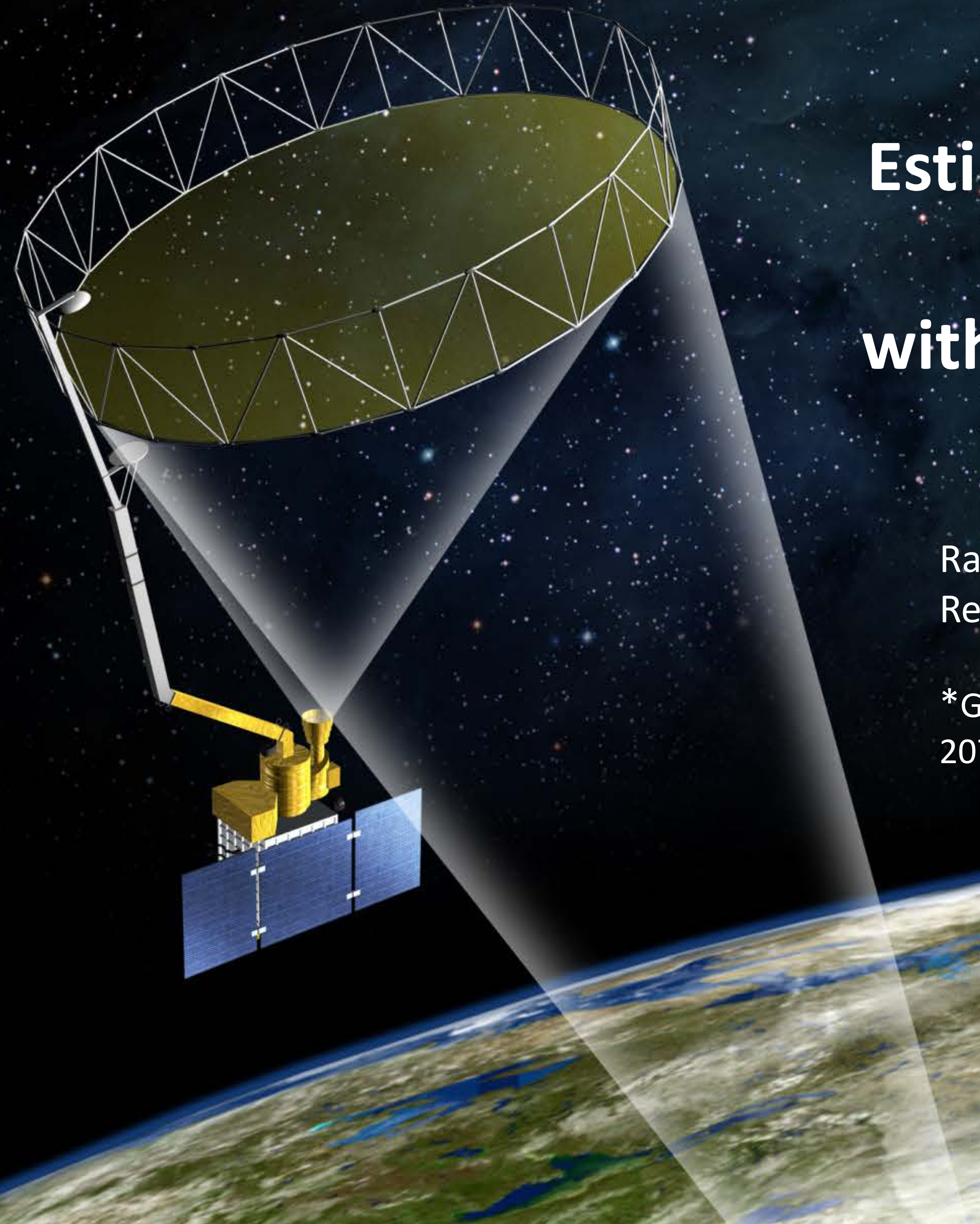
National Aeronautics and Space Administration

Soil Moisture
Active Passive
Mission

SMAP



Estimating Basin-Scale Water Budgets with SMAP Level 2 Soil Moisture Data

Randal Koster*, Wade Crow, Rolf Reichle, and Sarith Mahanama

*GMAO, NASA/GSFC, Greenbelt, MD 20771; randal.d.koster@nasa.gov

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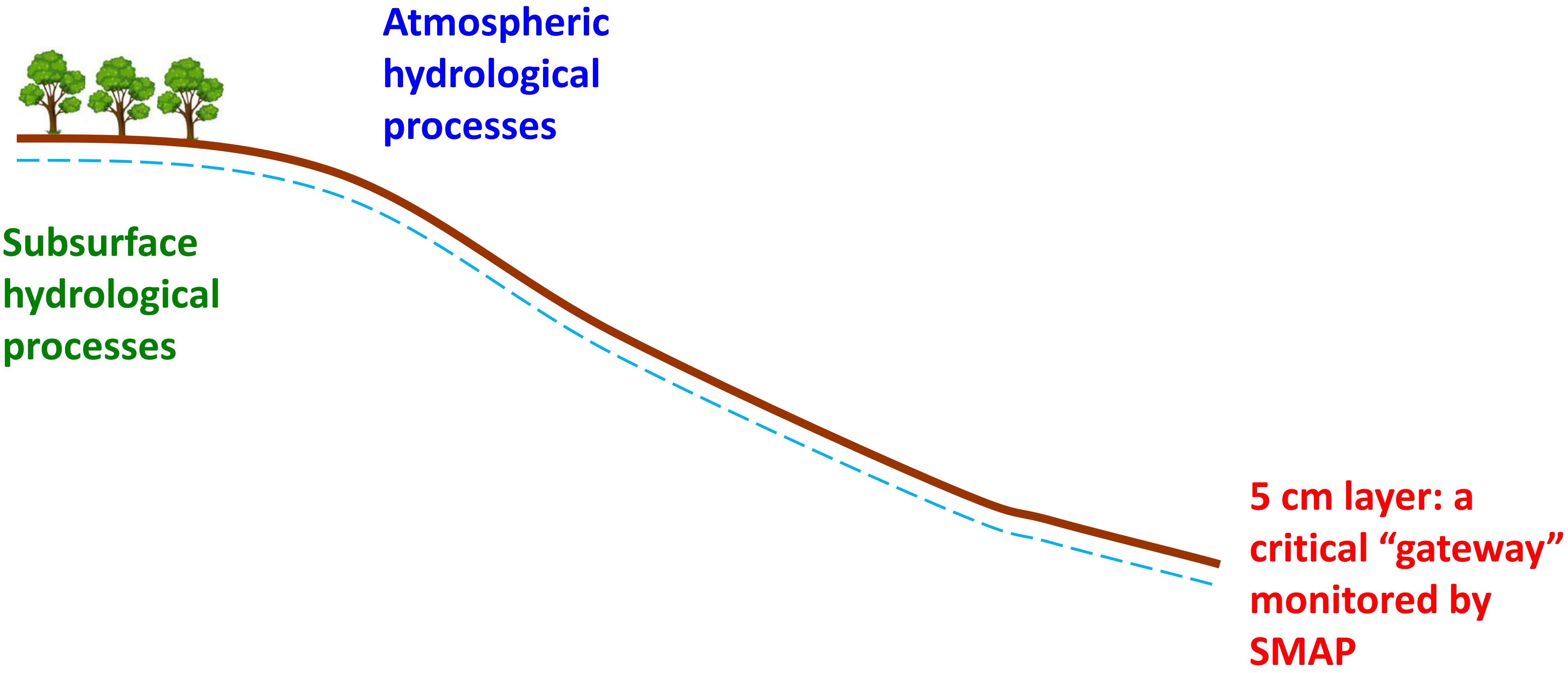
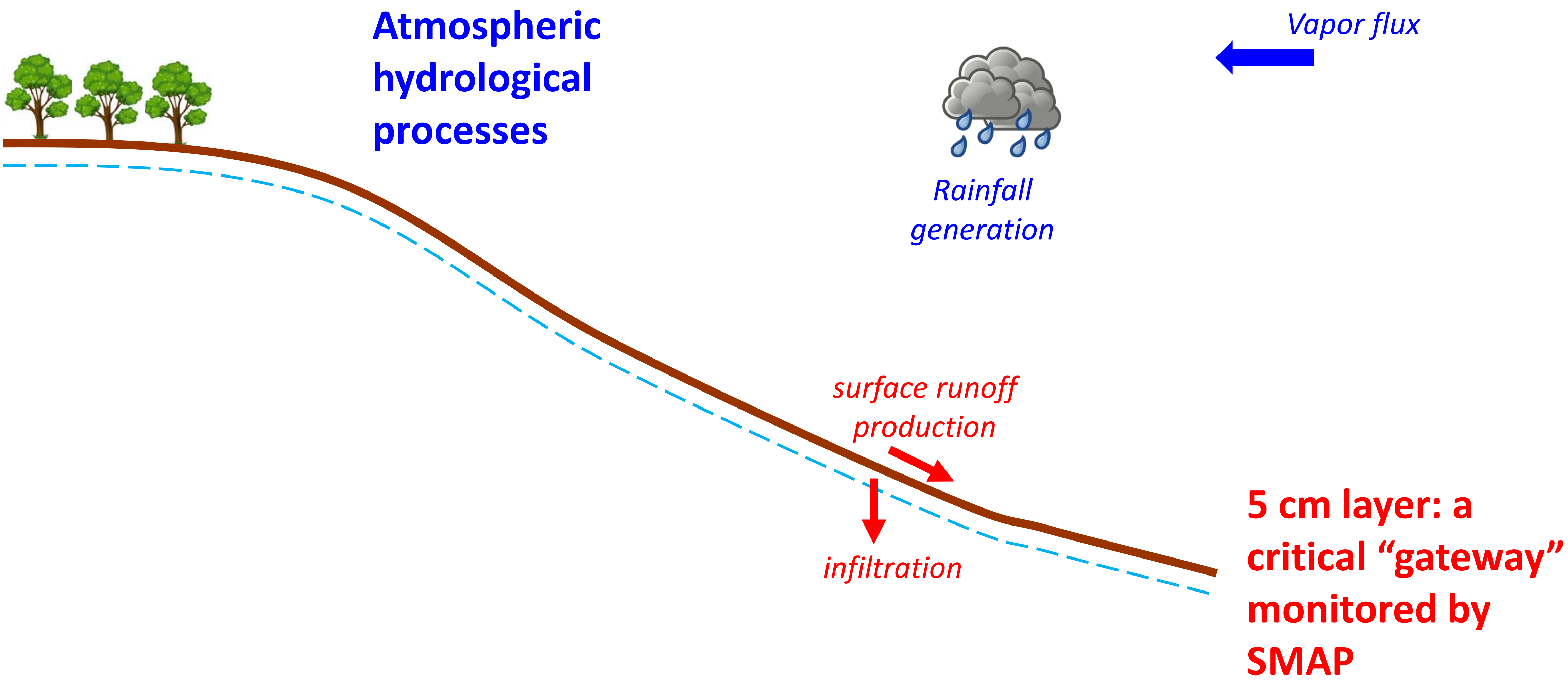
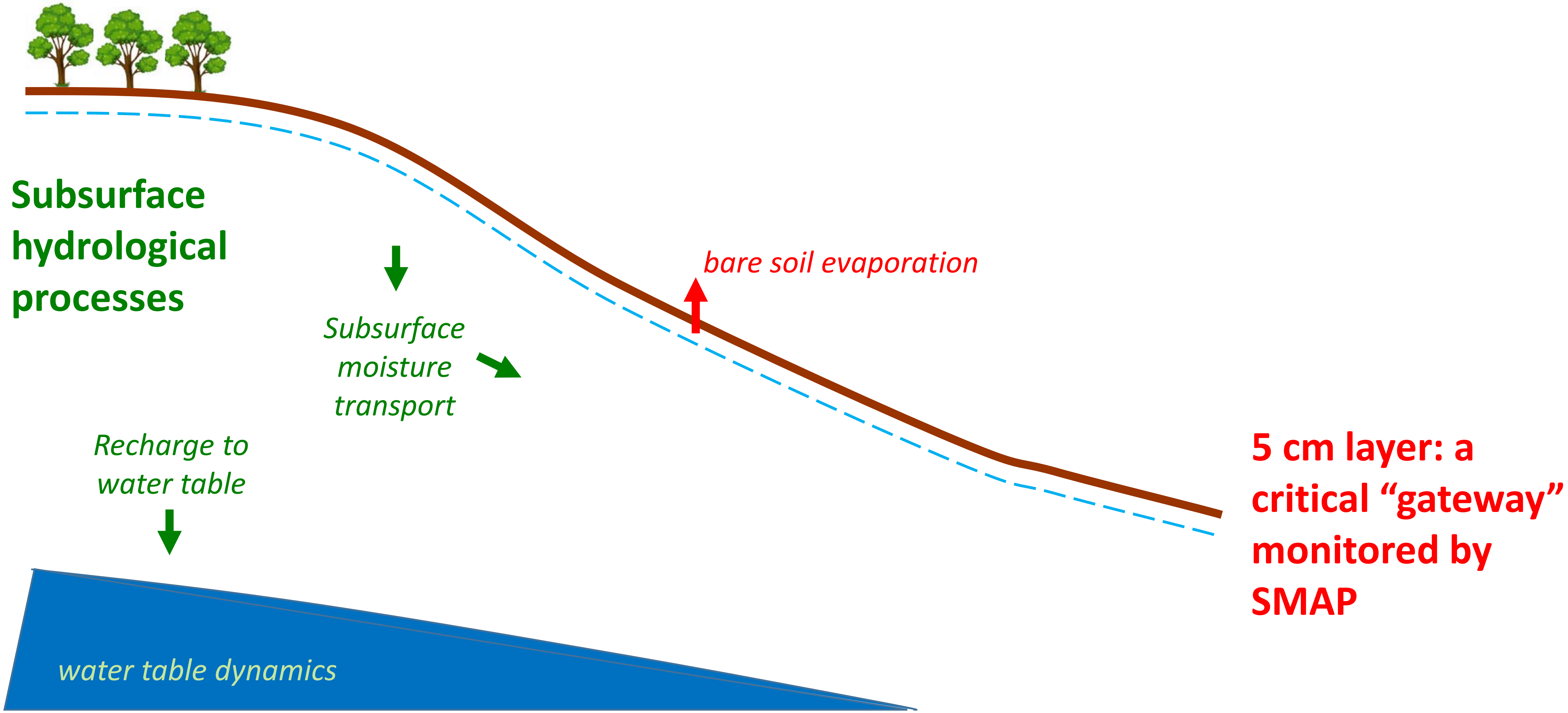
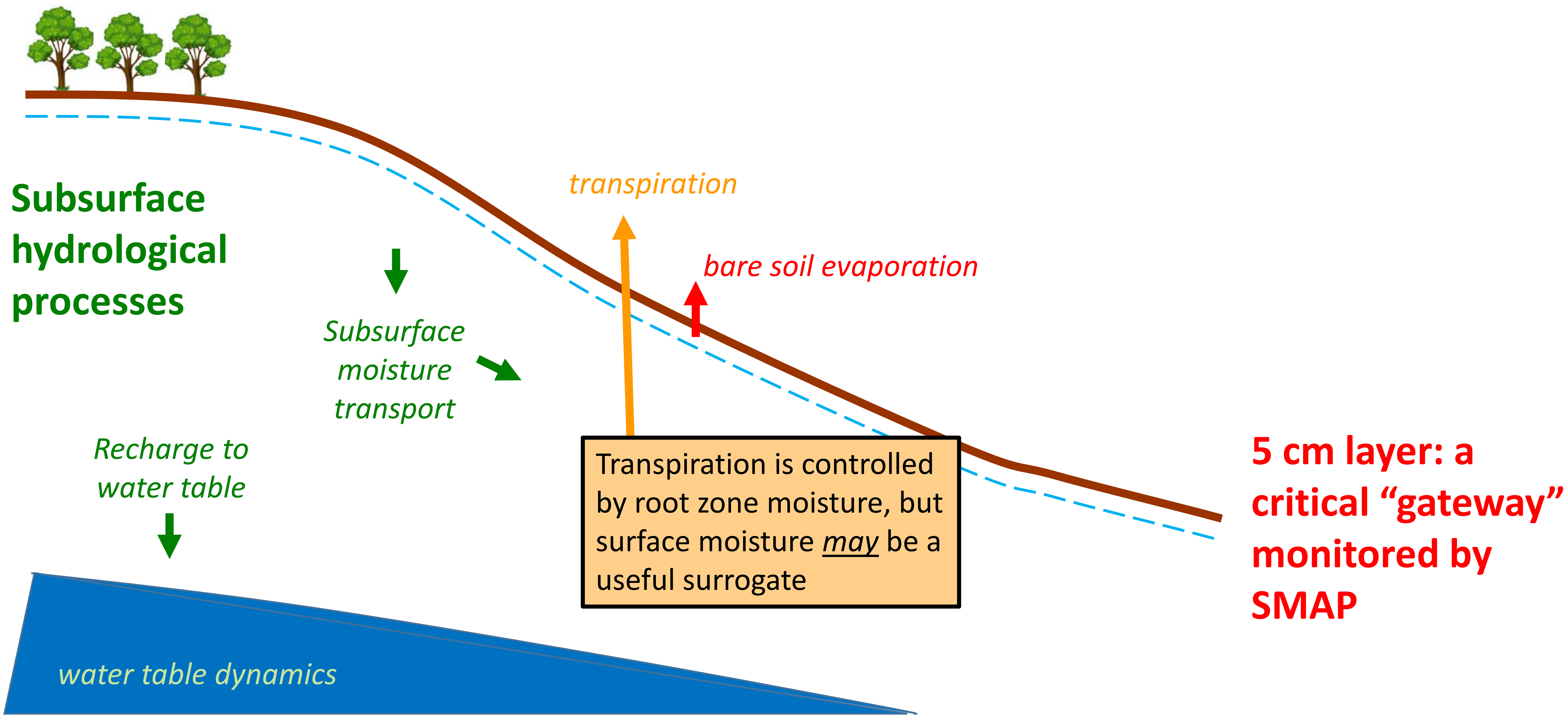
JPL, Pasadena


