Two Topics in Seasonal Streamflow Forecasting: Soil Moisture Initialization Error and Precipitation Downscaling

Randal Koster
NASA/GSFC
randal.d.koster@nasa.gov

(with help from Greg Walker and Sarith Mahanama)

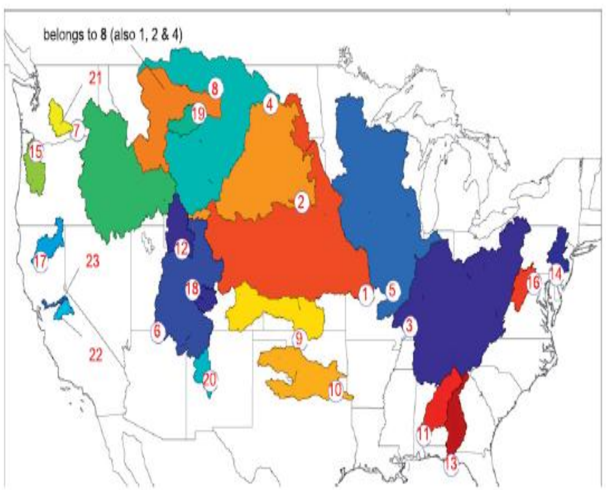
Here we address two separate questions associated with the prediction of seasonal streamflow (and thus the prediction of hydrological drought):

1) How does streamflow forecast skill improve with the improved estimation of soil moisture initial conditions?

2) Can we identify situations for which high-accuracy precipitation downscaling would <u>not</u> improve the accuracy of large-scale streamflow forecasts?

Topic 1: Soil moisture initialization error

Recent studies* have shown that the accurate initialization of soil moisture provides significant skill to streamflow forecasts.



<u>Brief overview of experimental procedure:</u>

1. Run multi-decadal offline simulation of land model across CONUS with observed met forcing.

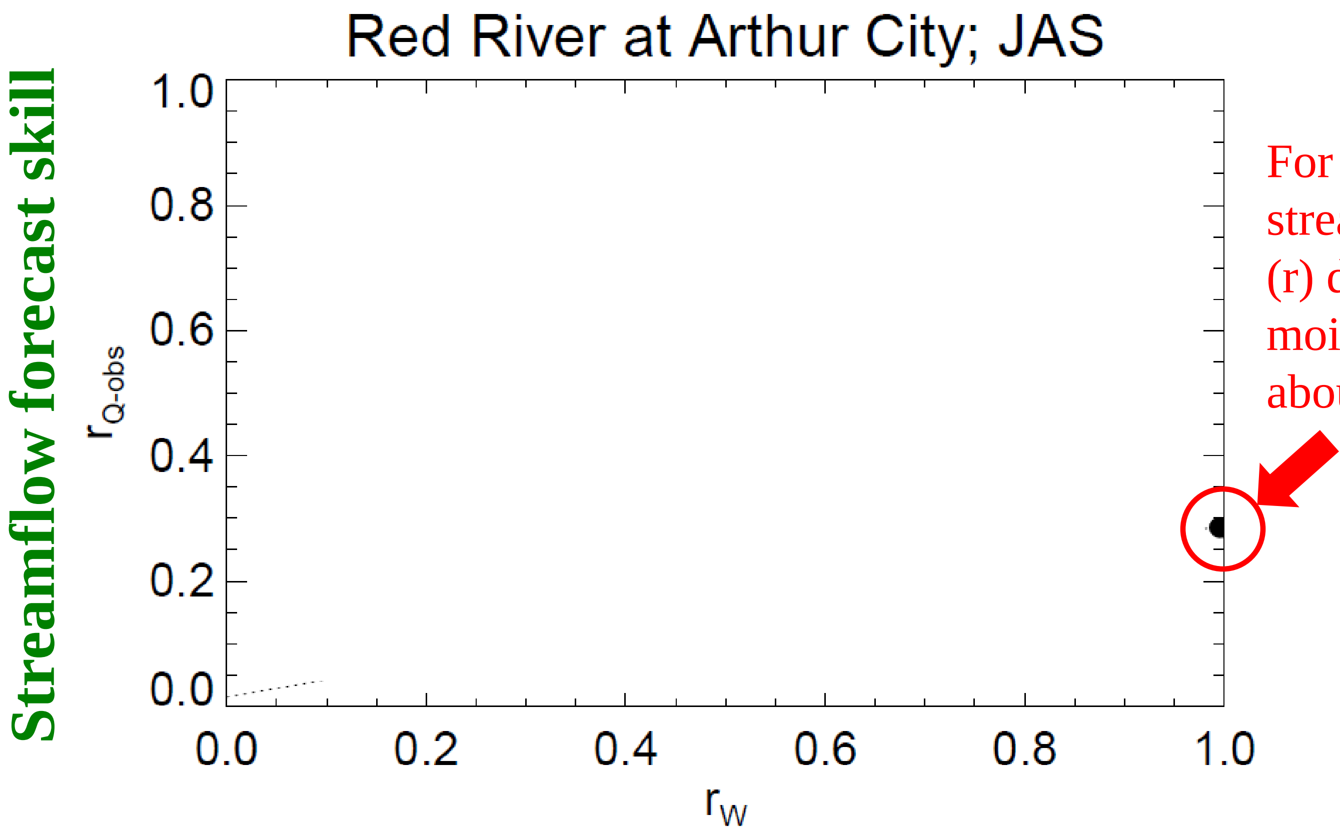
2. Use soil moistures from this run as initial conditions for offline seasonal forecasts spanning multiple decades; the offline forecasts are driven with climatological met forcing.

3. Compare forecasted streamflow with what actually occurred in the basins shown.

4. Quantify skill with correlation coefficient, r.

*For example: Koster, R. D. et al., 2010,Nature Geosci., 3, 613-616; Mahanama, S. et al., 2012, J. Hydromet., 13, 189-203.

