow water equivalent (SWE), soil moisture (SM)
Wood et al, HESS 2016

Crystal River in winter

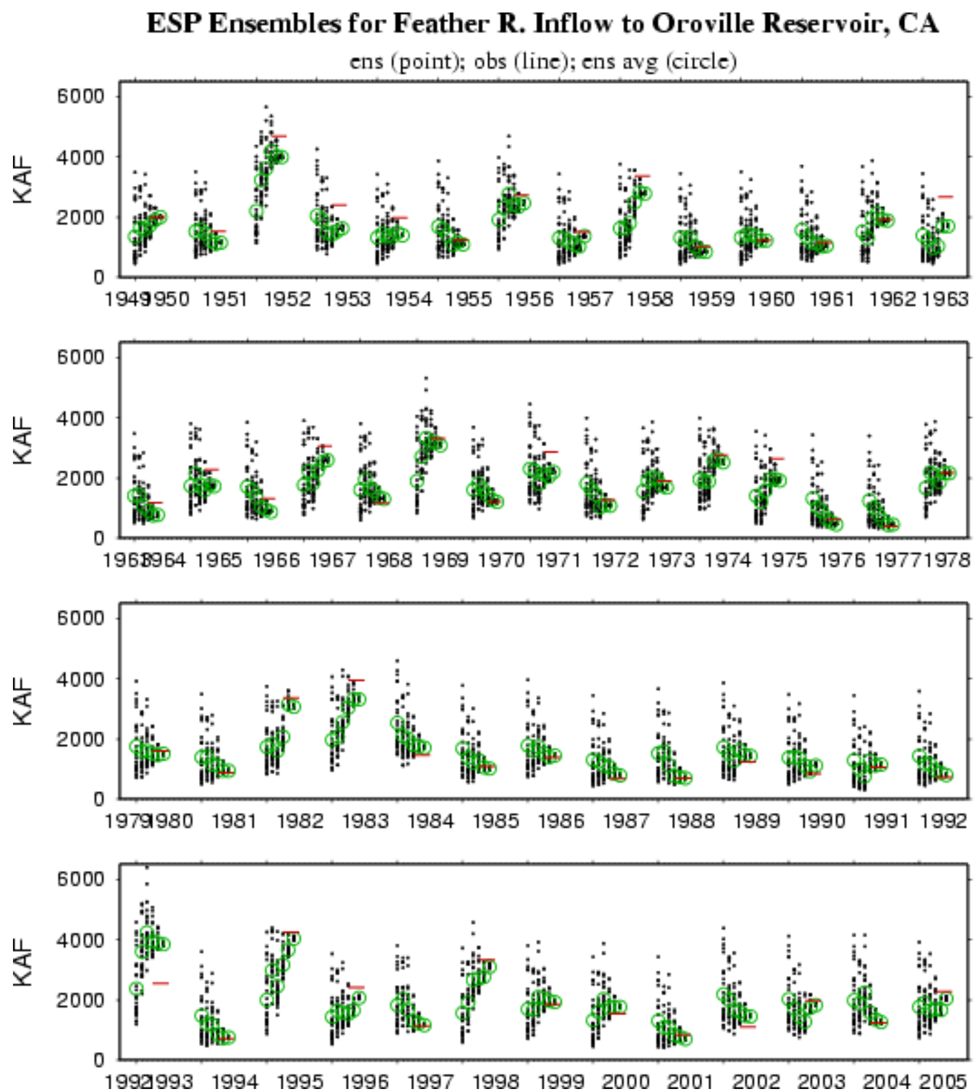
The practice of land prediction emphasized IC predictability

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

- 'Extended' Streamflow Prediction (ESP) first used at CADWR and CNRFC in the mid 1970s
  - eg, Day, 1985; Wood et al, 2016
- NWS began ESP development in 1975