Atmospheric hydrological processes
Subsurface hydrological processes
5 cm layer: a critical “gateway” monitored by SMAP

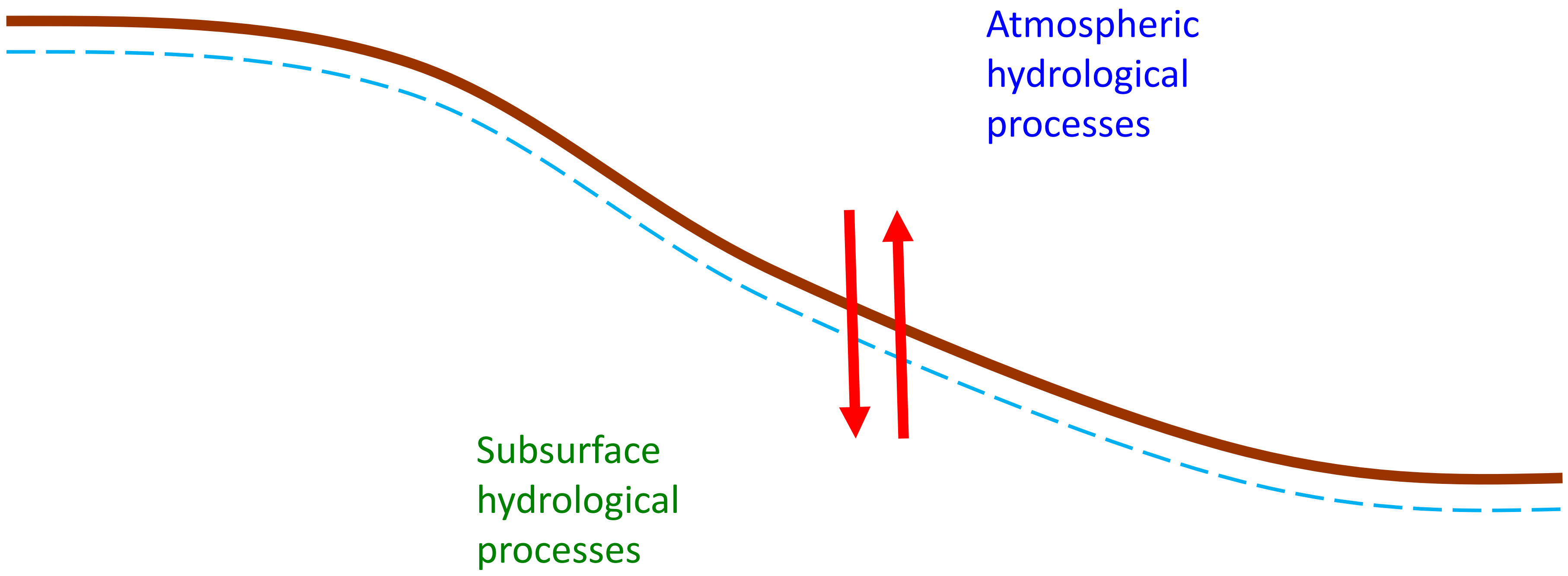

Atmospheric hydrological processes
Vapor flux
Rainfall generation
surface runoff production
infiltration
5 cm layer: a critical "gateway" monitored by SMAP


Subsurface hydrological processes
bare soil evaporation
Subsurface moisture transport
Recharge to water table
water table dynamics
5 cm layer: a critical “gateway” monitored by SMAP

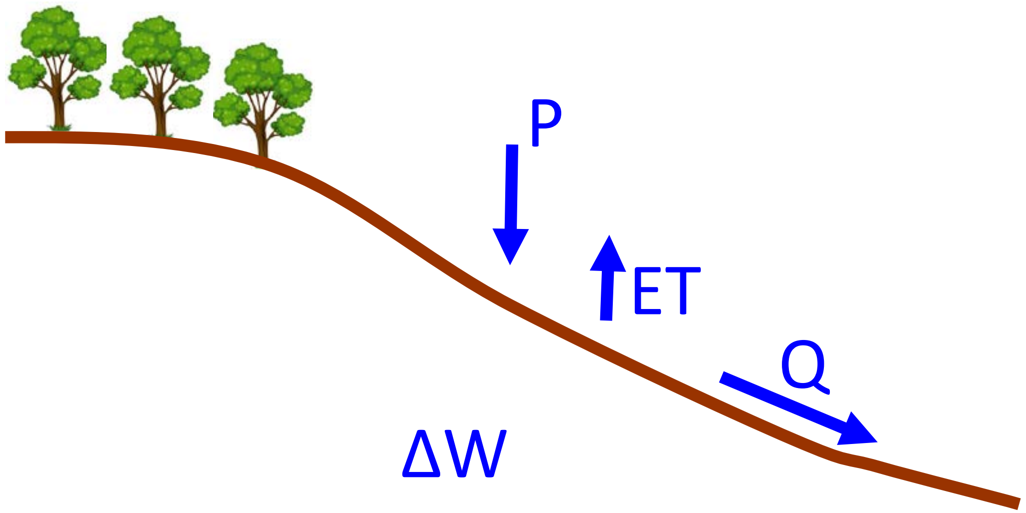

Subsurface hydrological processes
transpiration
bare soil evaporation
Subsurface moisture transport
Recharge to water table
Transpiration is controlled by root zone moisture, but surface moisture *may* be a useful surrogate
water table dynamics
5 cm layer: a critical “gateway” monitored by SMAP

Key point: Because SMAP data monitor the "critical gateway", they contain information on many important hydrological processes.

