NLDAS Science Testbed updates
(CLSM, Noah-MP, and HyMAP router)

David M. Mocko[1,2], Sujay V. Kumar[1], Christa D. Peters-Lidard[1],
Shugong Wang[1,2], Augusto Getirana[1,3],
Youlong Xia[4,5], Michael B. Ek[4], Jiarui Dong[4,5]

The **North American Land Data Assimilation System (NLDAS)** is a collaborative project between NOAA/NCEP, NASA/GSFC, Princeton Univ., Univ. of Washington, and NOAA/OHD, and is supported by the NOAA Climate Program Office’s Modeling Analysis, Predictions, and Projections (MAPP) Program.

Acknowledgements: Grey Nearing, Yudong Tian, Jim Geiger, Kristi Arsenault, and numerous members of both the NLDAS and LIS teams over the last 15+ years. Noah-MP and CLSM land-surface model developers.

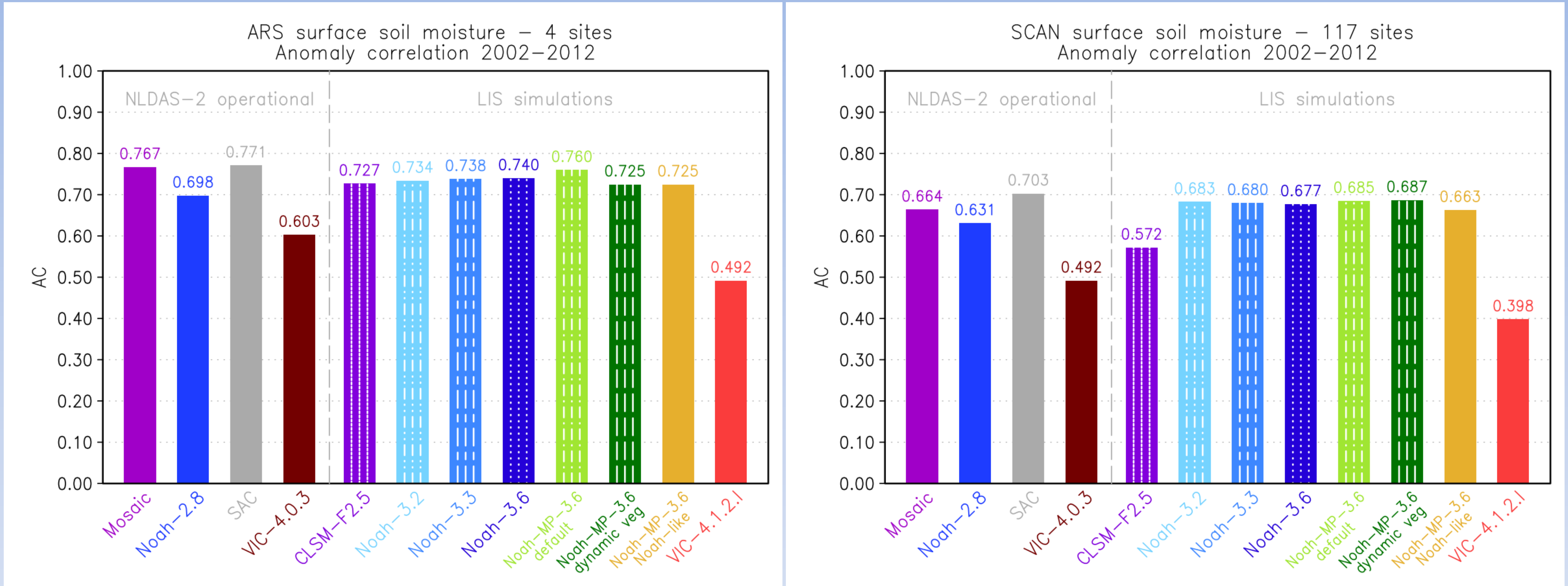
1 – NASA/GSFC; 2 – SAIC; 3 – Univ. MD; 4 – NOAA/NCEP/EMC; 5 – IMSG

NLDAS Science Testbed

The LIS group has developed an NLDAS Science Testbed, designed to test LSMs, parameters, and data assimilation within the **Land Information System (LIS)** using the NLDAS configuration. These simulations are also being evaluated against the four operational LSMs running in NLDAS Phase 2.