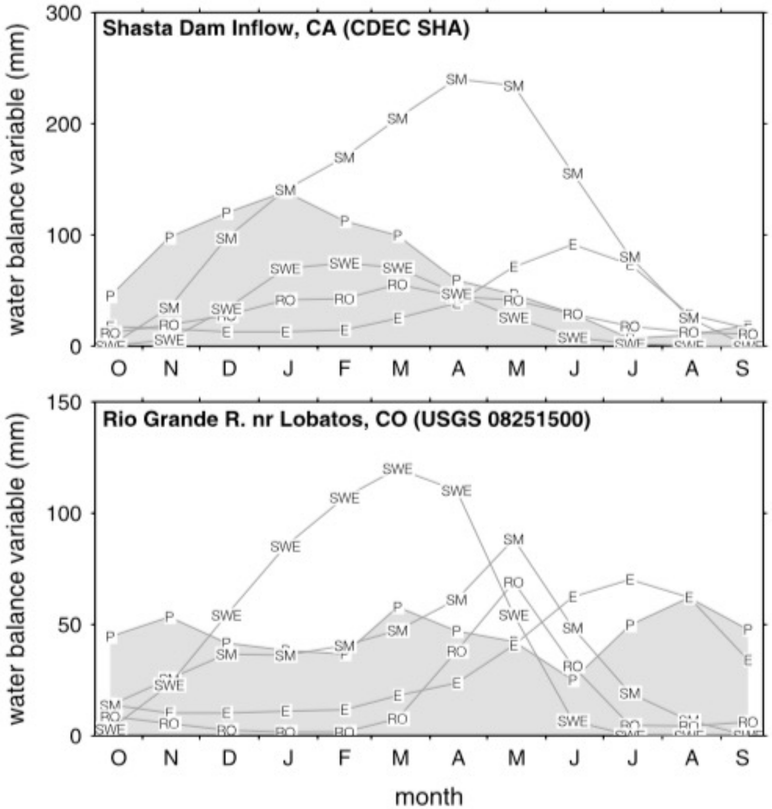


Ensemble hindcasts can be used to understand predictability



Exploring the sources of hydrologic predictability

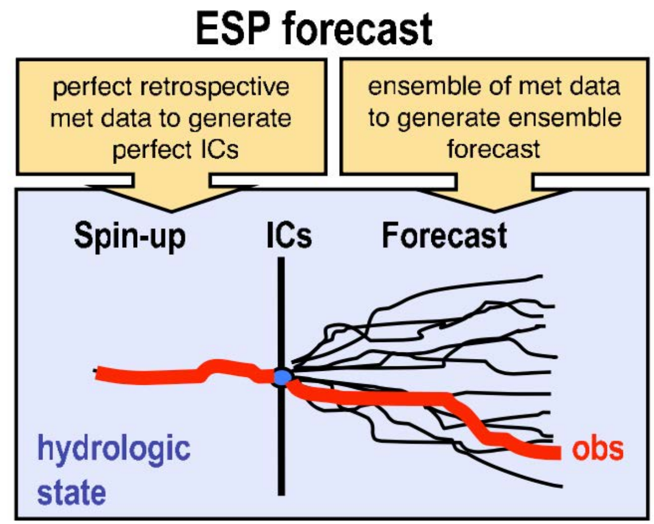
Demonstration focus on two different watersheds

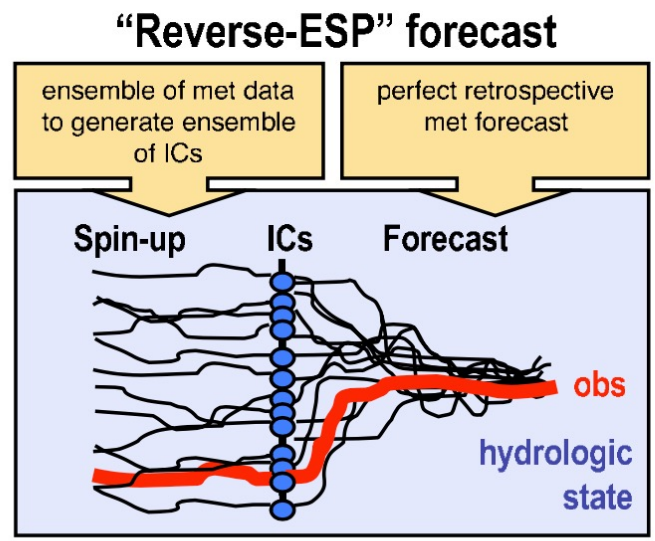


An ensemble approach for attribution of hydrologic prediction uncertainty

Andrew W. Wood[1,2] and Dennis P. Lettenmaier[1]

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

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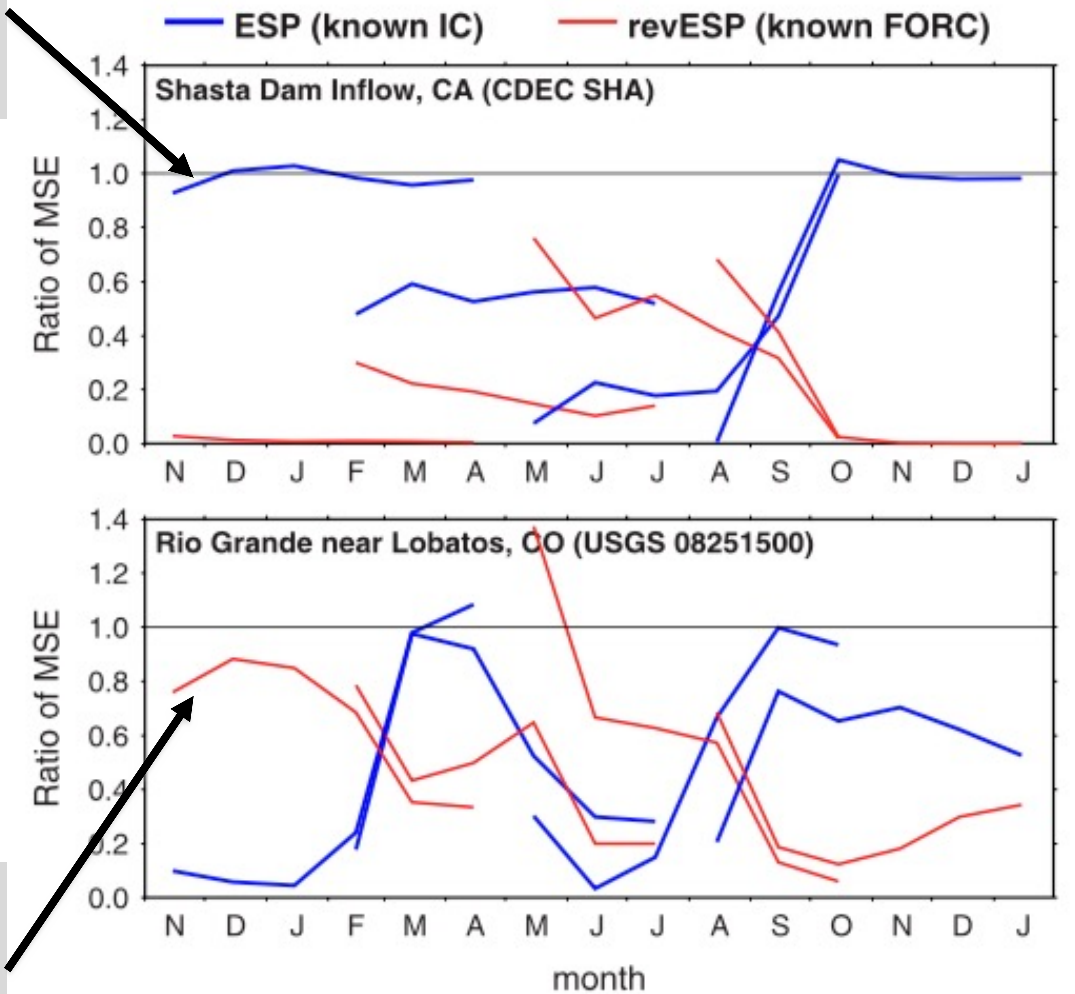
climate forecasts more important than initial conditions