⇨ *In essence, SMAP does more than just measure soil moisture…*



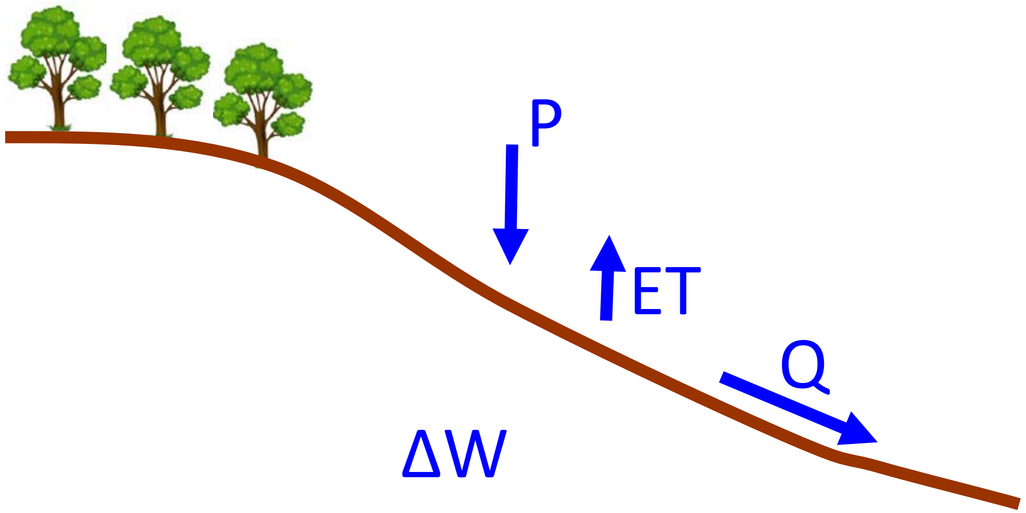
Sample Hydrological Application: Estimating terms in a basin's water balance.



$$P = ET + Q + \Delta W$$

- P: precipitation
- ET: evapotranspiration
- Q: runoff (streamflow)
- ΔW: change in storage

Sample Hydrological Application: Estimating terms in a basin's water balance.



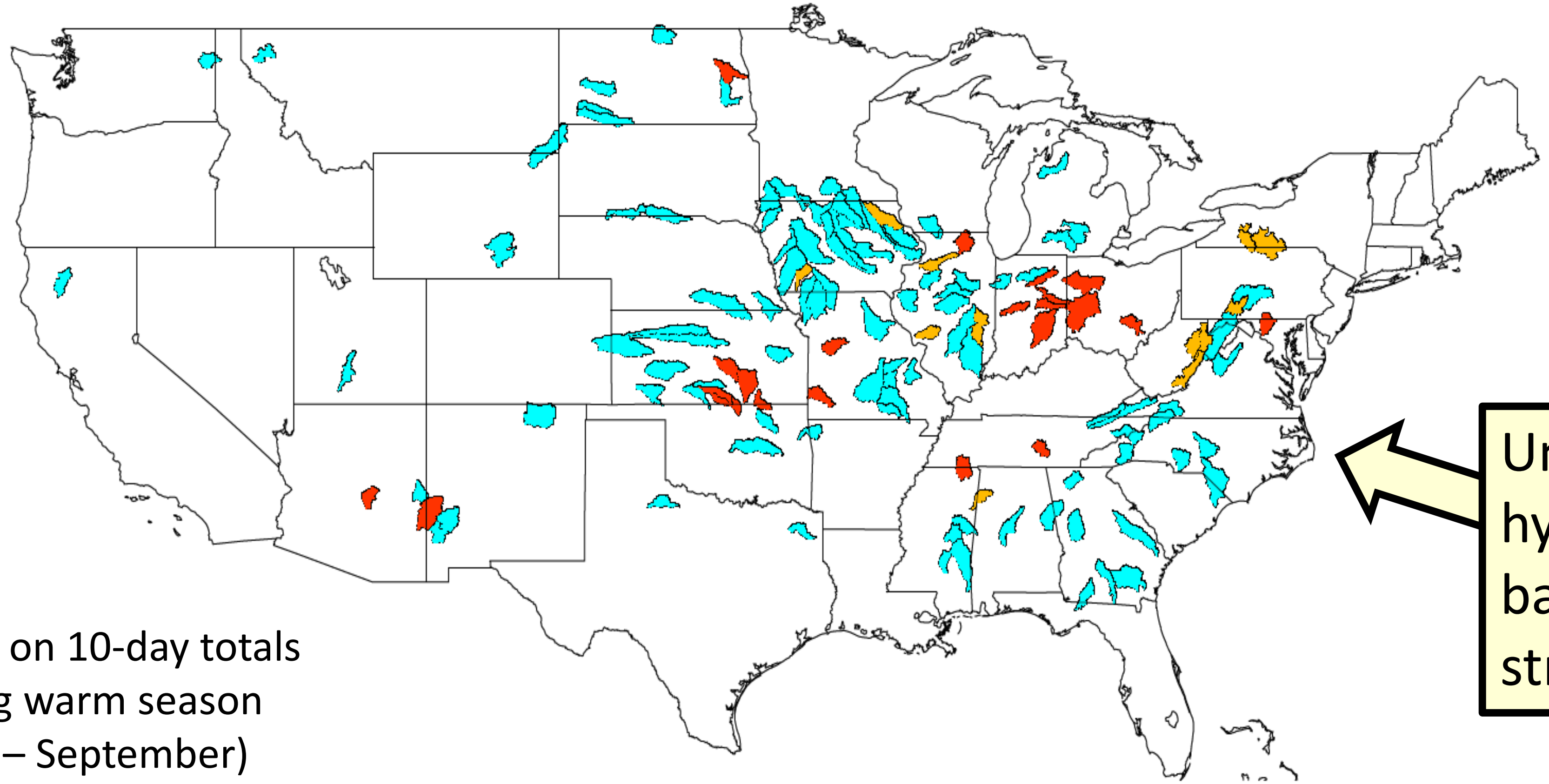
$$P = ET + Q + \Delta W$$

Today: a demonstration of how these terms can be estimated with SMAP soil moisture data

(not perfectly, but with <u>some</u> skill)

Basin level analysis (to allow for joint calculation of P and Q)

$$P = ET + Q + \Delta W$$

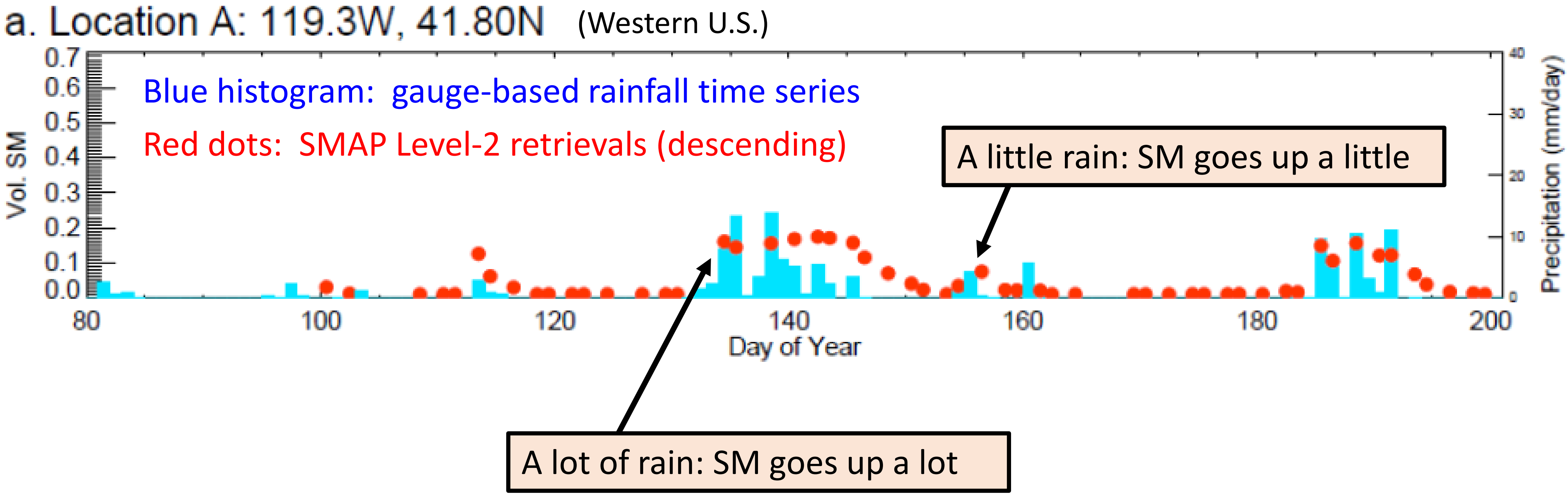


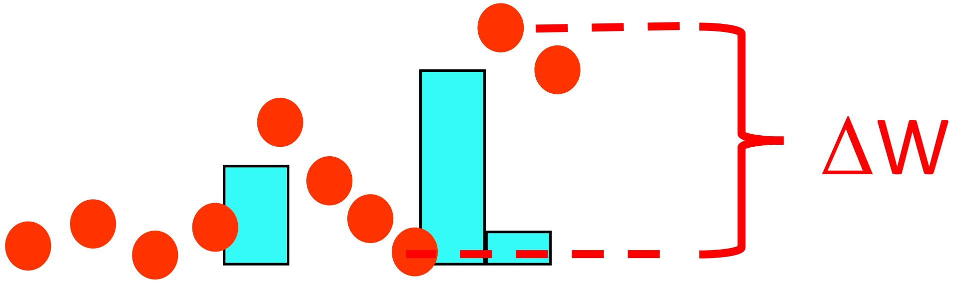
Unregulated hydrological basins with USGS stream gauges

Focus on 10-day totals during warm season (June – September)

Step 1: Precipitation Estimation

Notice: Rain gauge data and SMAP radiometer data generally look nicely consistent.

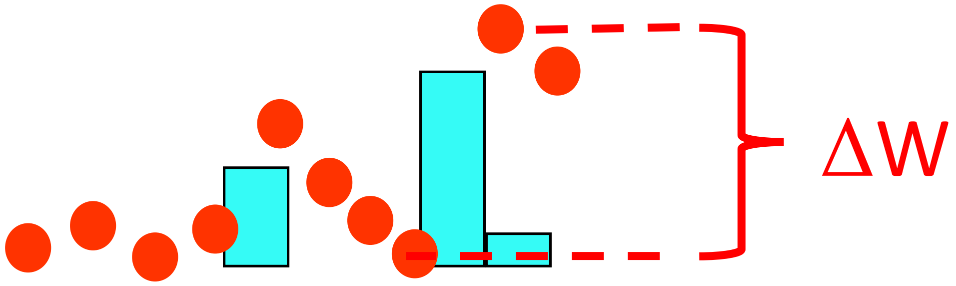




Precipitation estimation approach from Brocca et al. (2013):