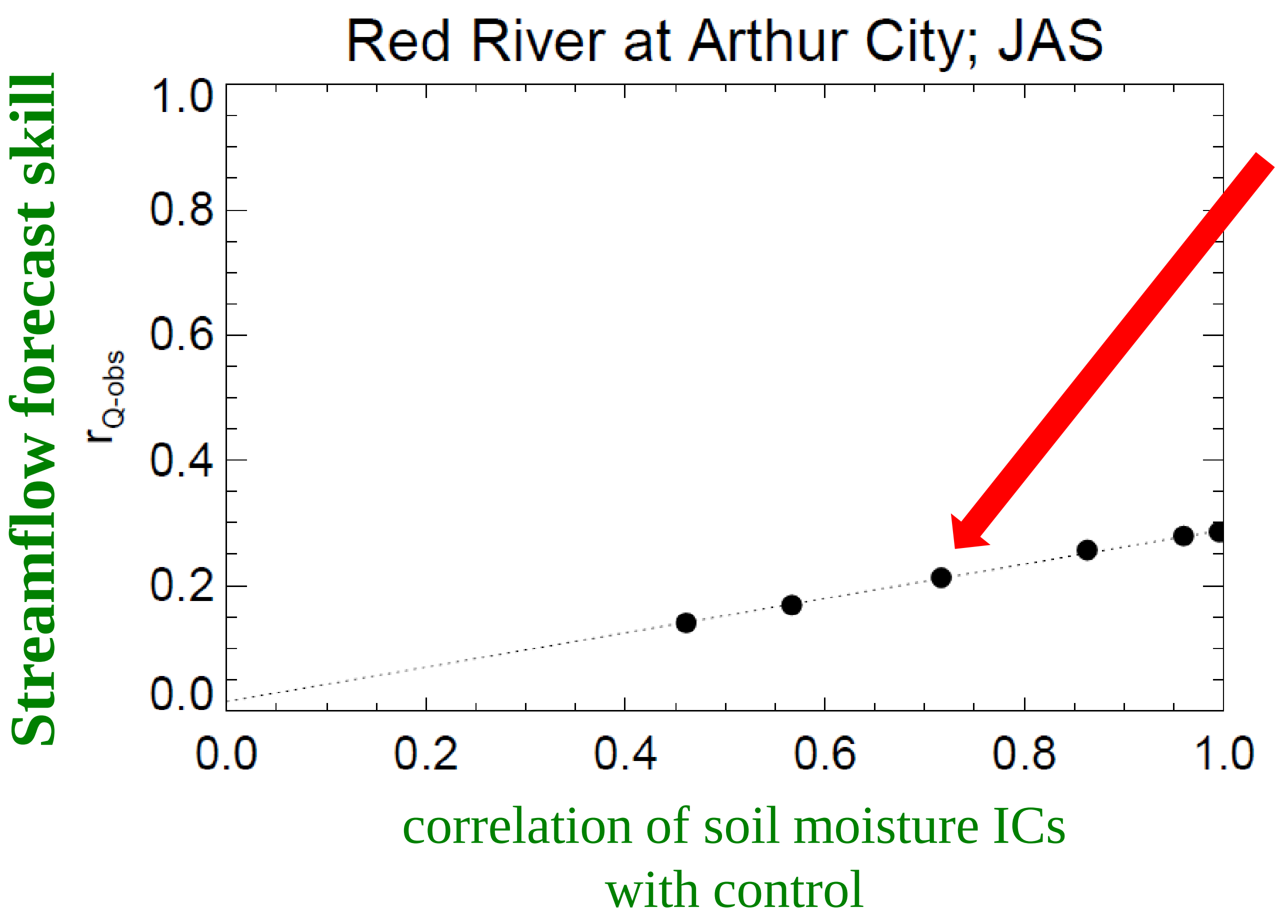
Sample result



For this basin, the streamflow forecast skill (r) derived from soil moisture initialization is about 0.3

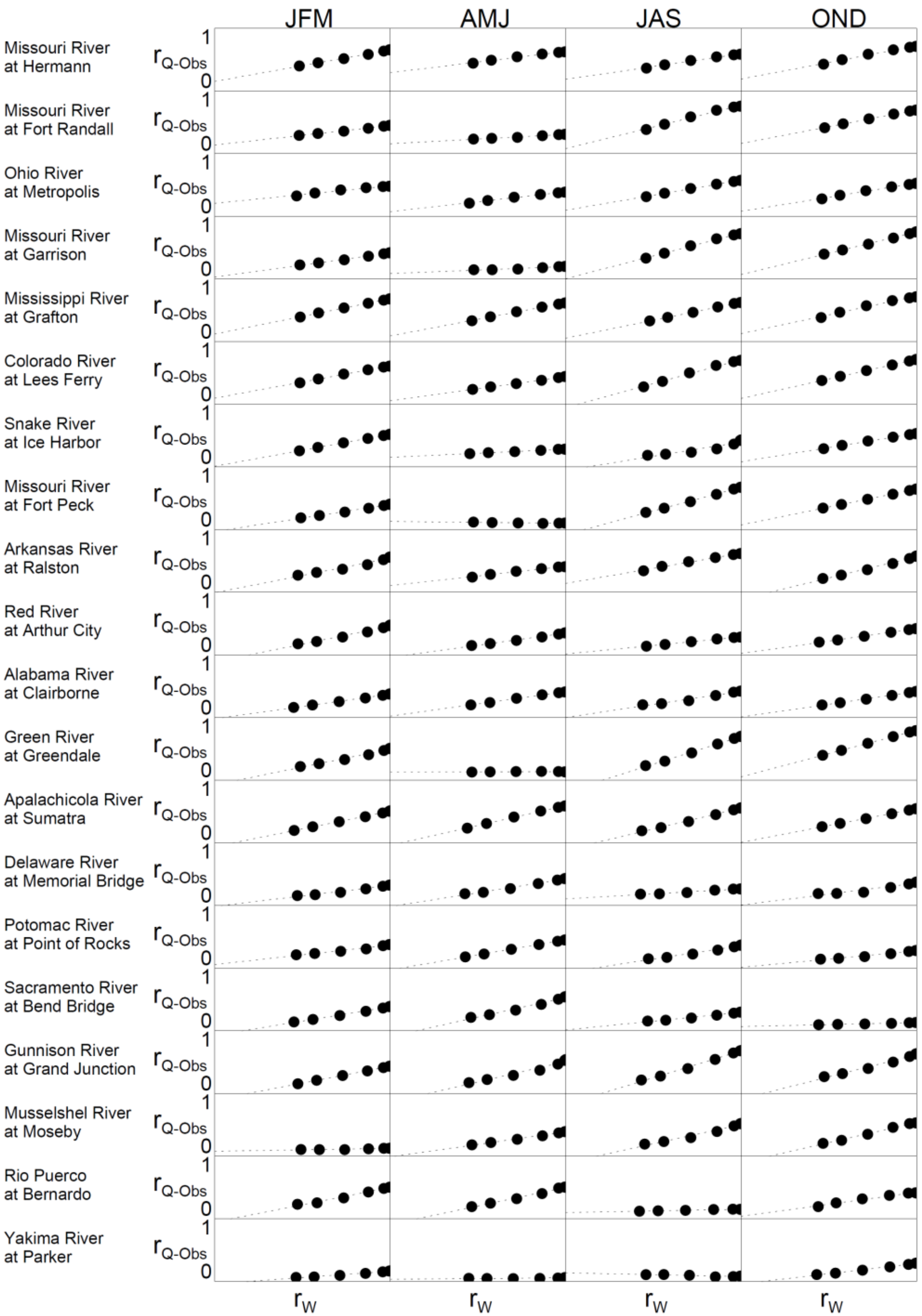
Now repeat the forecast experiment several times, each time adding a different level of spatially correlated error (across CONUS) to the soil moisture initial conditions.