- 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)

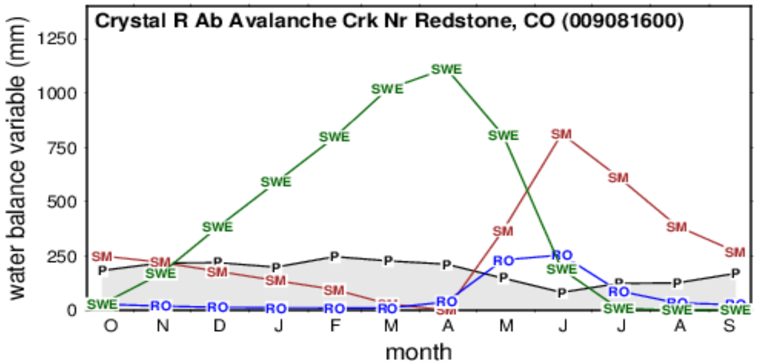
initial condition more important than climate forecasts

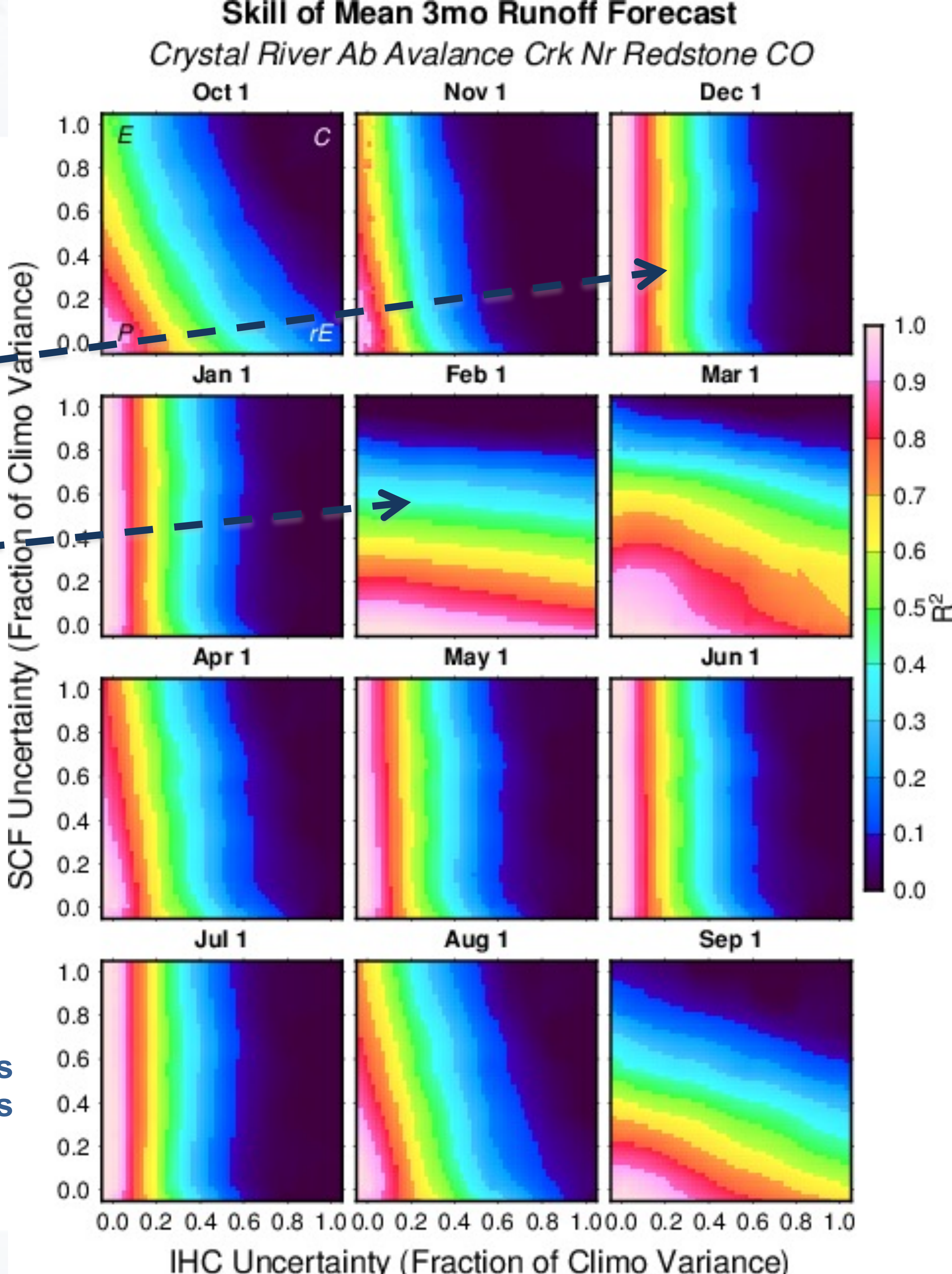


Seasonally varying influence of IC and climate information

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





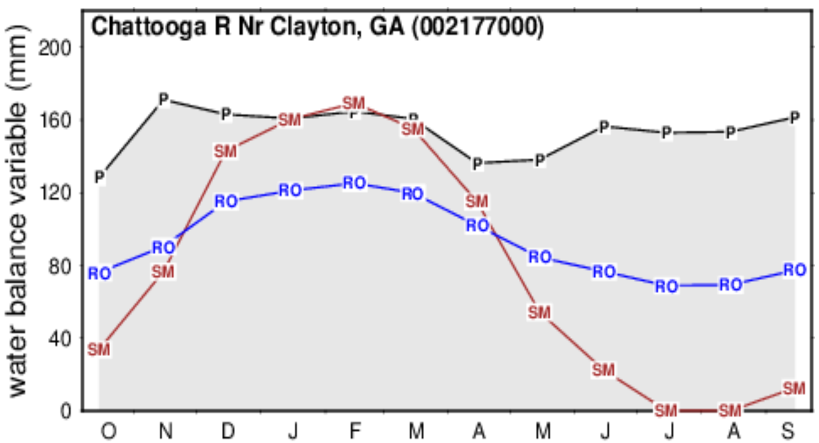