$$P \sim \mathrm{Max}\,(\,\Delta W \;-\; a\,W_{ave}^{\,b}\;,\;0.\,)$$

W_{ave} = average of the two consecutive retrievals



Updated approach:
This term replaced with calibrated loss function

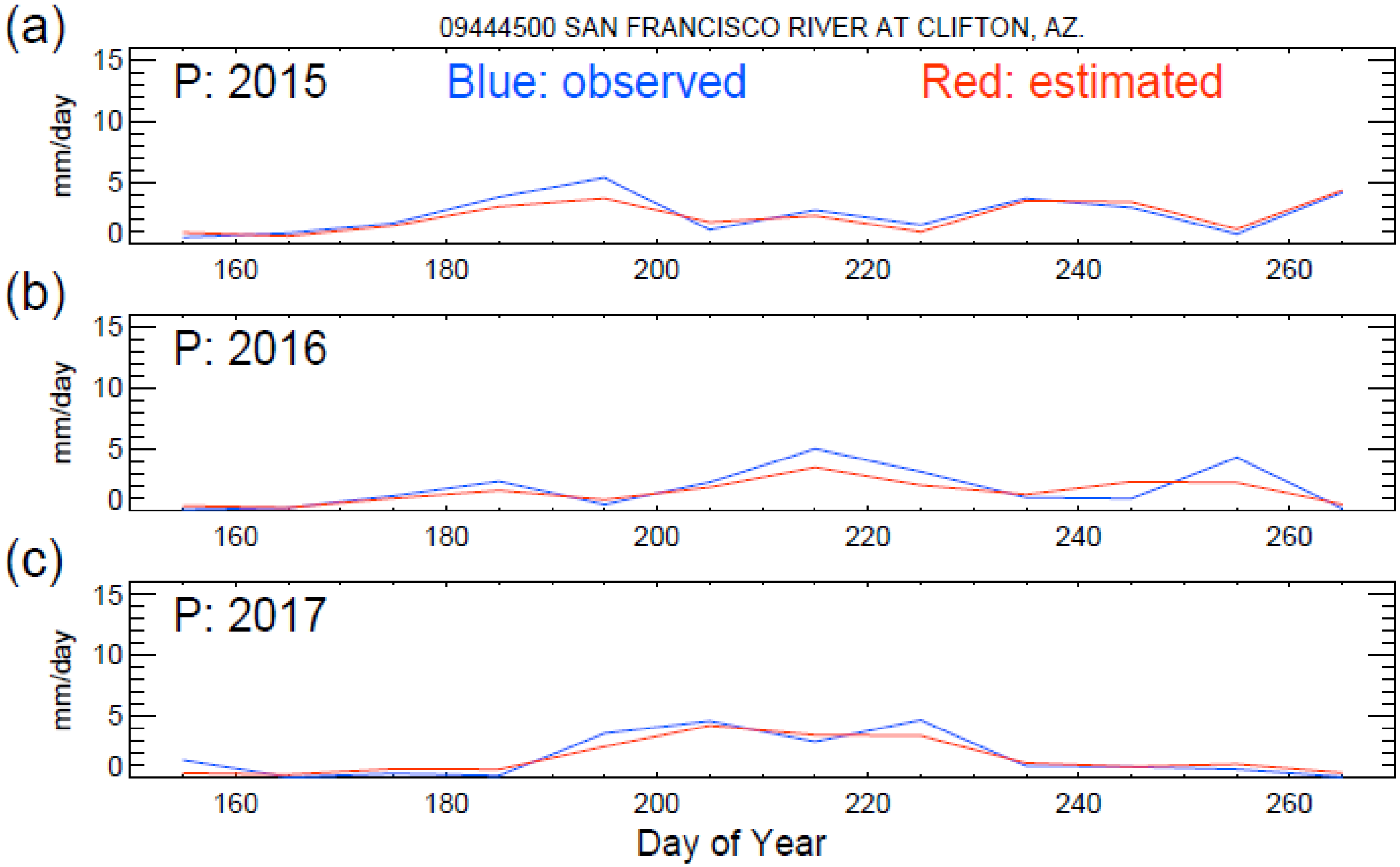
Precipitation estimation approach from Brocca et al. (2013):

$$P \sim \mathrm{Max}\left(\Delta W - a\, W_{ave}^{\,b},\ 0. \right)$$

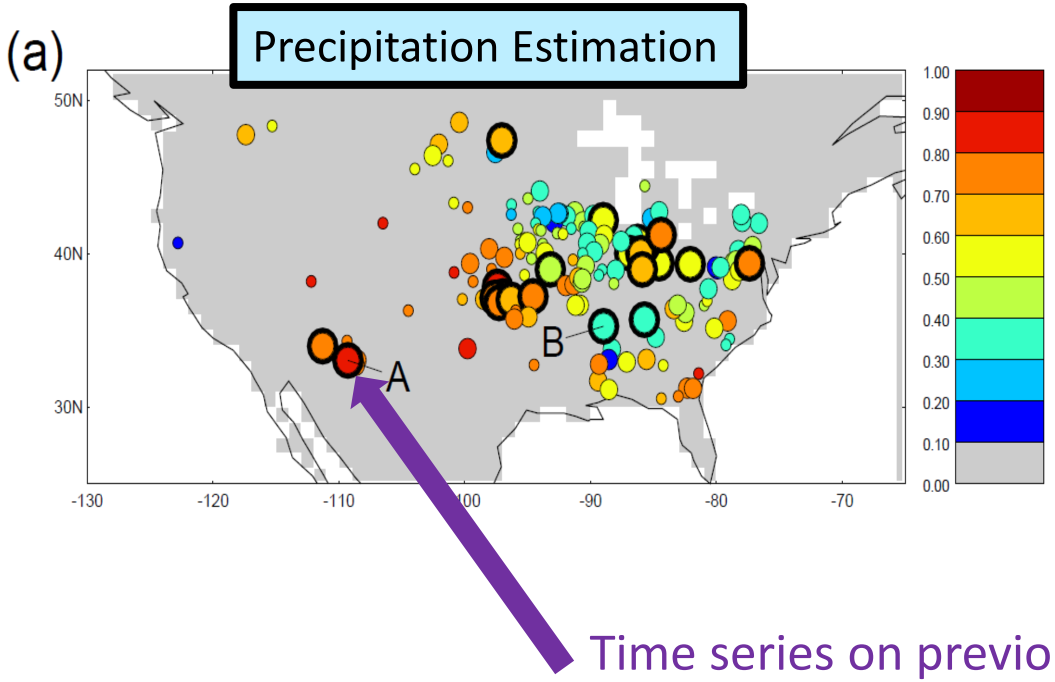
W_{ave} = average of the two consecutive retrievals

Some results! (One of the better estimations):

We can characterize the agreement in these time series with the square of the correlation coefficient, r^2.

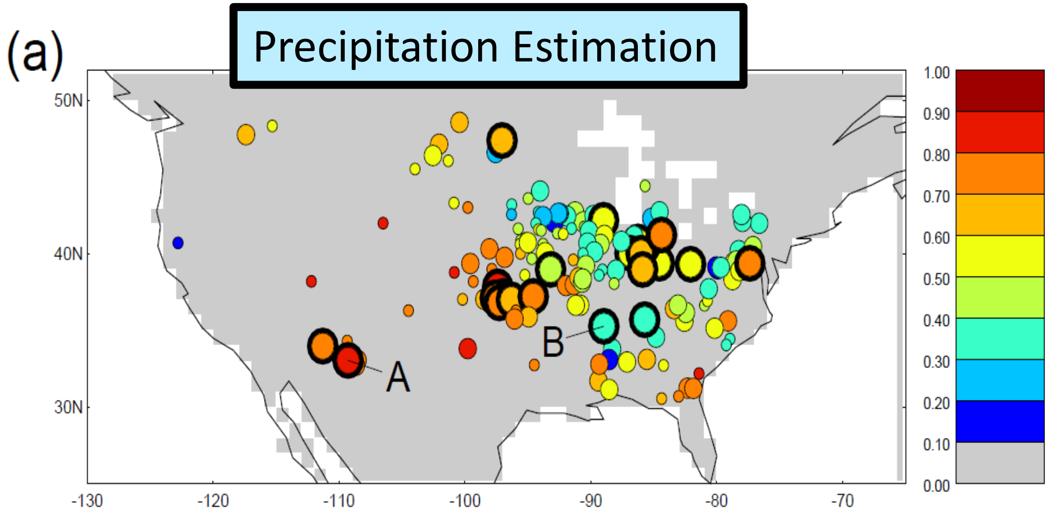


Basin level skill scores (time series of 10-day precipitation totals: r^2 vs observations)

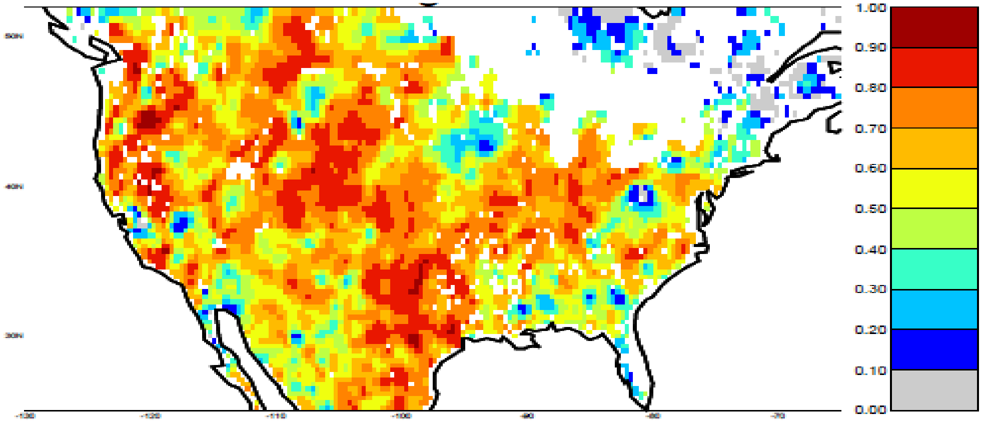


Time series on previous page were shown for this basin.

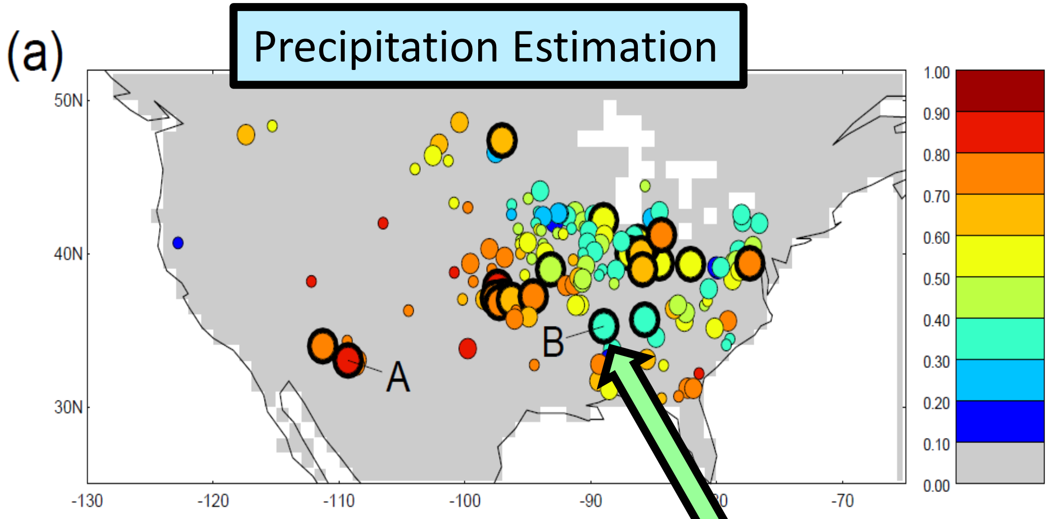
Basin level skill scores
(time series of 10-day precipitation totals: r^2 vs observations)

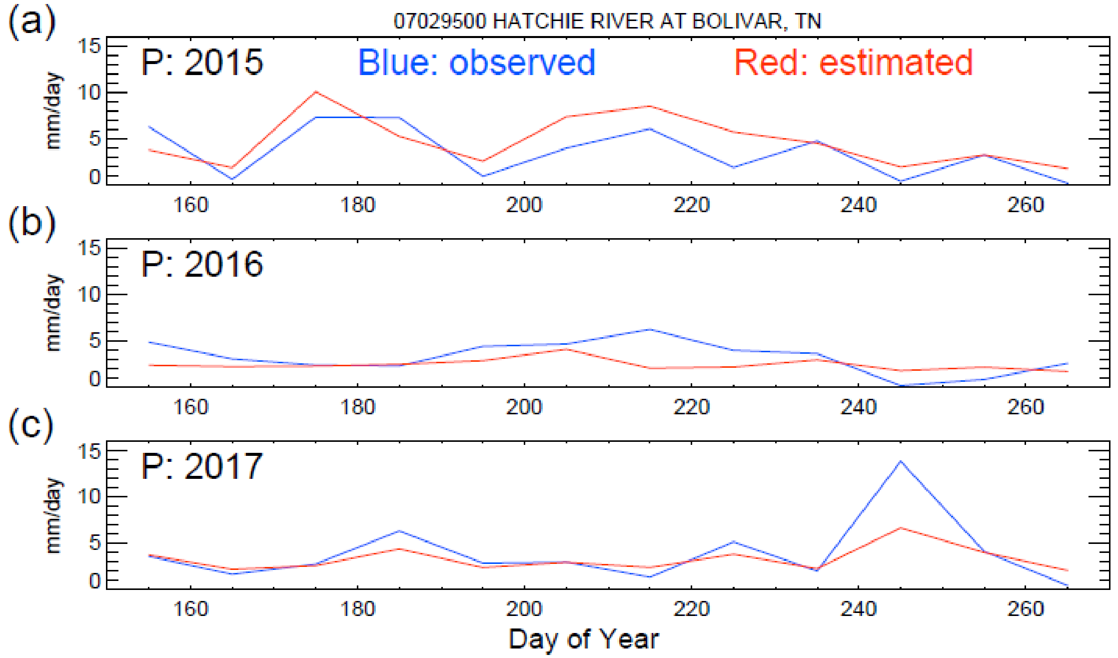


Aside: extending this analysis across the US, beyond "basins", indicates high skill throughout the west.