Sample result

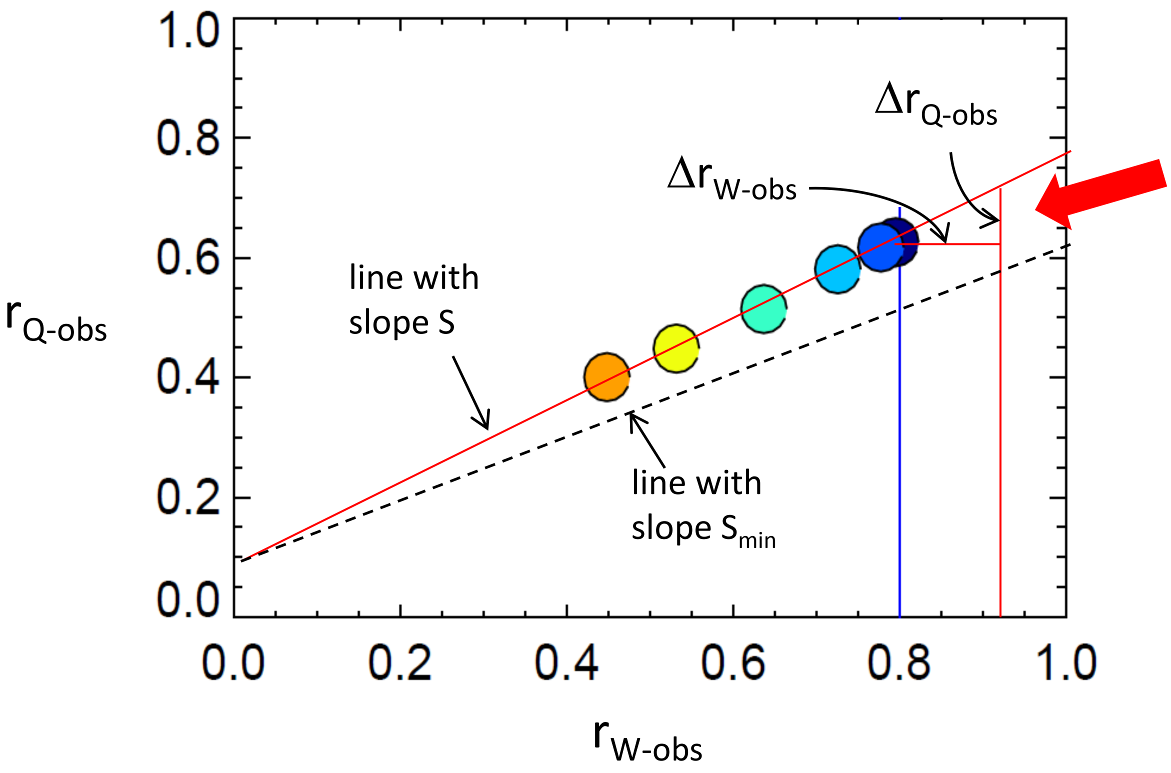


The skill decreases linearly as error is added to the soil moisture initial conditions.

The linear decreases are seen in all basins examined, for all seasons.