IHC: initial Hydrologic Conditions
SCF: Seasonal Climate Forecasts

Wood et al (JHM, 2016)

Seasonally varying influence of IC and climate information

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



IHC: initial Hydrologic Conditions
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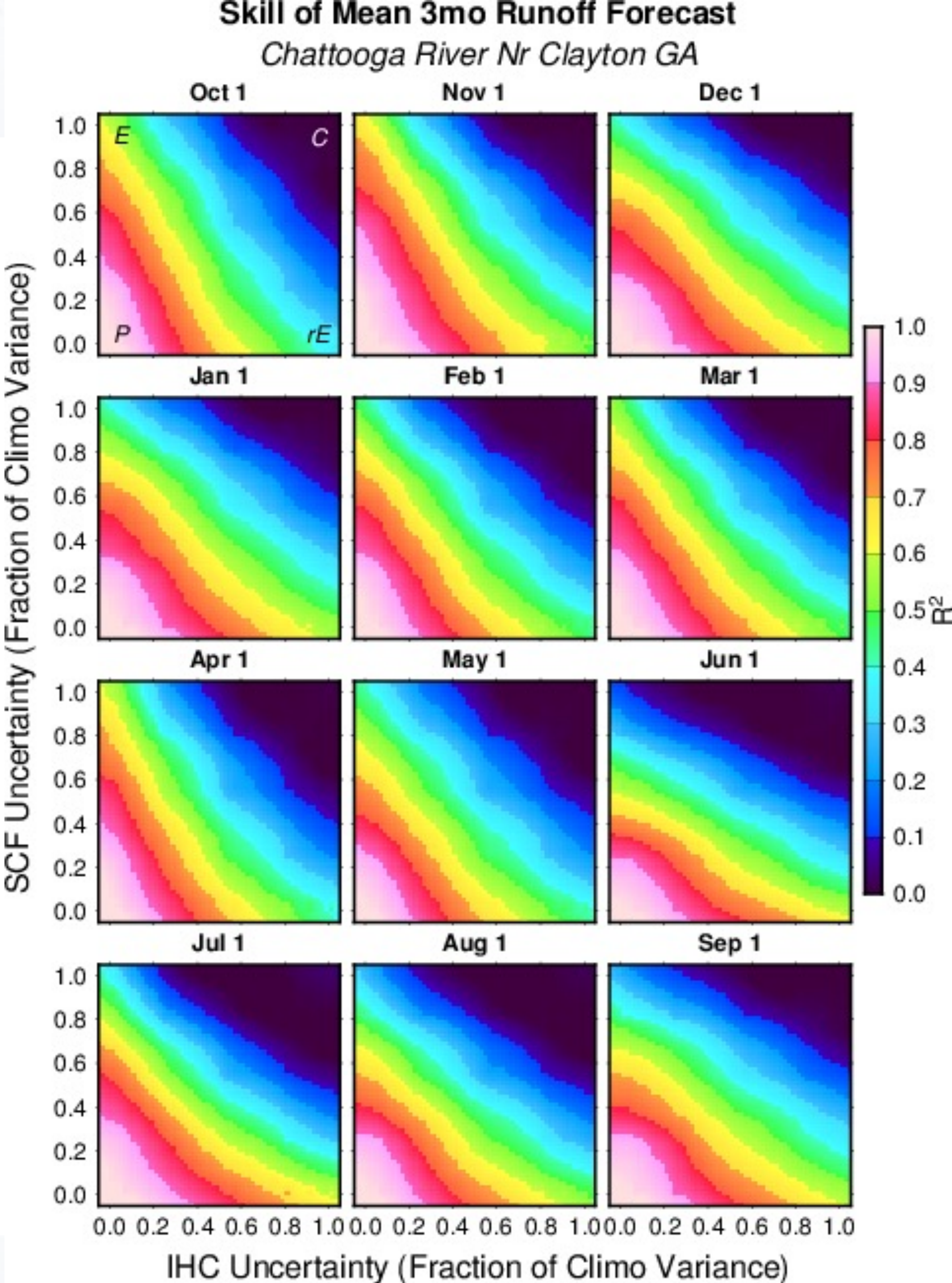
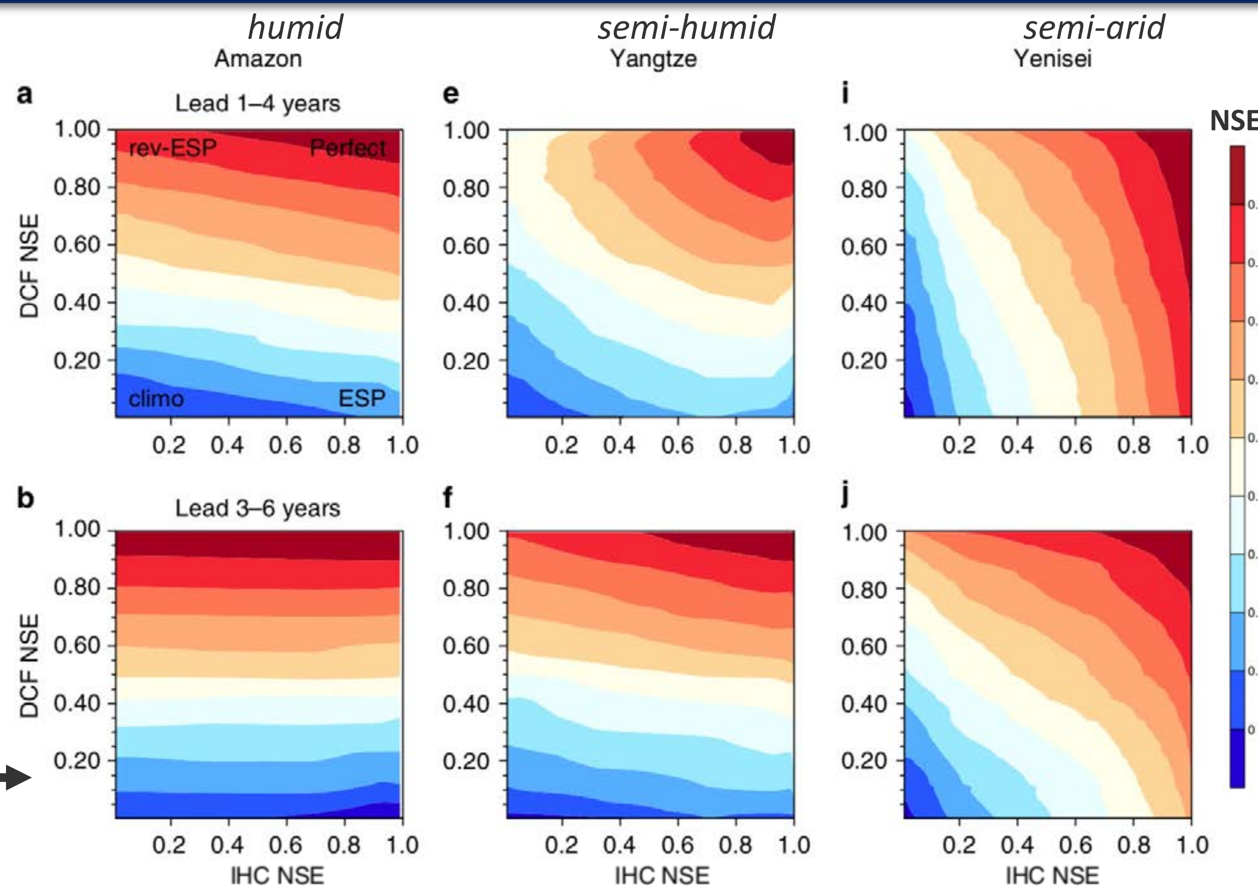