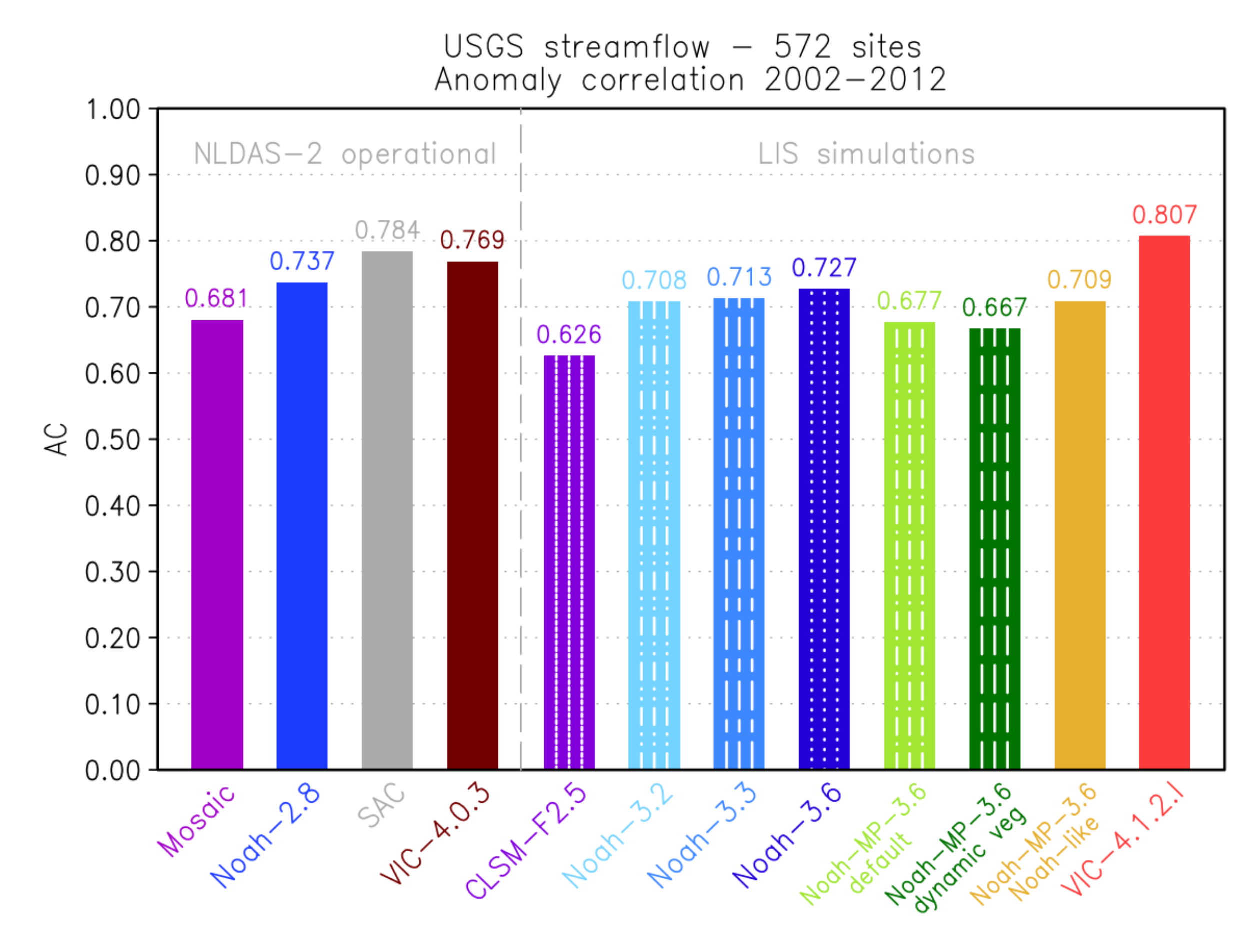
- Spin-Up: 70 years (1979 to 2014 twice) – and then running 1979 to 2015
- Evaluation period: (2002-2012; 11 years with the most evaluation data)
- Output:
  - Monthly water/vegetation states during the two spin-up periods
  - Daily output during the third simulation of all relevant energy/water terms
- Evaluation: Using the **Land Verification Toolkit (LVT)** to evaluate soil moisture, snow, ET/fluxes, surface radiation, runoff, streamflow, groundwater, etc.