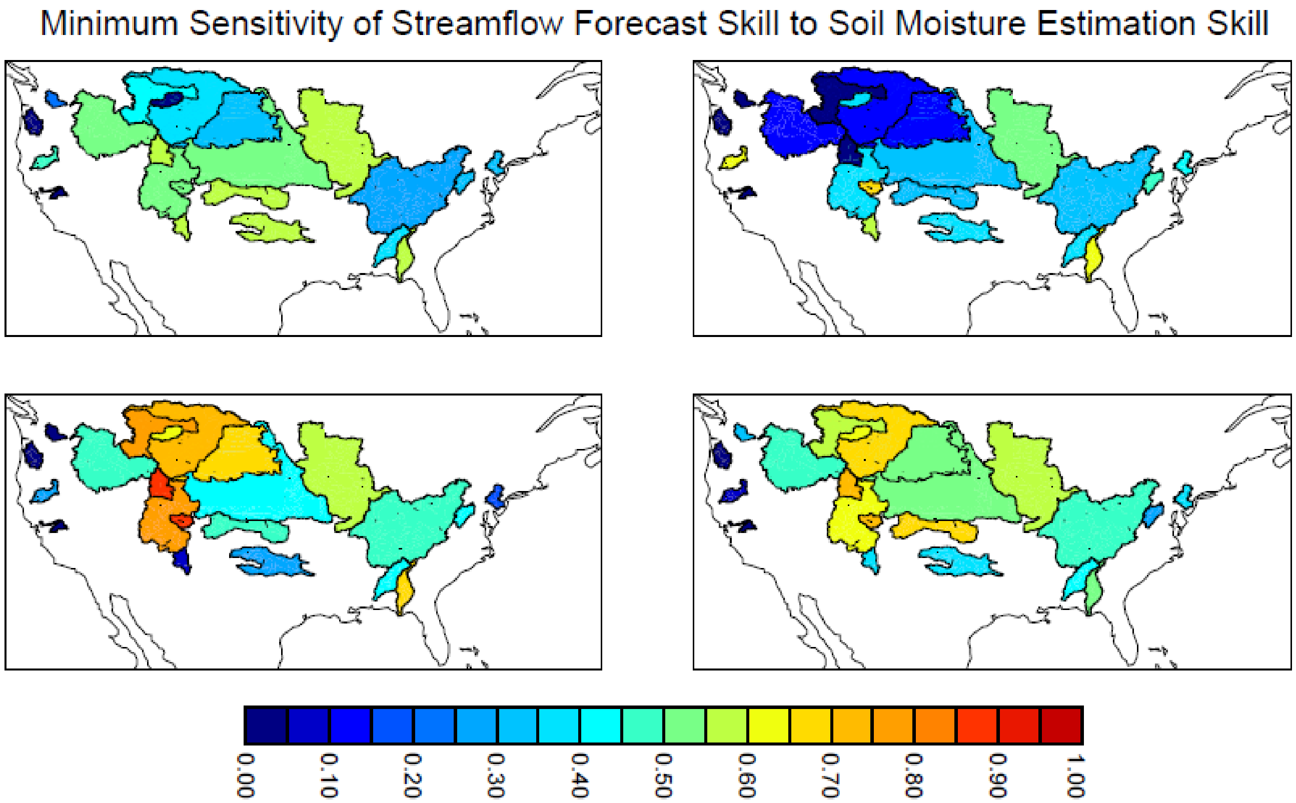
Given this linearity,…



…we can (in principle) translate an *increase* in soil moisture estimation accuracy into the corresponding increase in streamflow forecast skill.

We may not know the baseline soil moisture estimation skill, but since this skill cannot exceed r=1, we can get a useful estimate of *minimum* sensitivity:

$$\left[\frac{d(\text{streamflow forecast skill})}{d(\text{soil moisture estimation skill})} \right]_{\text{min}} = \text{slope of line when } r_W = 1$$



Summary: Topic 1

By adding artificial error to the initial conditions of a series of streamflow forecast simulations, we can examine the impact of soil moisture error on streamflow forecast skill.

For the land model tested, the addition of a given level of soil moisture error leads to a linear decrease in streamflow forecast skill, allowing a direct estimation of

$$\left[\frac{\text{d(streamflow forecast skill)}}{\text{d(soil moisture estimation skill)}} \right]_{\text{min}}$$

Such exercises can help us quantify the practical benefits of improved soil moisture estimation, e.g., through the SMAP satellite mission.

Topic 2: Impact of precipitation downscaling

Broad research question:

To what extent does the downscaling of subseasonal-to-seasonal precipitation forecasts improve the prediction of streamflow?

(Associated question with a "drought" flavor: to what extent does downscaling improve the prediction of streamflow deficits, i.e., hydrological drought?)

Must first ask the question:

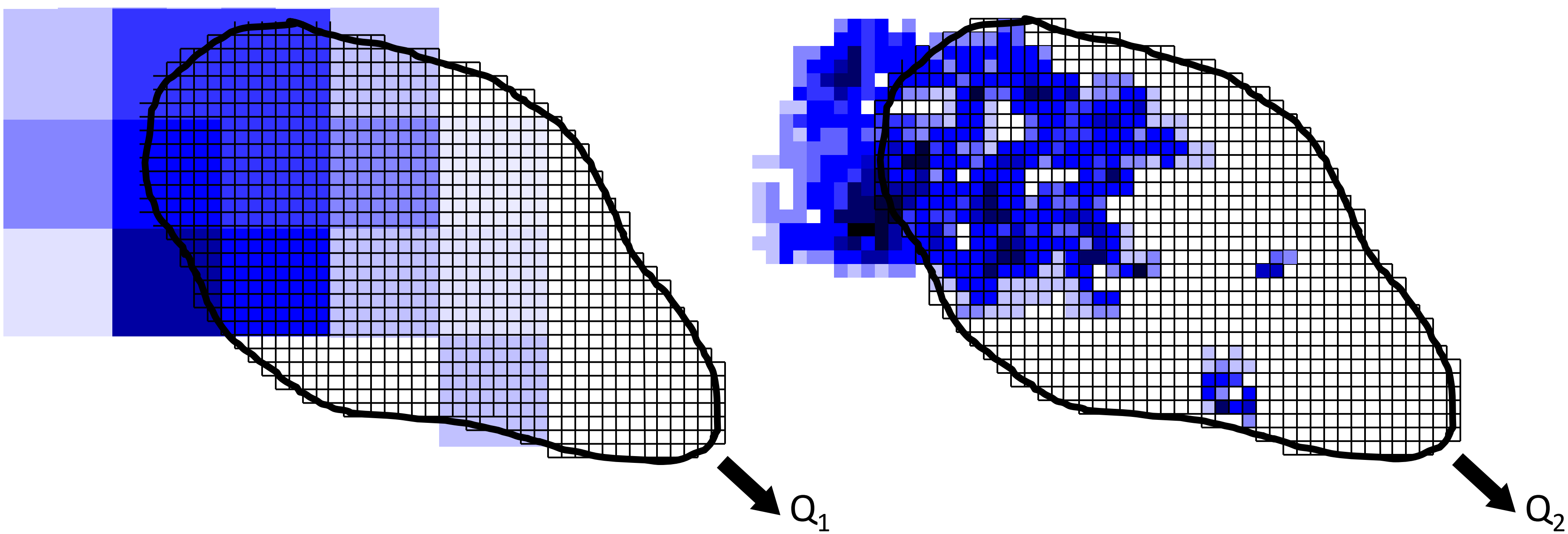
To what extent does high resolution precipitation forcing improve the estimation of streamflow in the first place?