Describing the influence of predictability source using *forecast skill elasticity*

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 →

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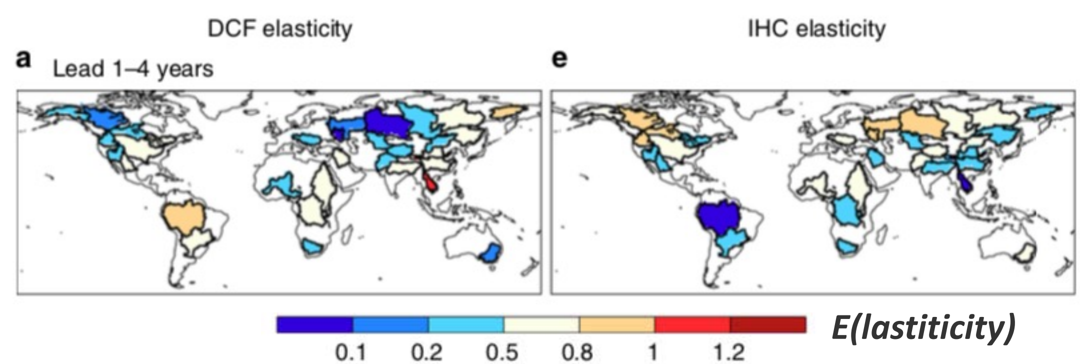
ARTICLE

https://doi.org/10.1038/s41467-019-09245-3 OPEN

Benchmark decadal forecast skill for terrestrial water storage estimated by an elasticity framework

Enda Zhu[1,2], Xing Yuan[1,3] & Andrew W. Wood[4]