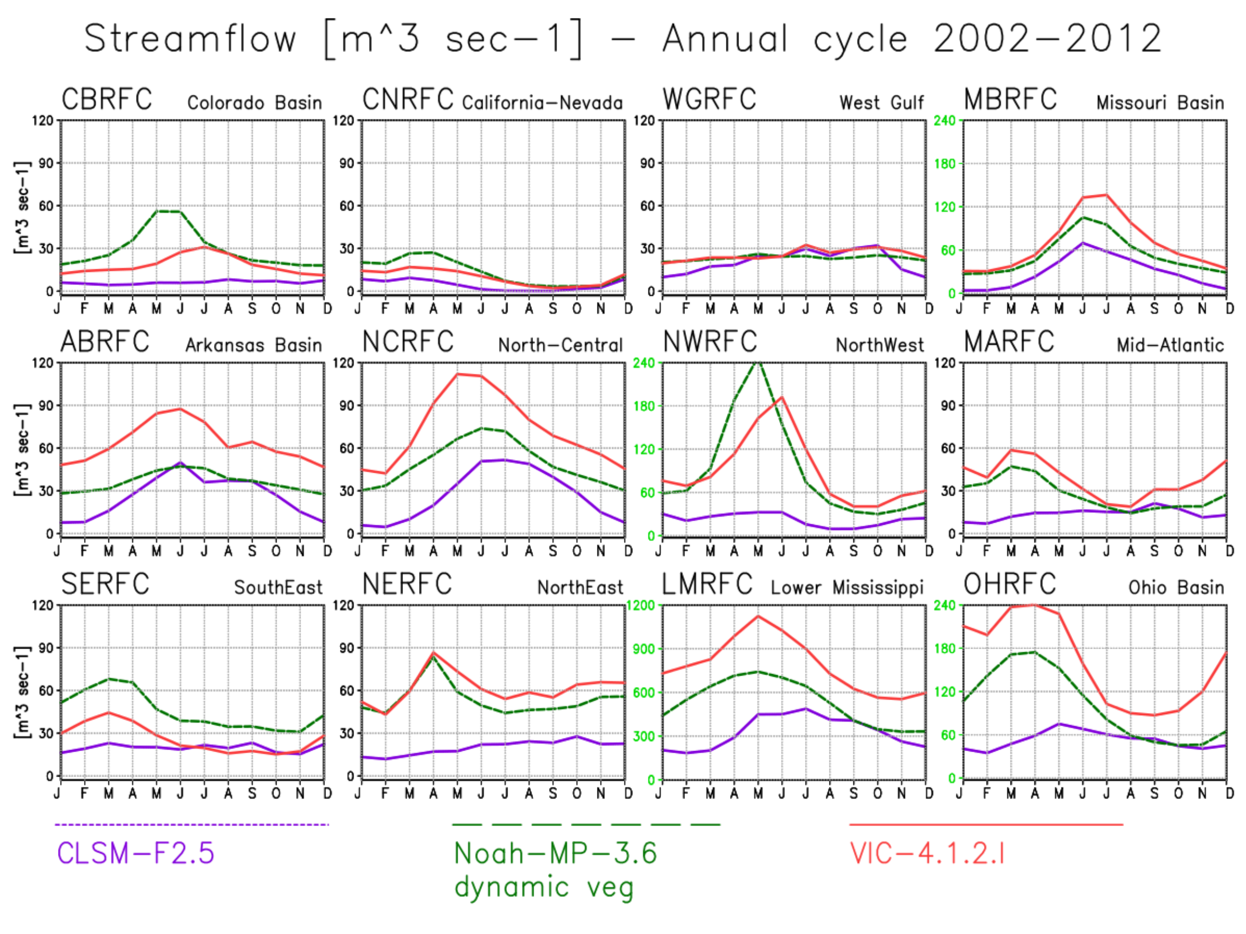
Soil Moisture – anomaly correlations



SM evaluations show: 1) CLSM-F2.5 does not do as well as Mosaic; 2) Noah-3.x versions are improved over Noah-2.8; 3) Noah-MP slightly better than Noah-3.x; 4) Noah-MP dynamic veg. does about as well as default Noah-MP; and 5) VIC-4.1.2.l does not do as well as VIC-4.0.3.