(That is, how much would we actually <u>gain</u> from the downscaling, assuming that the coarse-scale precipitation prediction *and* the downscaling were perfect?)

The idea that high resolution precipitation data can produce high-resolution streamflow data is somewhat trivial; here we consider the impact of precipitation downscaling on *large-scale* streamflow averages.

a. Distributed hydrological model with coarse resolution precipitation data

b. Distributed hydrological model with high resolution (downscaled) precipitation data



We start by taking one step further backwards, using a "synthetic truth" dataset:

Taking a high resolution land model simulation as synthetic truth, to what extent does re-running the simulation with "coarsened" rainfall forcing affect (i.e., distort) the simulation of large-scale runoff at the coarse grid-cell scale?

This, of course, is but one facet of the downscaling question; we do not purport here to cover comprehensively the downscaling problem. Still, we find some interesting and relevant things…

Synthetic truth simulation:

Model used: GMAO Catchment LSM.

Simulation domain: Continental U.S. on a 1/8^o grid.

Time period: 1981 – 2006.

Land surface properties: Uniform, to simplify analysis. (Results are similar for distributed case.)

Forcing data:

- NLDAS 1/8^o precipitation product.
- 1^o Princeton forcing for all other variables, disaggregated to 1/8^o.

Coarsened precipitation simulation:

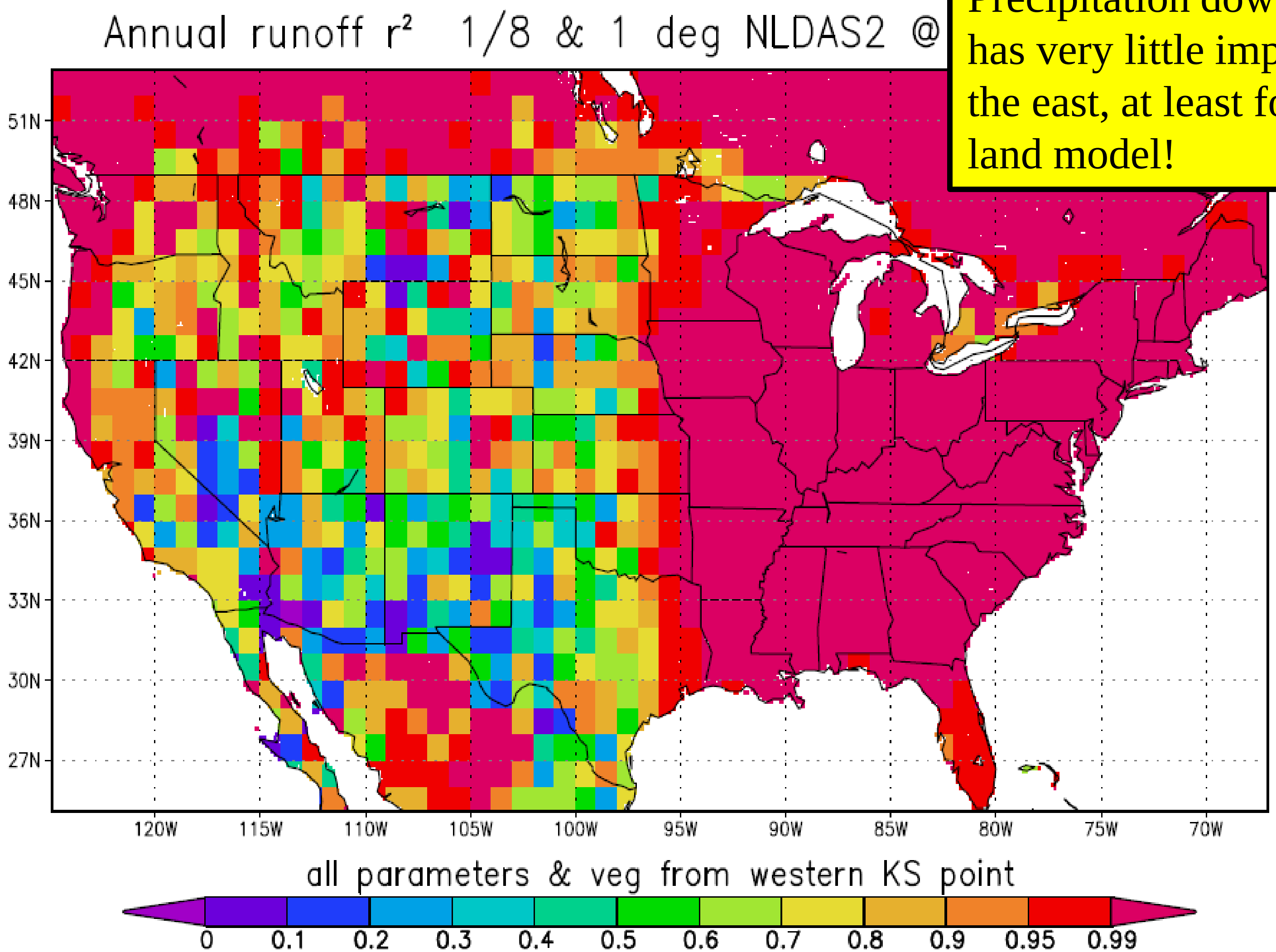
(Same, except that the NLDAS precipitation values for a given time step in each 1^o grid box are spatially averaged, and the spatial average is reassigned to the 64 1/8^o cells.)

Both simulations were initialized from a coarse simulation run spun up for 31 years (1948-1978); each simulation then had two years of spin-up (1979-1980) at its own resolution.

Analysis: Compute the square of the correlation coefficient (r^2) between the streamflows generated in the two sets of simulations (high resolution and low resolution).

If the r^2 is high, then precipitation downscaling has little impact on the simulated streamflows → it cannot benefit seasonal streamflow forecasting.