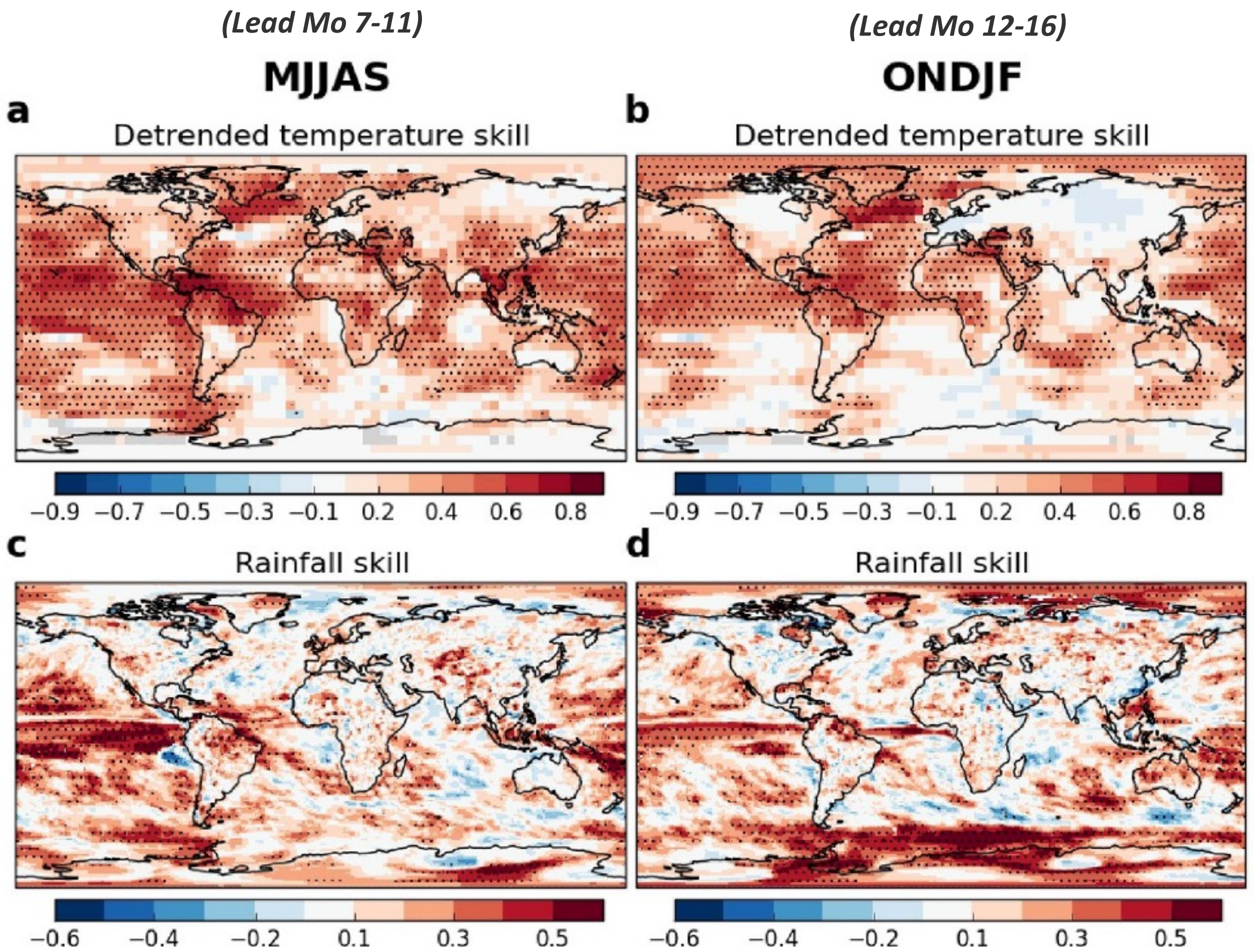


see: Wood et al, HESS, 2016; Arnal et al, JHM, 2017

Actual Interannual Forecast Skill for Climate using Large Ensembles

- 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

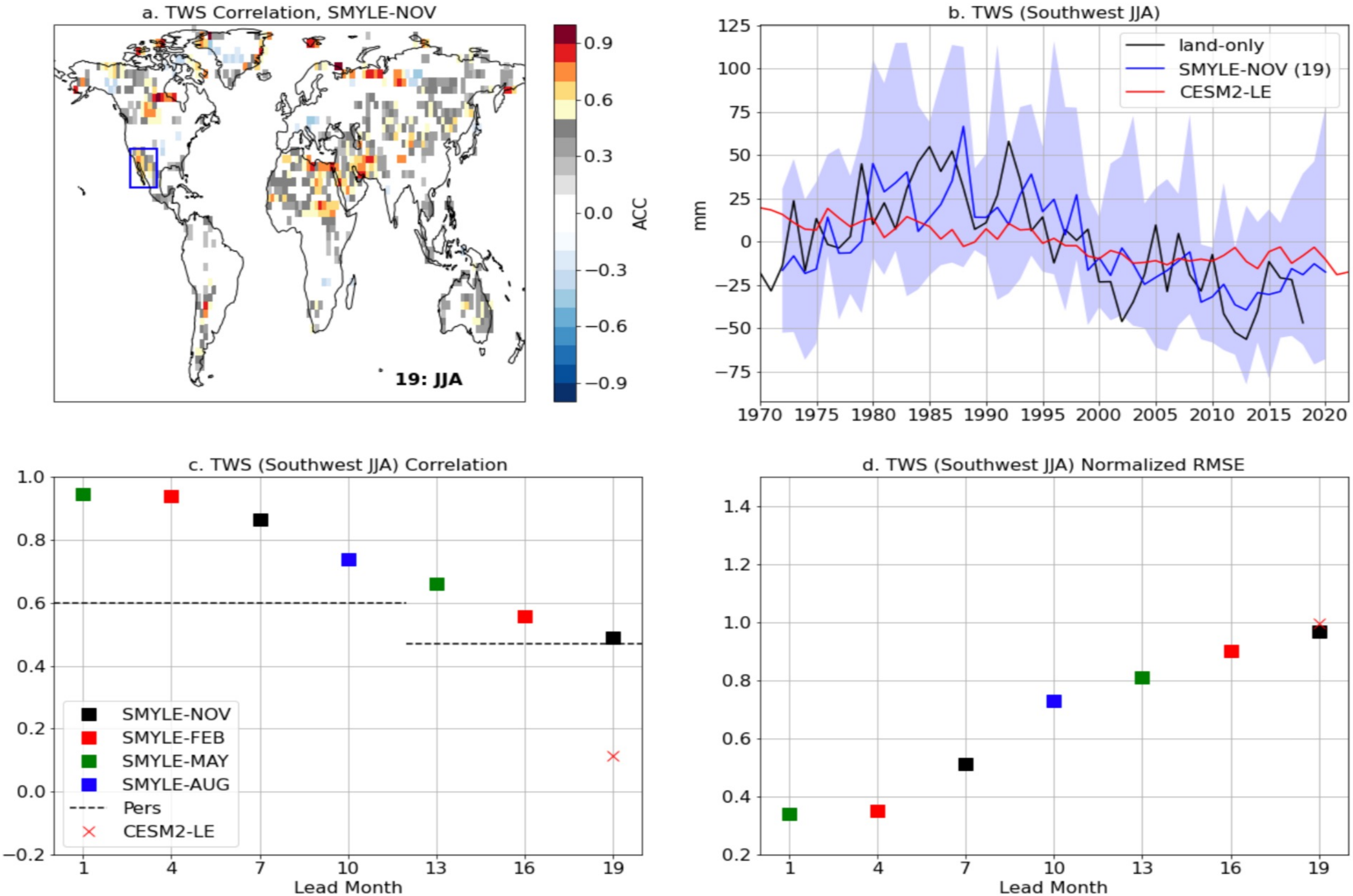