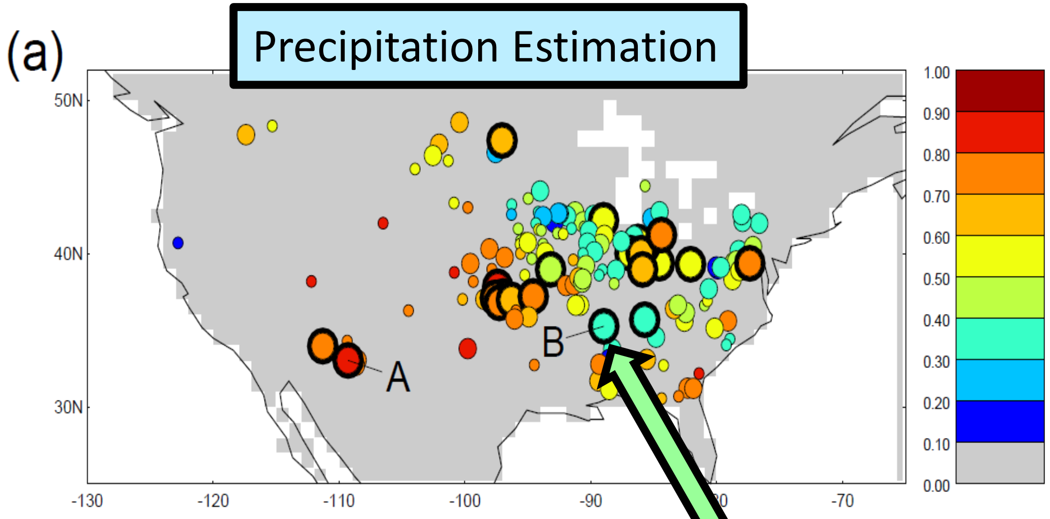
Basin level skill scores (time series of 10-day precipitation totals: r^2 vs observations)



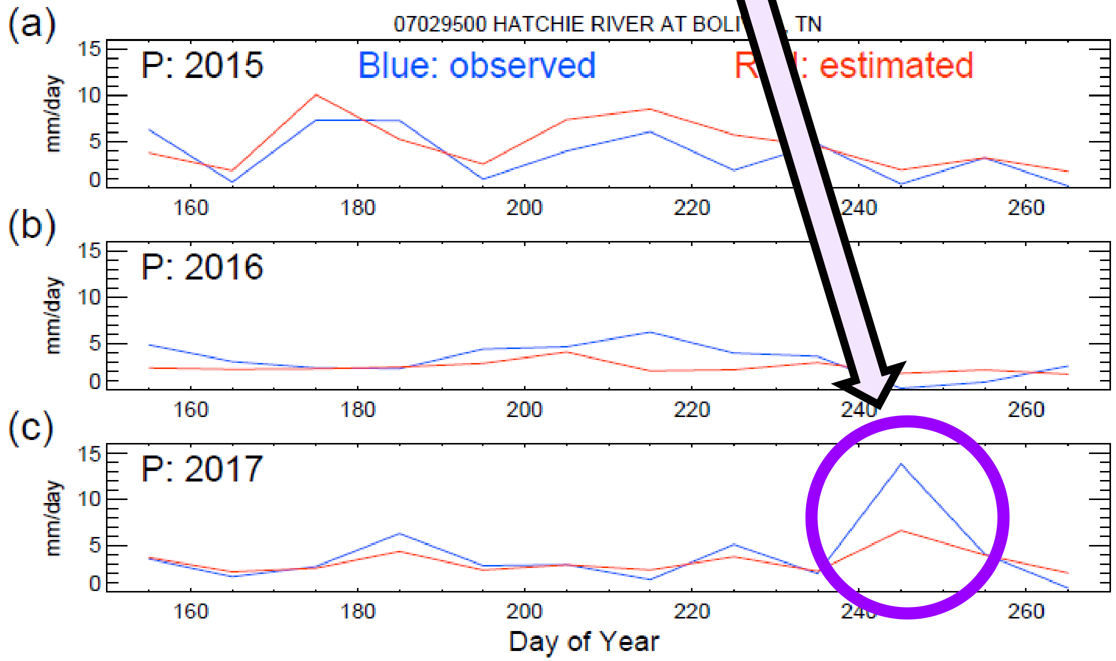


The algorithm works relatively poorly in this basin. Still, there is some valid information in the estimates

Basin level skill scores (time series of 10-day precipitation totals: r^2 vs observations)



Pardon the pun:
High rainfall saturates the soil moisture signal, making rainfall estimation difficult.



The algorithm works relatively poorly in this basin. Still, there is some valid information in the estimates

Step 2: Streamflow Estimation

Consider:

- The fraction of rainfall, P, that is converted to surface runoff, Q_{fast}, increases with surface soil moisture, W_{surf} :

$$Q_{fast} / P = f_1 (W_{surf})$$

- Drainage of moisture, Q_{slow}, to the water table (and eventually into streams) increases with increased soil moisture, W:

$$Q_{slow} = f_2 (W)$$

basin-scale P

basin-scale W

Apply multiple regression:

$$Q = Q_{fast} + Q_{slow} = a\,P\,W + b\,W + c$$

Note – in practice, more complex and accurate approaches would be used. This simple approach has the advantage, though, of demonstrating unequivocally that SMAP data hold relevant information.

Cross-validate!

Calibrate (i.e., find a, b, and c) using two years of observations:

obs Q from 2 SMAP years

obs P from 2 SMAP years

SMAP W from 2 SMAP years

$$Q = a\,P\,W + b\,W + c$$

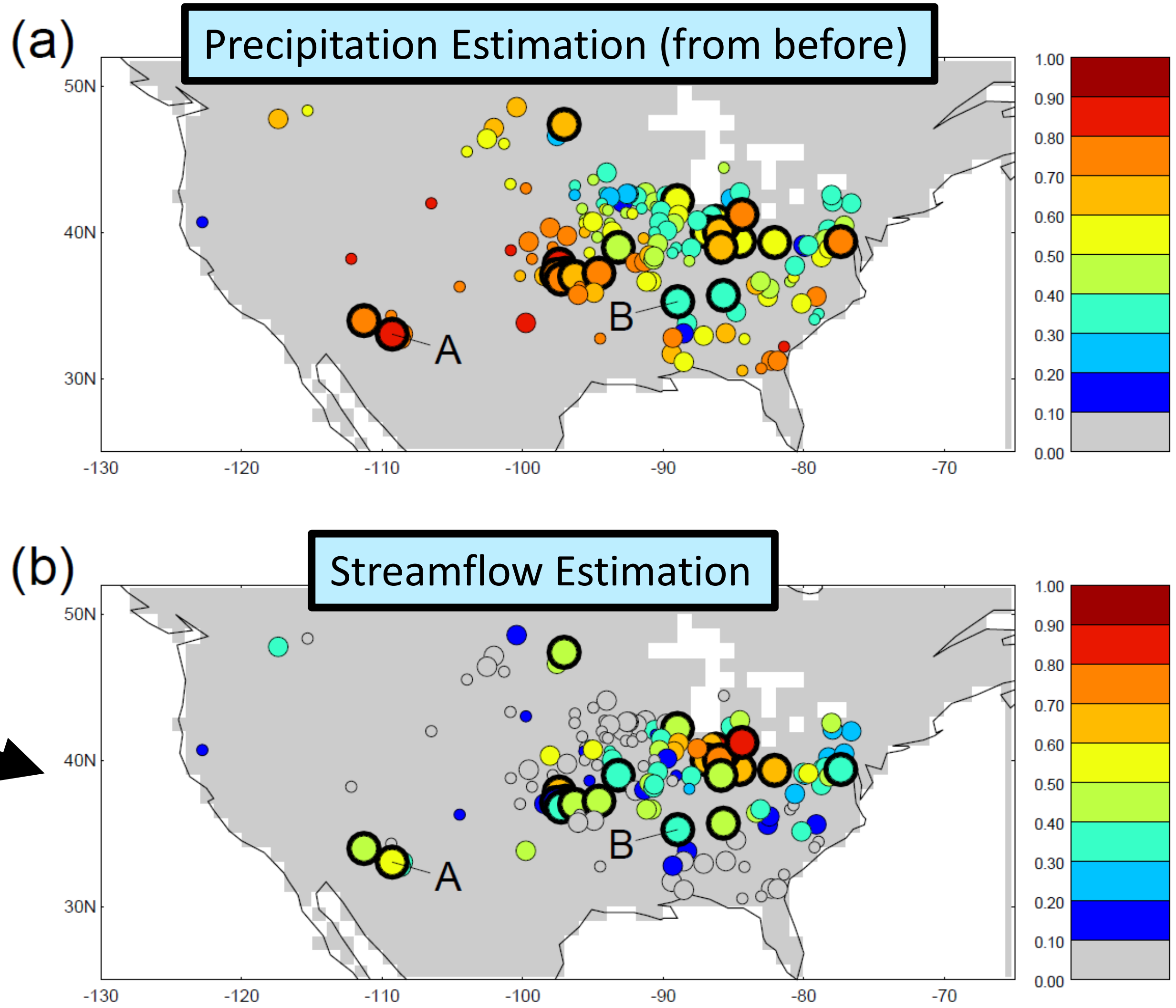
Validate against data from third year:

SMAP-based P estimate for 3rd year

SMAP W in 3rd year

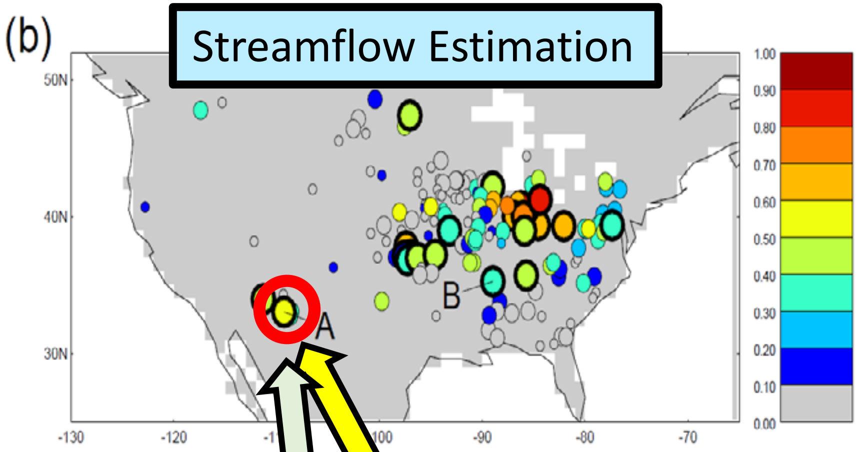
$$Q = a\,P\,W + b\,W + c$$

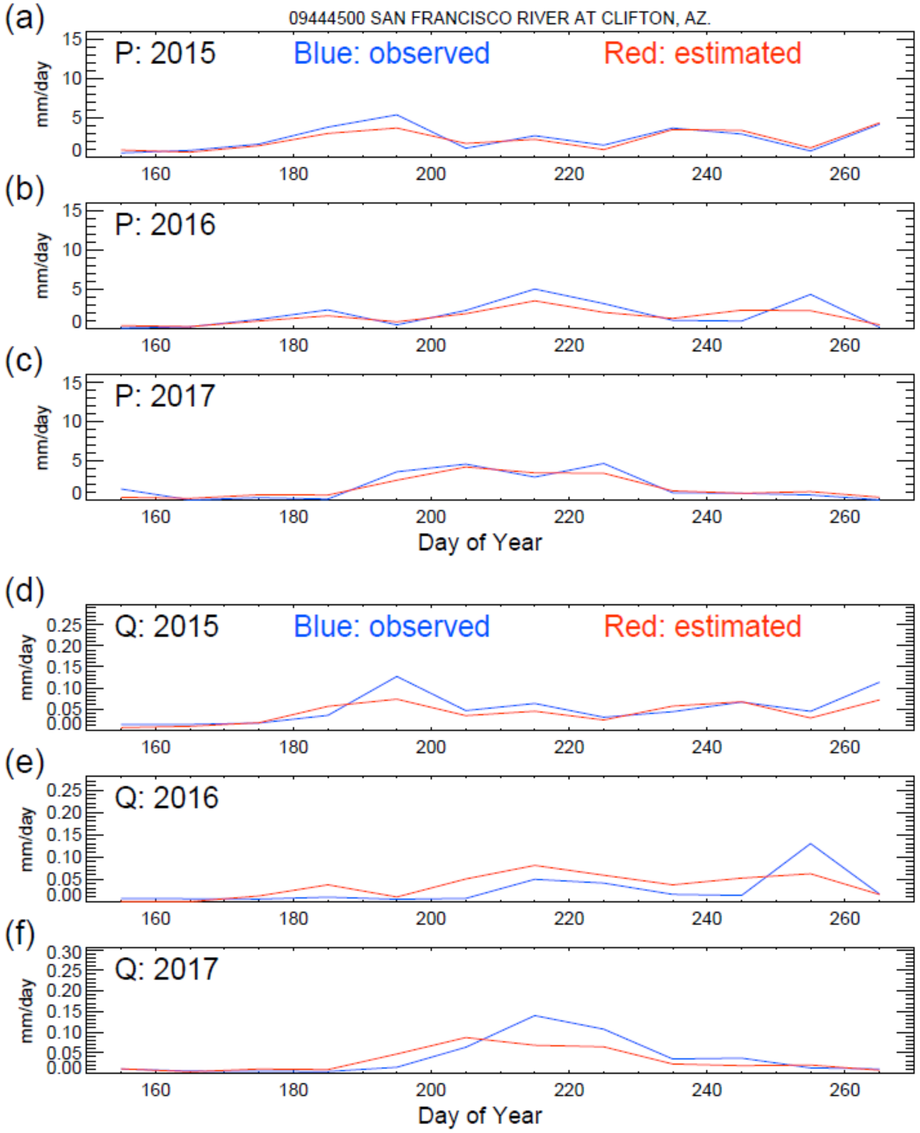
estimate of Q in 3rd year derived solely from SMAP data



Estimation skill (time series of 10-day streamflow totals: r^2 vs observations)

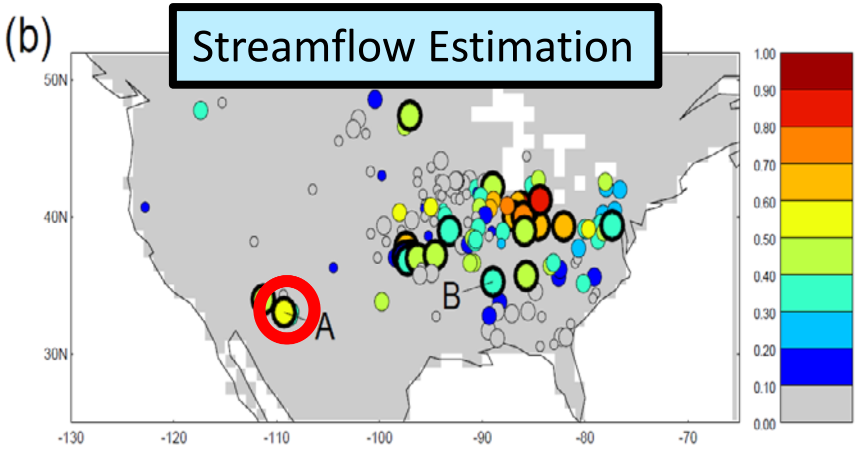
Streamflow Estimation

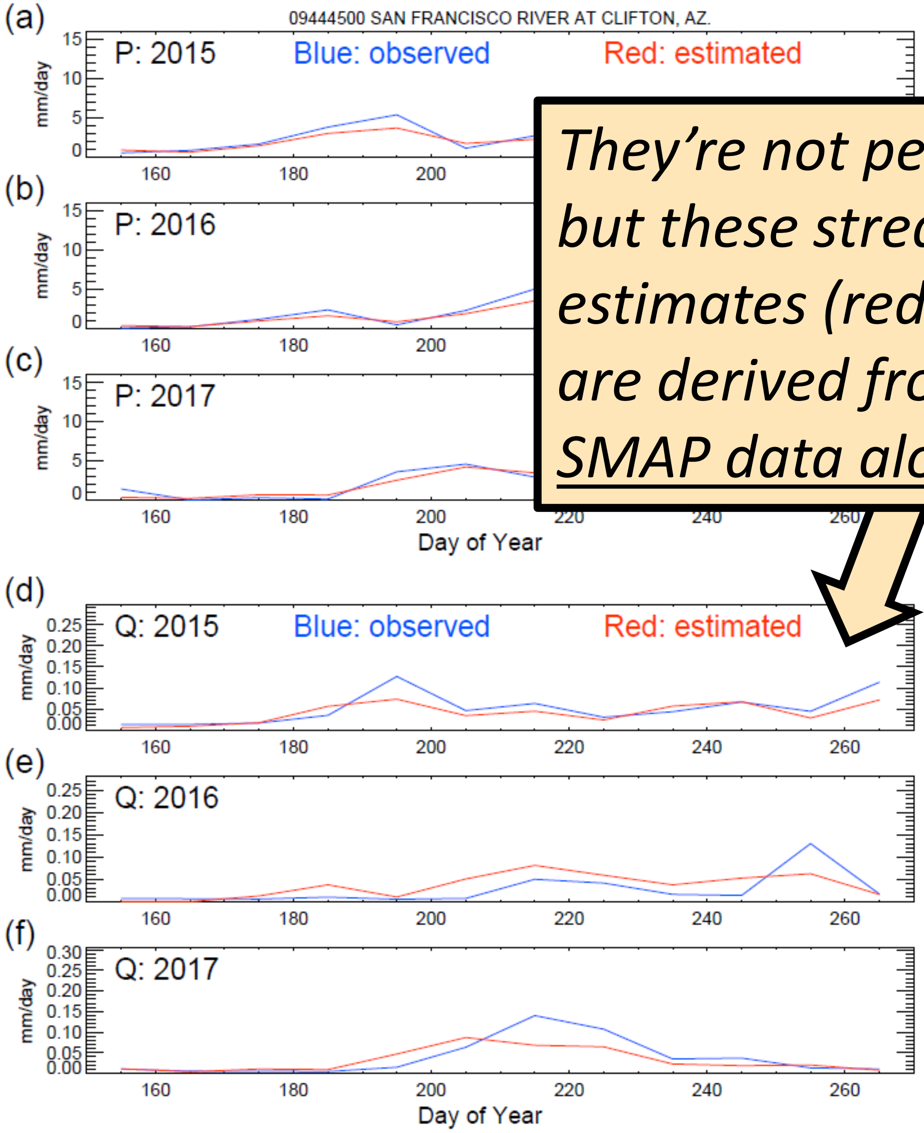




Precipitation estimates (from before)

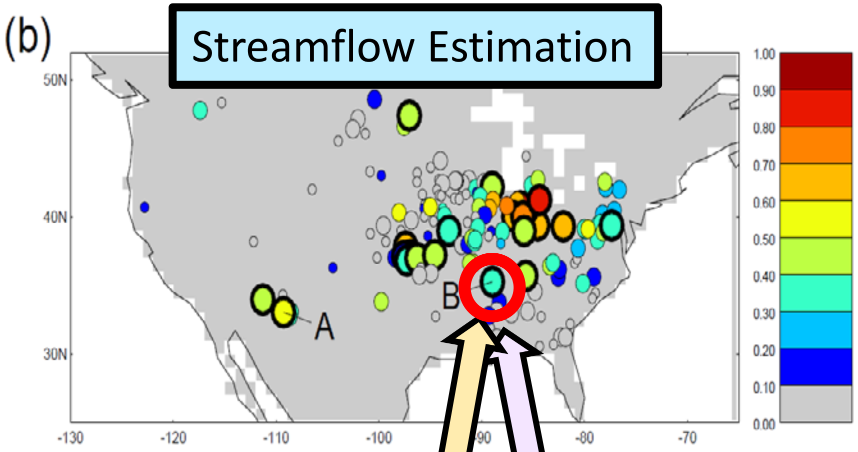
Streamflow estimates capture some of the observed behavior.





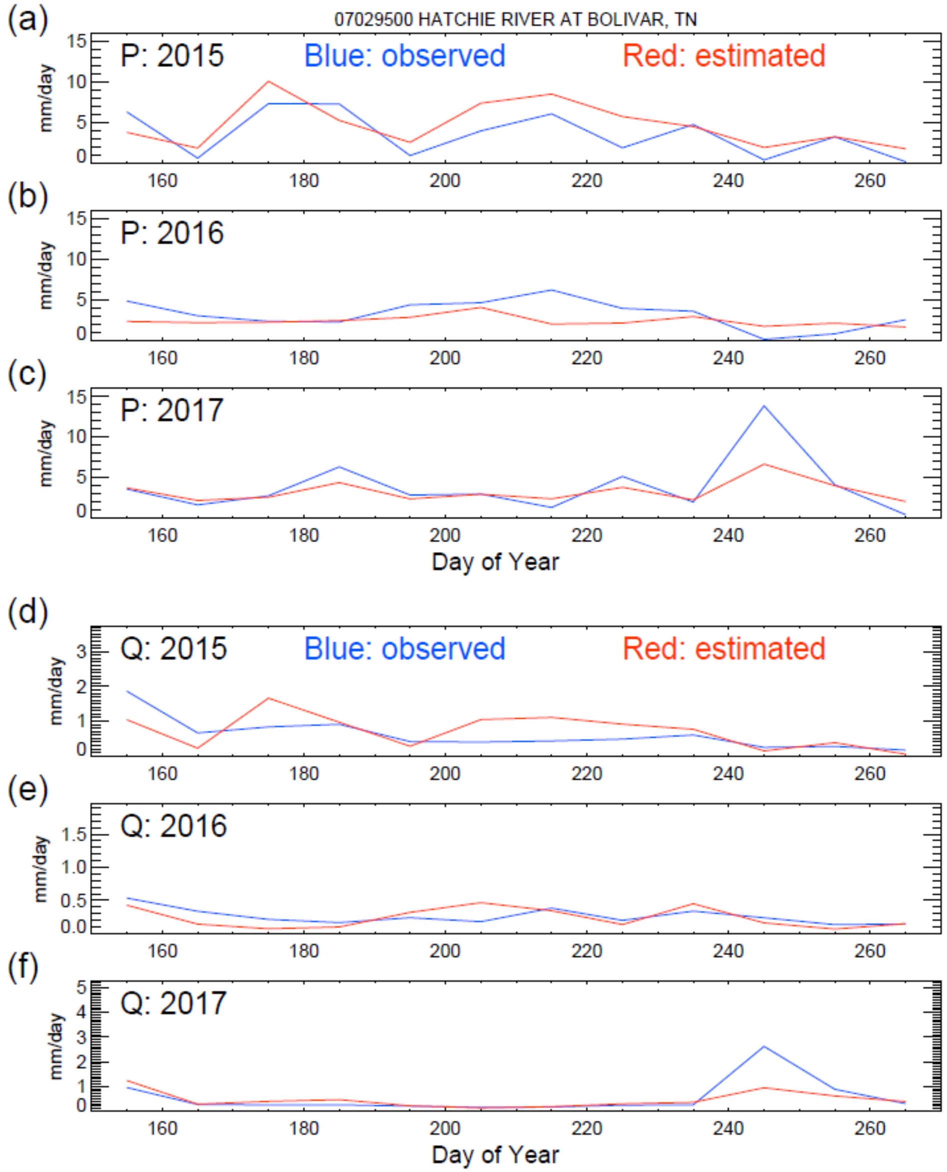
They're not perfect, but these streamflow estimates (red lines) are derived from SMAP data alone!