Results

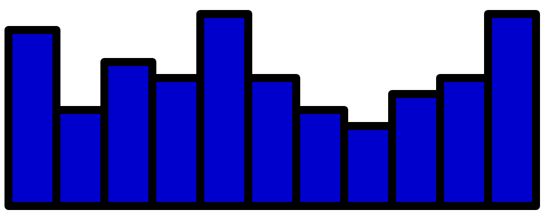


Precipitation downscaling has very little impact in the east, at least for this land model!

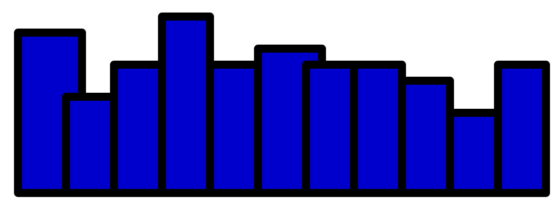
Can we explain this pattern? Possibly, to a degree…

Consider two possible disaggregations of forecasted precipitation across, say, ten subgrid cells.

Forecasted precipitation amount for large-scale grid cell



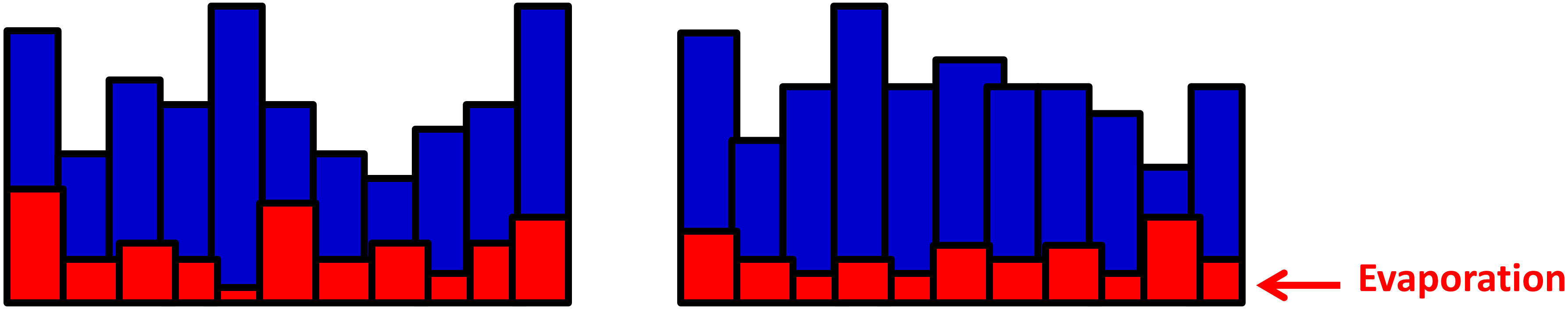
Disaggregation 1 (across 10 subgrid cells)



Disaggregation 2 (across 10 subgrid cells)

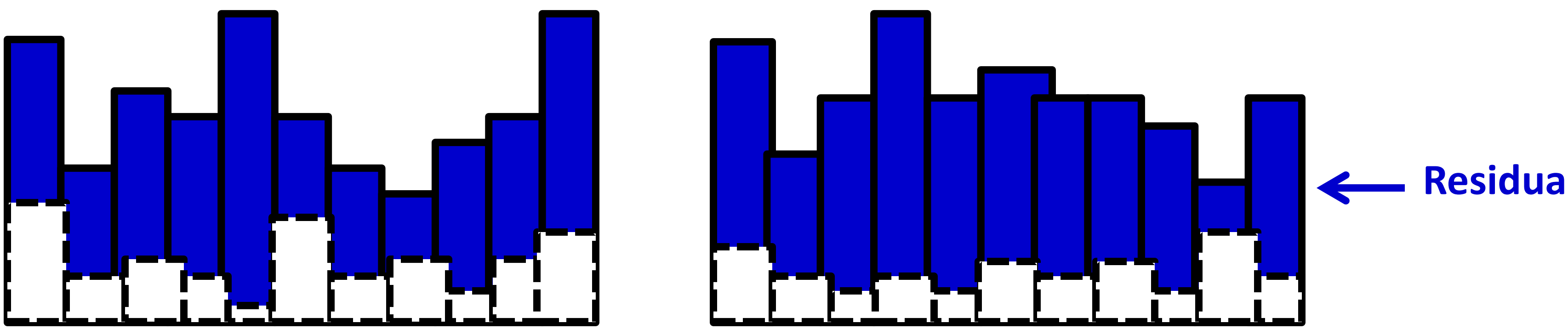
Both disaggregations preserve total precipitation volume.

If evaporation was in the soil-moisture-controlled regime (i.e., if it varied across the grid cell and from year to year due to soil moisture variations)…



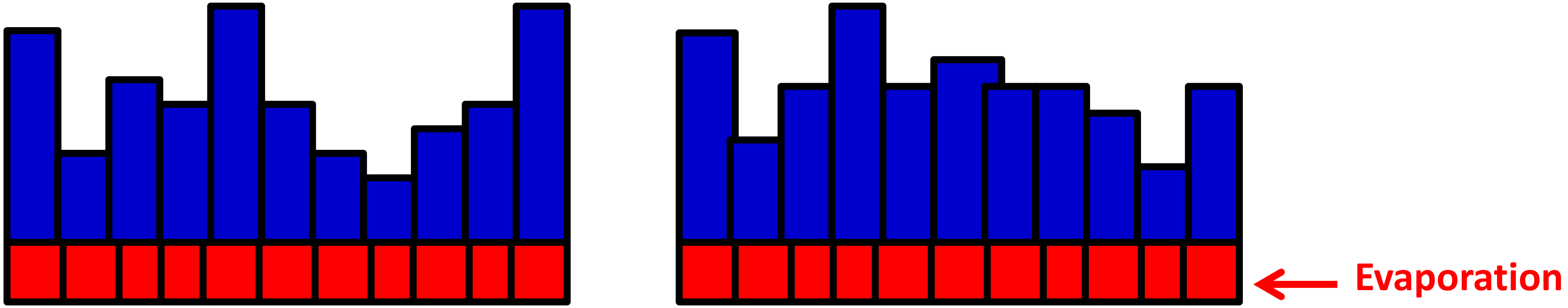
Disaggregation 1 Disaggregation 2

… the sum of the residuals (in blue below) might differ. This sum is what contributes to the grid-cell-averaged runoff (as well as to soil moisture storage).