Dunstone et al. (2020)

slide material from Steve Yeager, NCAR

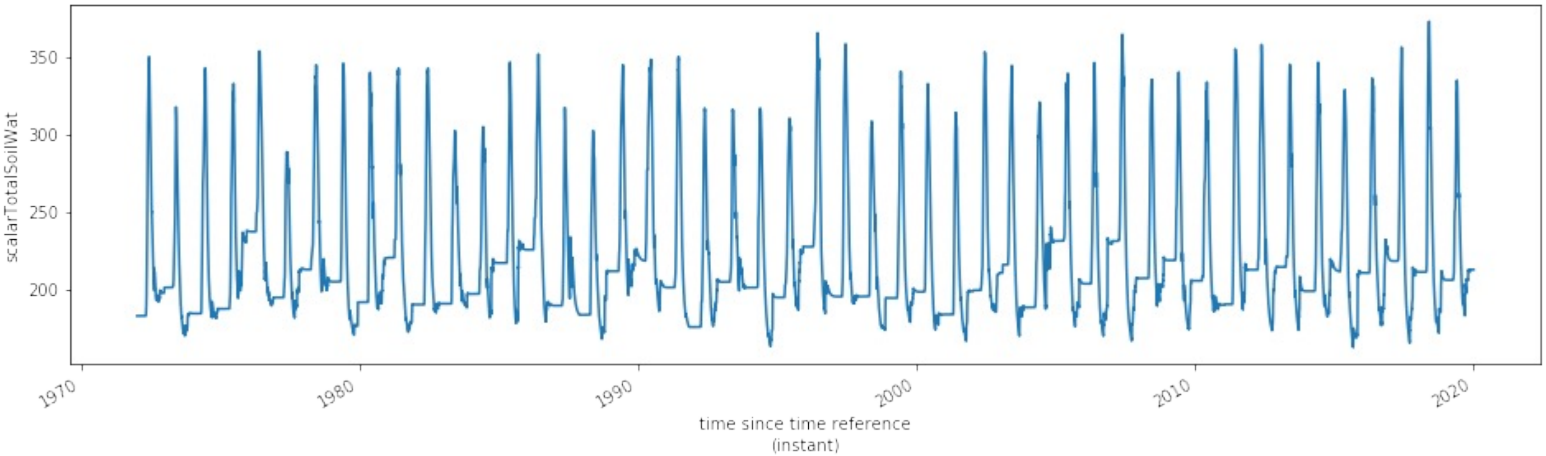
Total water storage (TWS) interannual prediction skill

- Month 19 skill (detrended) can be significant in places … (Yeager et al, 2022)