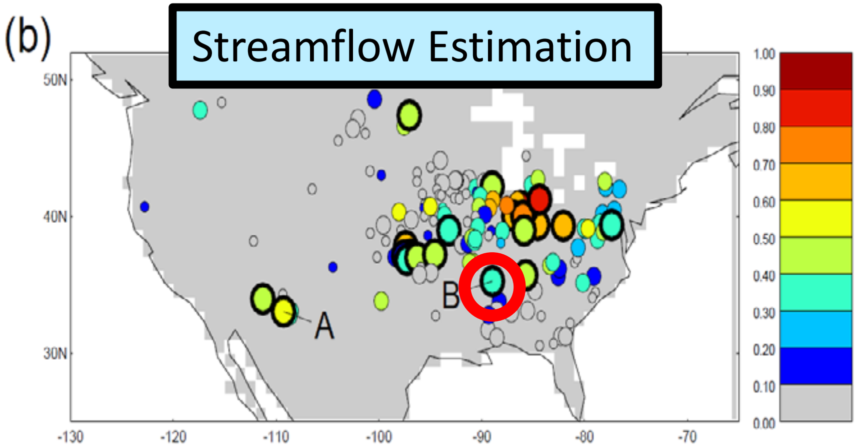
Streamflow Estimation

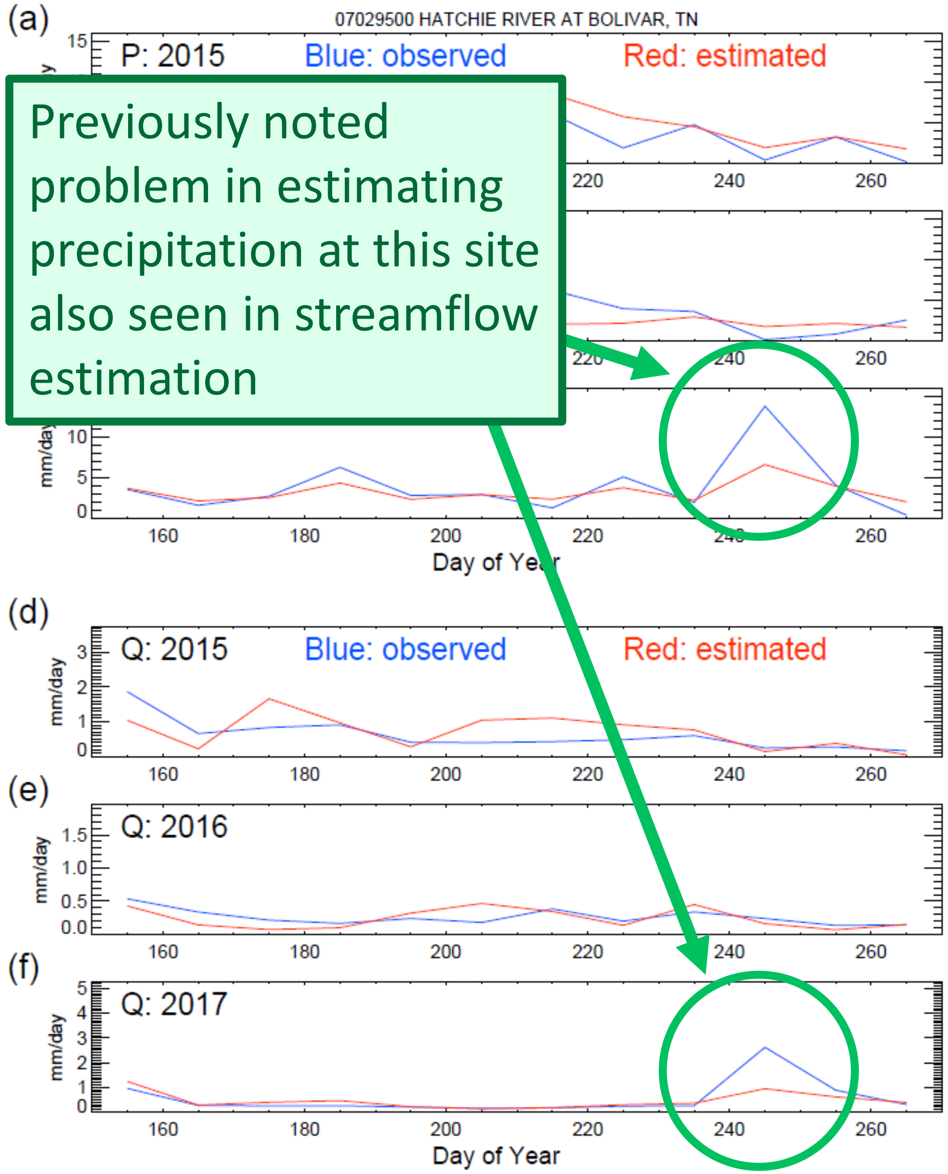


Precipitation estimates in "poorer basin" (from before)

Streamflow estimates capture less of the observed behavior.

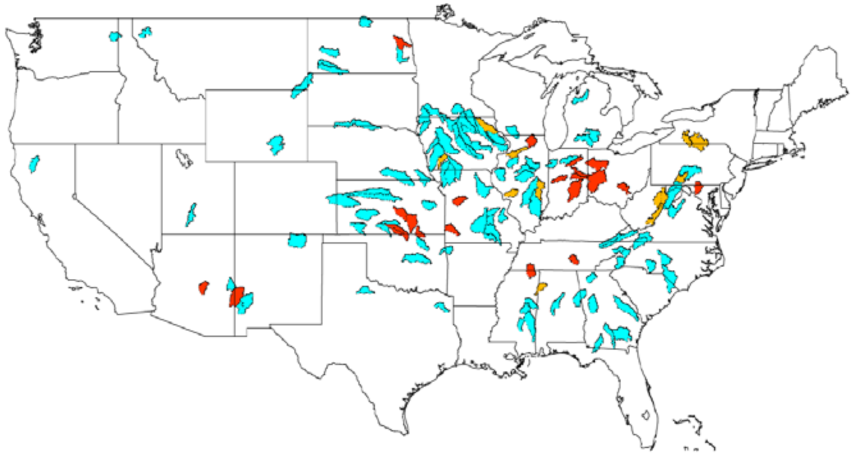


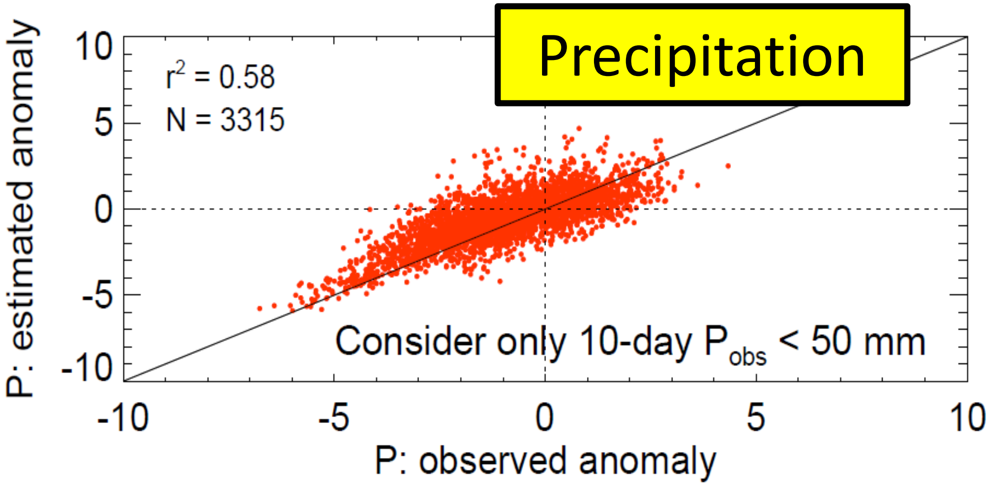

(b)
Streamflow Estimation
50N
40N
30N
-130
-120
-110
-100
-90
-80
-70
A
B
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

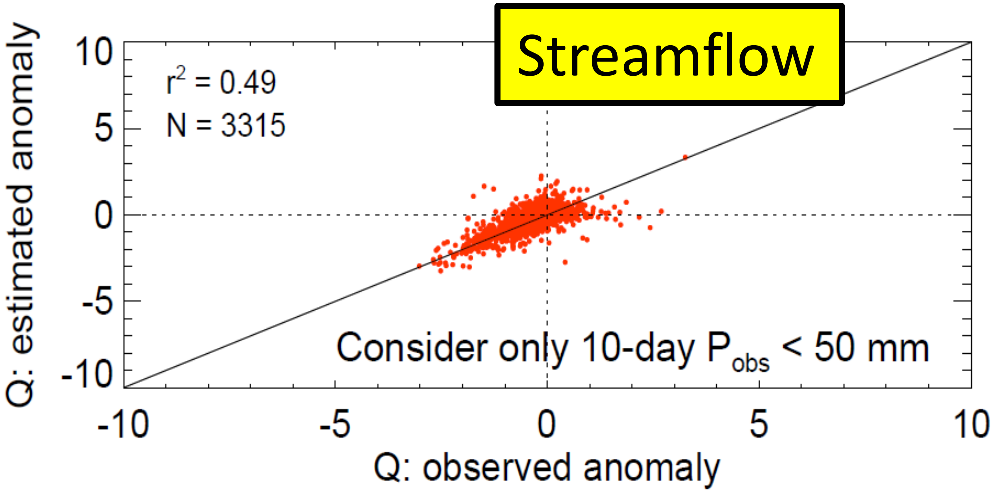

(a)
07029500 HATCHIE RIVER AT BOLIVAR, TN
P: 2015
Blue: observed
Red: estimated
Previously noted problem in estimating precipitation at this site also seen in streamflow estimation
mm/day
Day of Year
(d)
Q: 2015
Blue: observed
Red: estimated
(e)
Q: 2016
(f)
Q: 2017
mm/day
160
180
200
220
240
260
Day of Year

Inter-basin analysis

(throw results for all considered basins onto the same scatterplot)