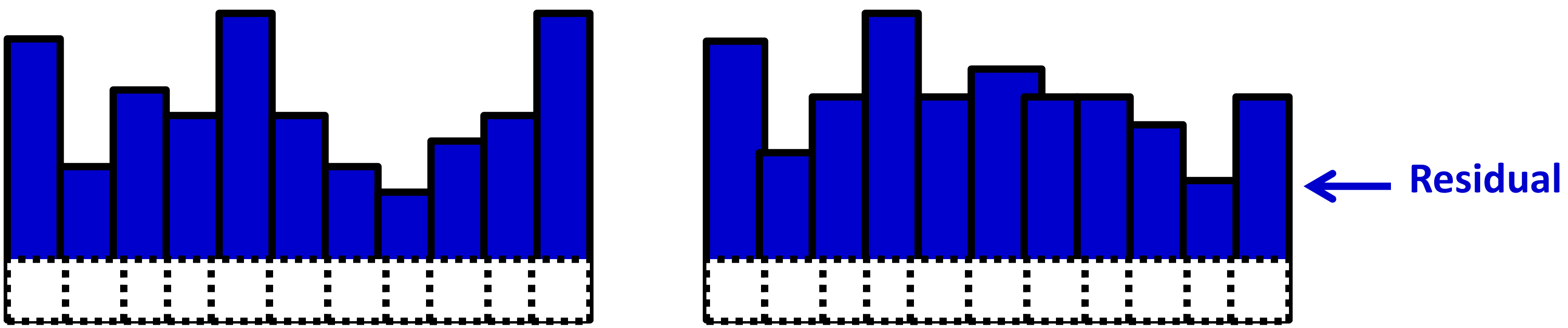
Disaggregation 1 Disaggregation 2

However, in an atmosphere-controlled evaporation regime, the evaporation across the grid cell and from year to year is roughly the same…



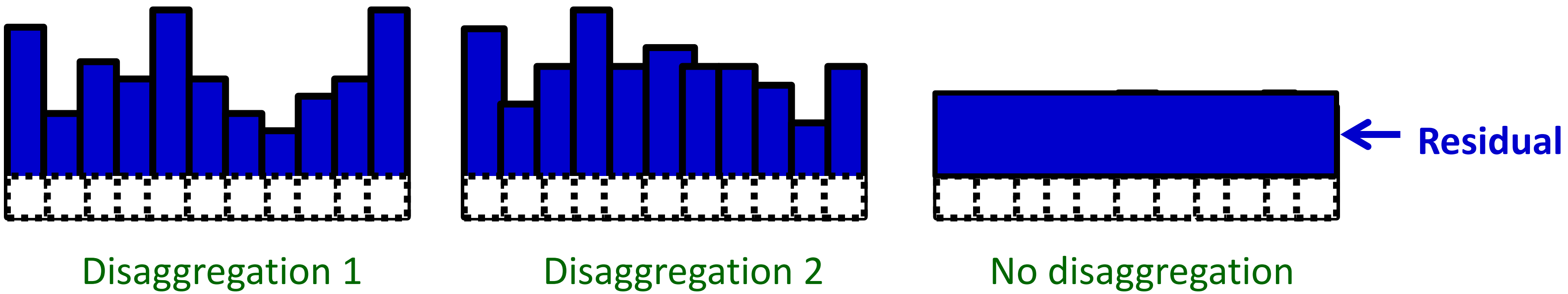
Disaggregation 1 Disaggregation 2

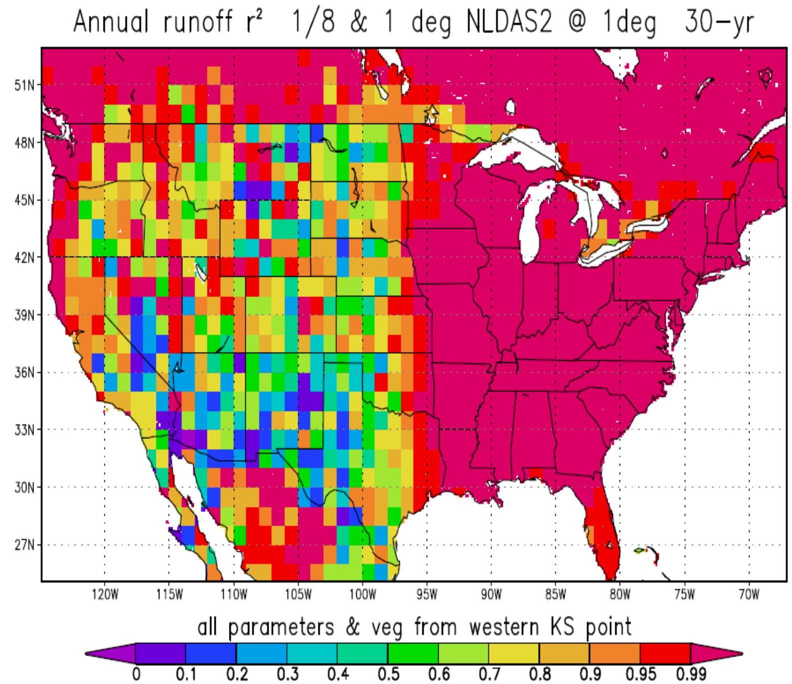
… so that that the sum of the residuals across the cell, regardless of disaggregation, will also be roughly the same. When considered over long time periods, storage variations become small, and the total residual is reflected in the runoff.