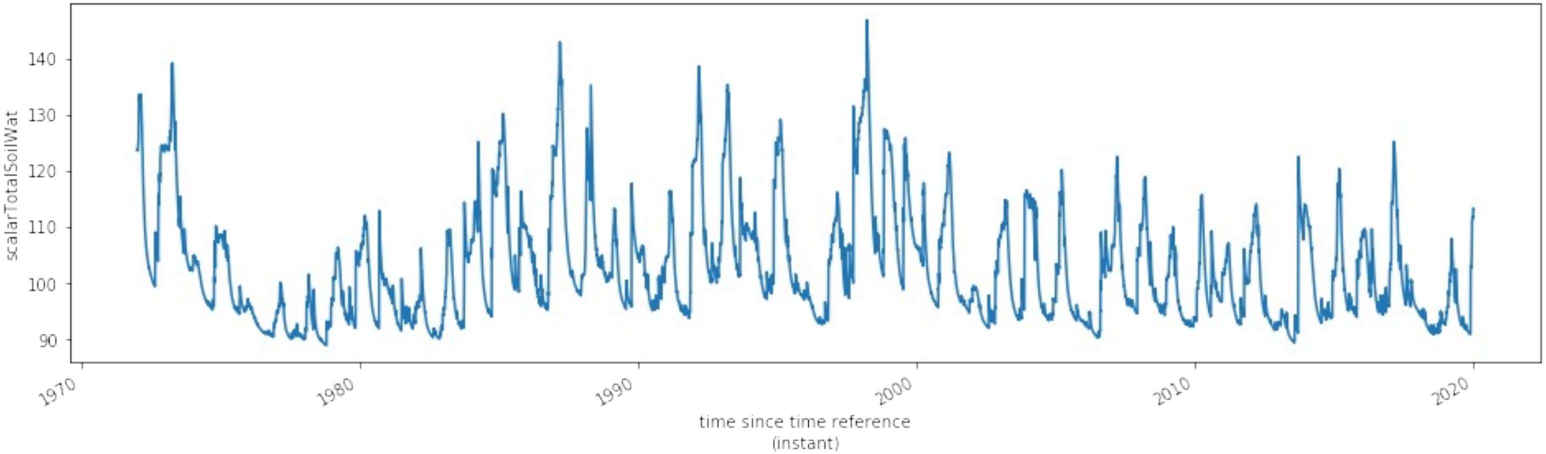
Predictability: annual precipitation versus land moisture storage

Modeled soil moisture: annual precip greater than storage → regular refill → memory loss



SF Flathead R, MT

Modeled soil moisture: annual precip greater than storage → irregular refill → memory



Rio Puerco, NM

Results based on SUMMA watershed modeling at NCAR

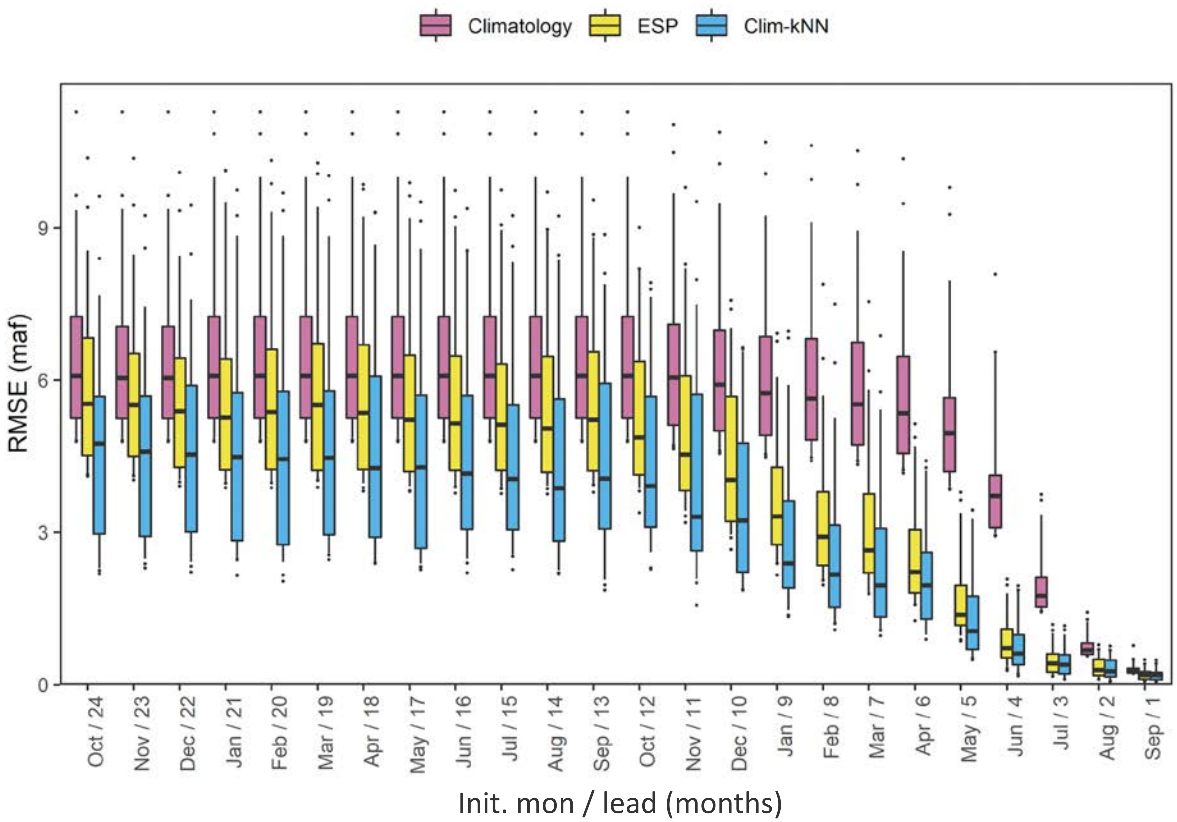
Multi-year prediction applications in water management

In applied/operational contexts,
there is some evidence of multi-year memory in SW US river basins such as the Colorado

How can improvements to streamflow forecasts effect reservoir operations in the Colorado River Basin?

- 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

Baker, SA, AW Wood, B Rajagopalan, J Prairie, C Jerla, E Zagona, RA Butler, R Smith, 2021, 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)

Working toward an understnading of terrestrial decadal predictability

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

For example …

• excursions from normal are driven by climate, rapid recovery possible • most predictability from climate forecasts	• can have prolonged excursions from normal are driven by climate and sustained by land • predictability from both ICs and climate forecasts
• excursions from normal are driven by climate rapid recovery possible • little predictability	• can have prolonged excursions from normal are driven by climate and sustained by land • most predictability related to ICs

Climate Predictability ↑

Land Storage/Annual Precipitation →

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