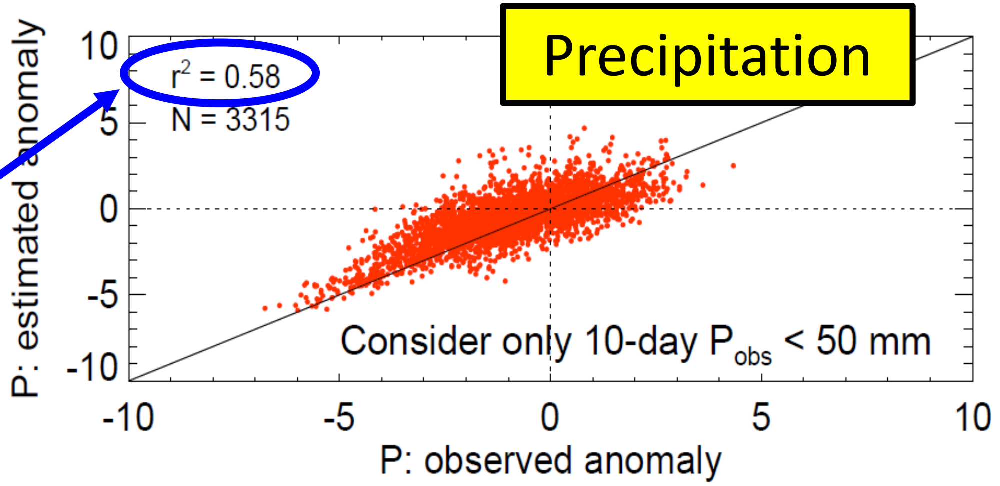




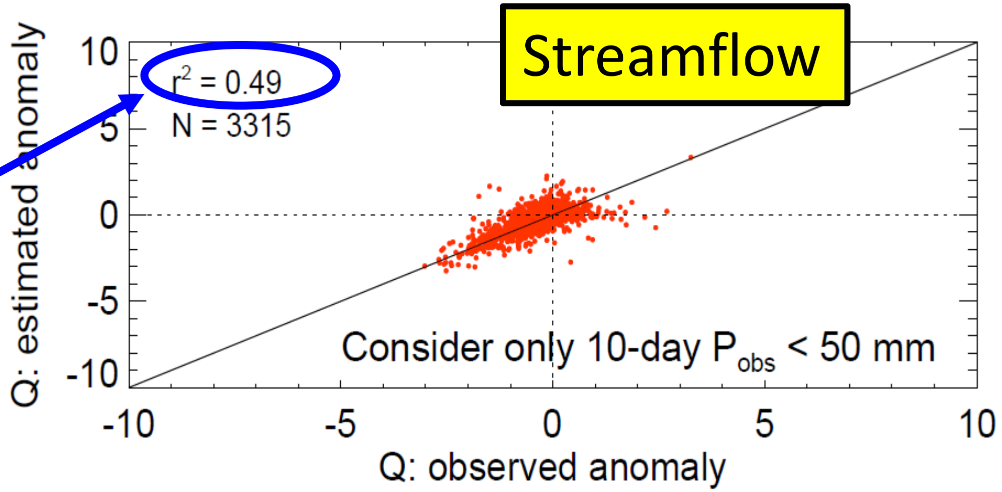
Inter-basin analysis

(throw results for all considered basins onto the same scatterplot)

For 10-day periods in which rainfall does not exceed 50 mm), SMAP data “explain” 58% of precipitation variance…

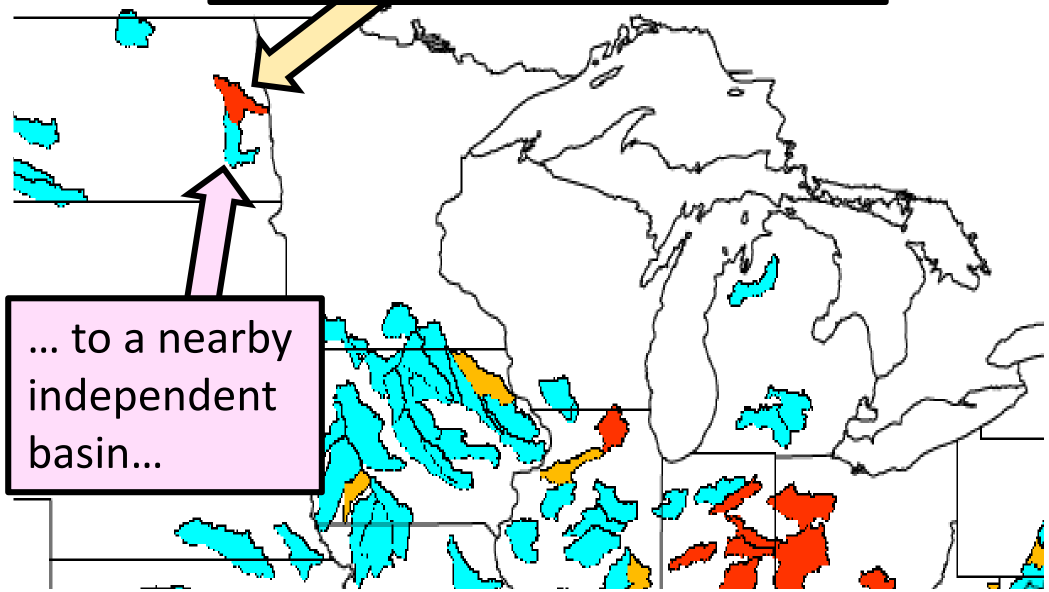


… and 49% of the streamflow variance



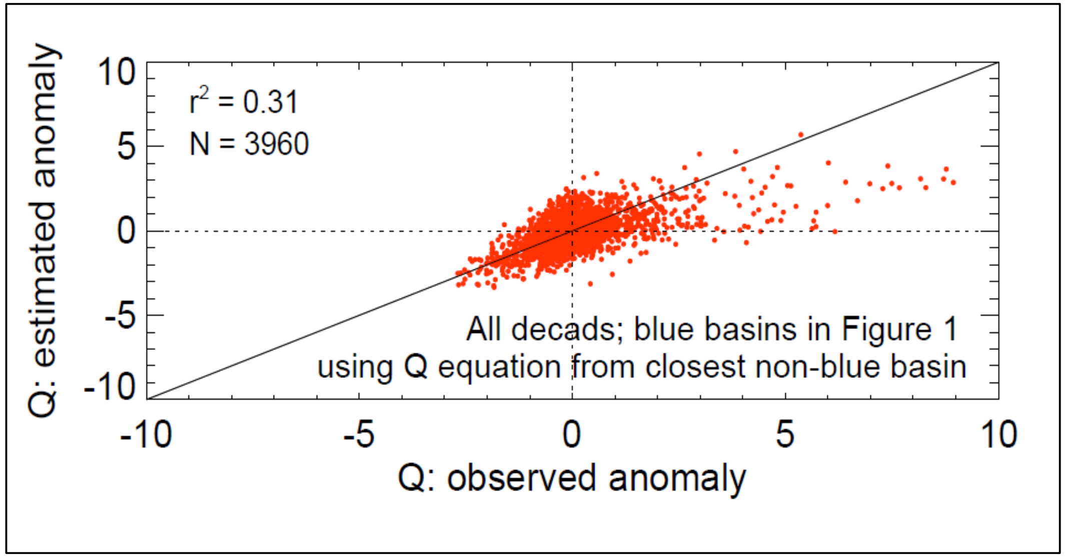
Transferability (streamflow)

Applying streamflow equations calibrated in one basin…



… to a nearby independent basin…

… produces streamflow estimates with some skill
⇨ *there's hope for estimating streamflow in basins that never had a streamflow gauge.*



Main Finding:

The SMAP estimates of rainfall and streamflow are not perfect, but they do contain relevant information.

➪ *At the very least, they should prove useful for constraining, or otherwise contributing to, rainfall and streamflow estimates obtained with more conventional approaches.*

A final comment...

Obvious question: What is the potential for examining other basin water budget components?

$$P - E - Q - \Delta storage = 0$$

(P ✓, E ?, Q ✓, Δstorage ?)

We know that evapotranspiration is a strong function of soil moisture
➩ SMAP data could, in theory, be used to estimate it.

SMAP actually measures directly some of the storage change.

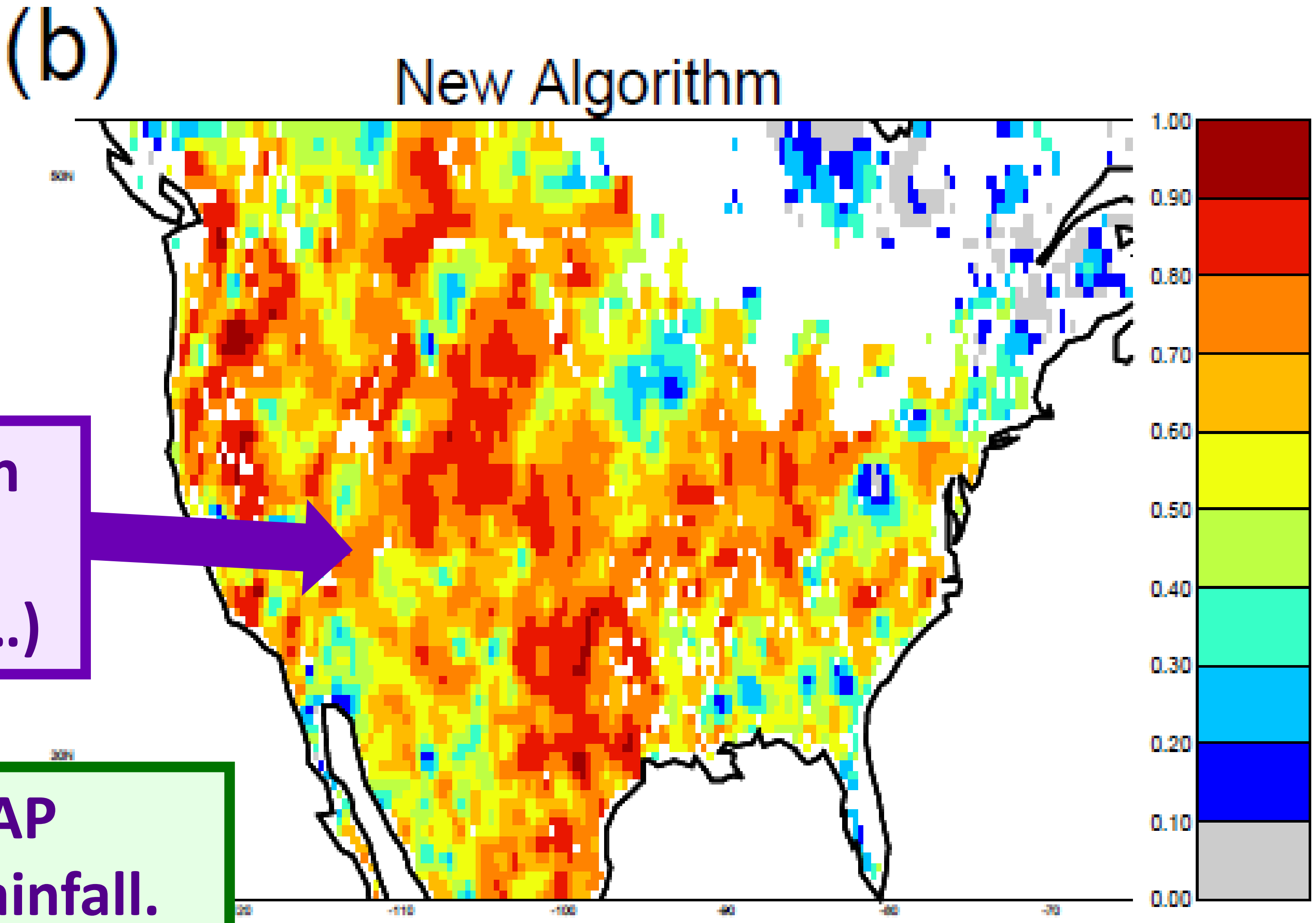
➩ The potential for estimating the other components as well is indeed there.

Extra Slides

Skill (r^2, vs rain gauge observations) of ~100 km, 5-day precipitation estimates

Calibrate: using P observations in June - September of 2015-2016

Validate (map on right): June – September of 2017



SMAP-based precipitation estimates are accurate! (At least to some degree…)

⇨ We can use SMAP data to estimate rainfall.

Aggregate 10-day gridded precipitation estimates across hydrological basin of interest

⇨ hydrological basin precipitation estimates.

(Cross-validate:
-- Use 2015,2016 data to calibrate model for 2017 estimates.
-- Use 2015,2017 data to calibrate model for 2016 estimates.
-- Use 2016,2017 data to calibrate model for 2015 estimates.)

Basic idea:

We have already shown that precipitation rates, P, can be estimated with SMAP Level 2 data (Koster et al., 2016):

$$P = F_1(W_{SMAP})$$

Wade has also shown that SMAP data contain information on the ratio of runoff, Q, to precipitation (Crow et al., 2017):

$$Q/P = F_2(W_{SMAP})$$

Logically, then, runoff (streamflow) itself should be extractable from SMAP data:

$$Q = F_3(W_{SMAP})$$