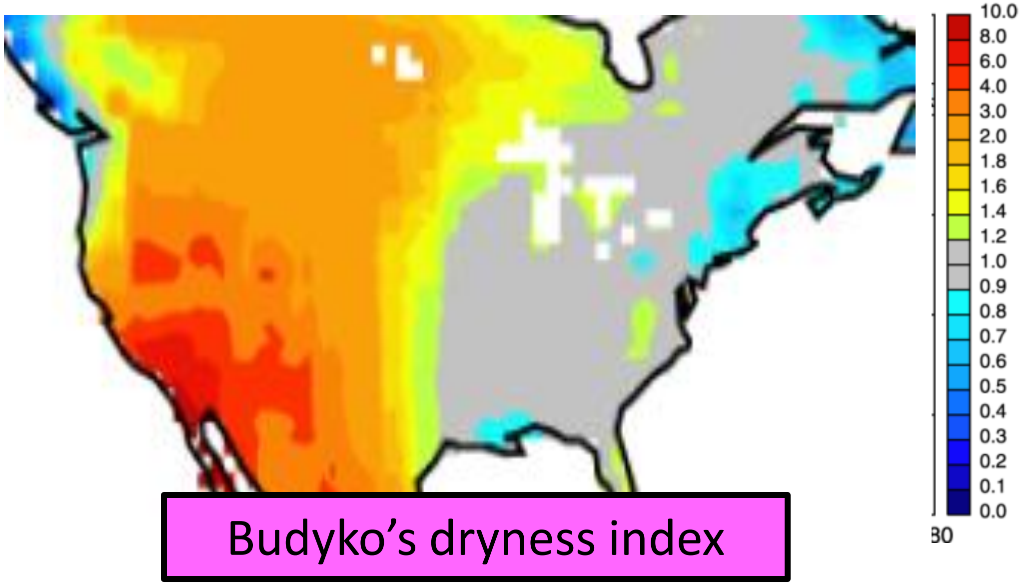
Disaggregation 1 Disaggregation 2

The residual in this case is also the same if the precipitation is <u>not</u> disaggregated.



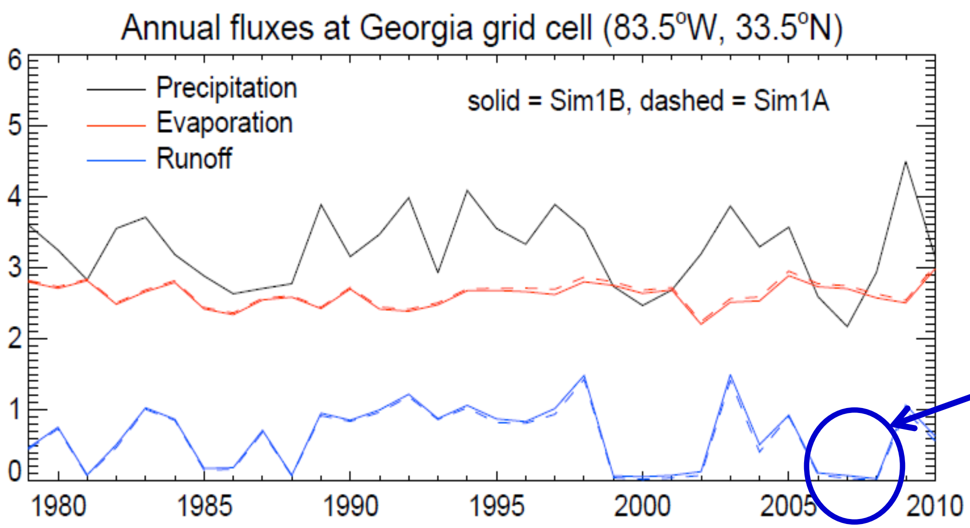


We indeed know that the eastern U.S. is generally in an atmosphere-controlled evaporation regime.



The upshot of these results is that even a perfect downscaling of precipitation forecasts would not improve large-scale streamflow forecasts in the Eastern U.S. …

Georgia grid cell

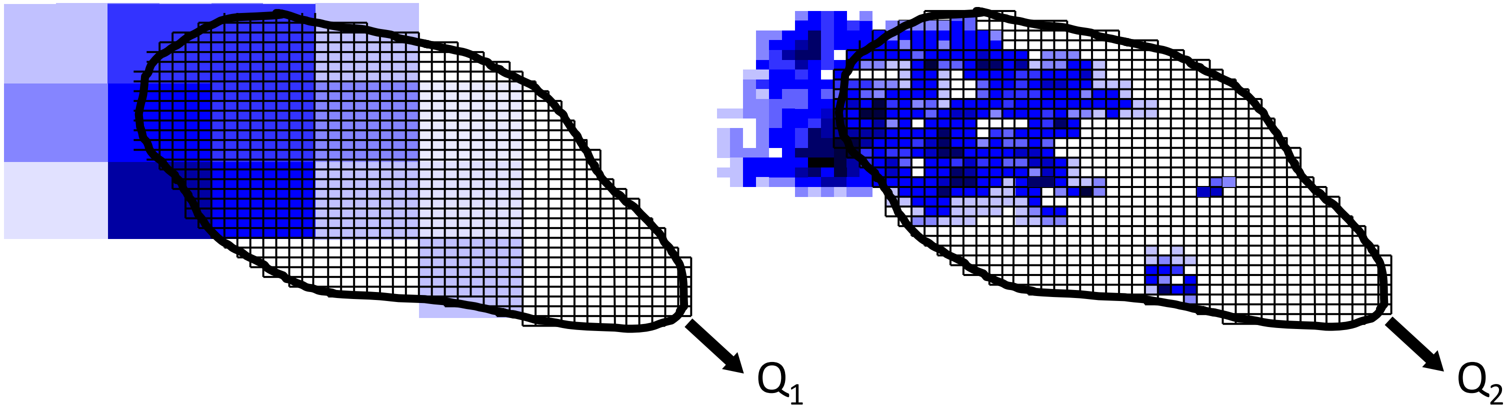


… even in drier years.

Dry conditions captured similarly by lo-res and hi-res simulations.

Summary: Topic 2

"Conventional wisdom" would seem to suggest that accurate precipitation downscaling should lead to improved simulation of large-scale streamflow. (i.e., Q_2 should be more accurate than Q_1.)



Our offline analysis suggests, however, that this may not be the case in energy-limited evaporation regimes.