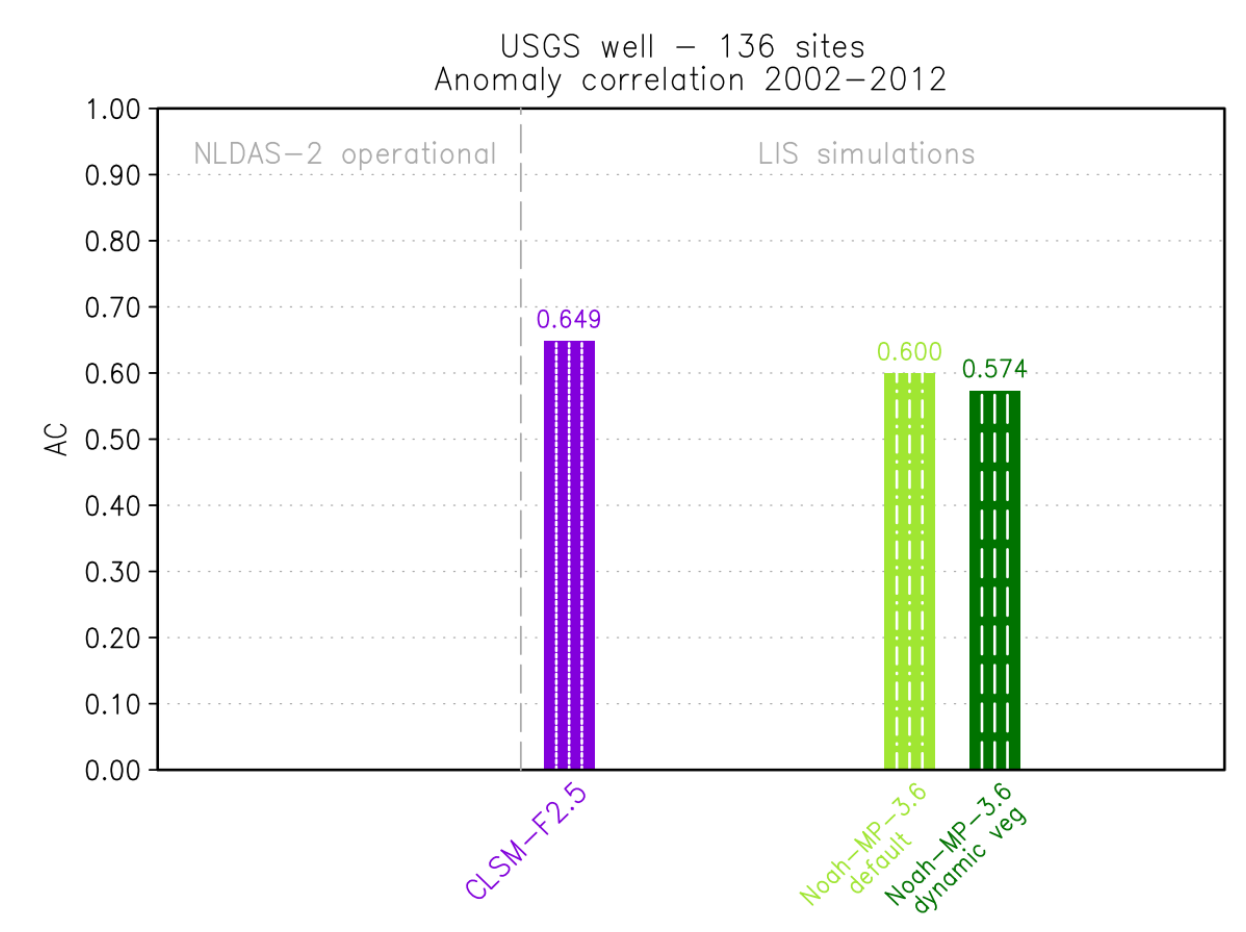
Streamflow – AC and monthly cycle

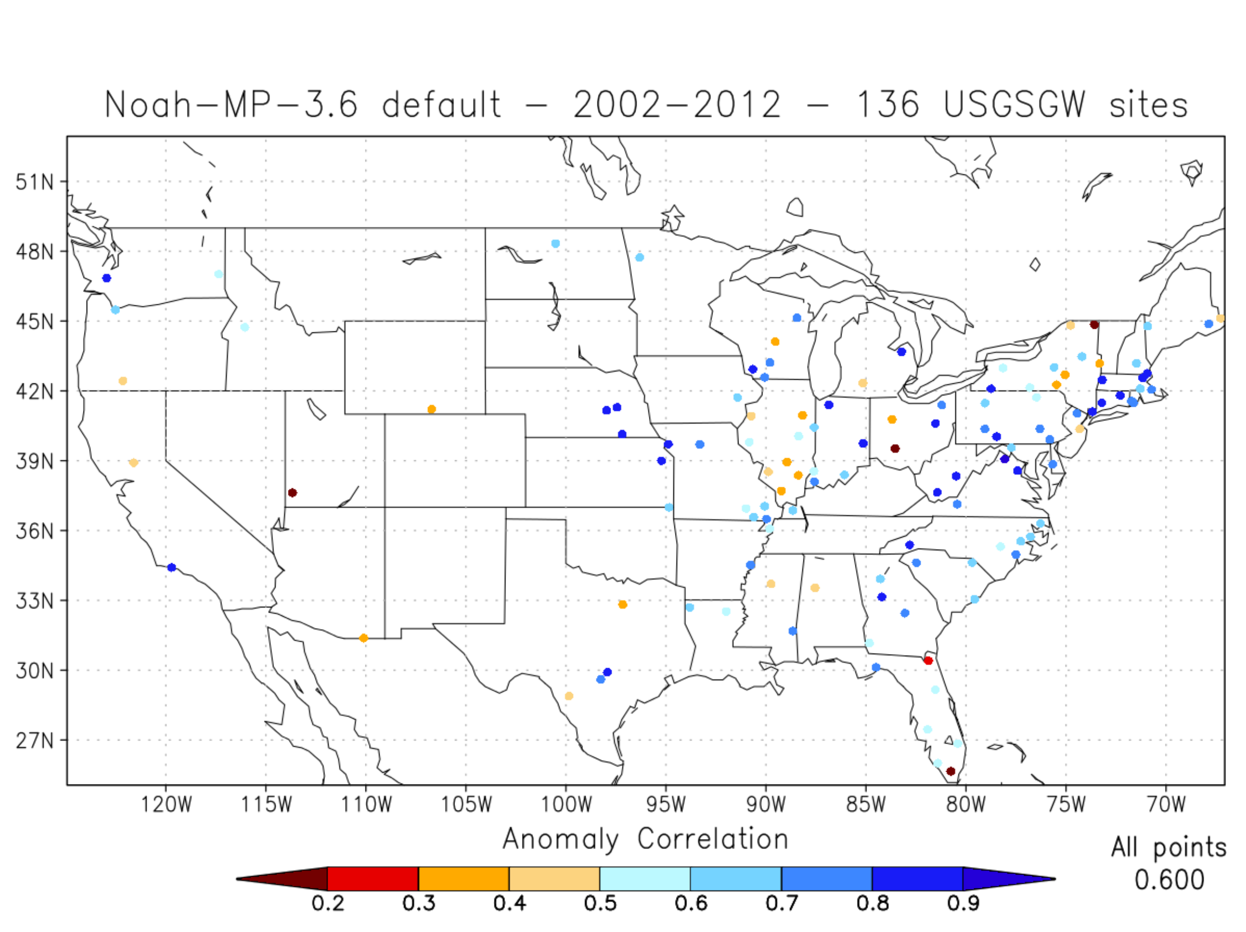




Streamflow evaluations show: 1) CLSM-F2.5 does not do as well as Mosaic, and has low values for streamflow; 2) Noah-3.x performs similarly to Noah-2.8; 3) Noah-MP is slightly worse than Noah-3.x; and 4) VIC-4.1.2.l has higher streamflow and is improved over VIC-4.0.3.

Groundwater – Anomaly correlations

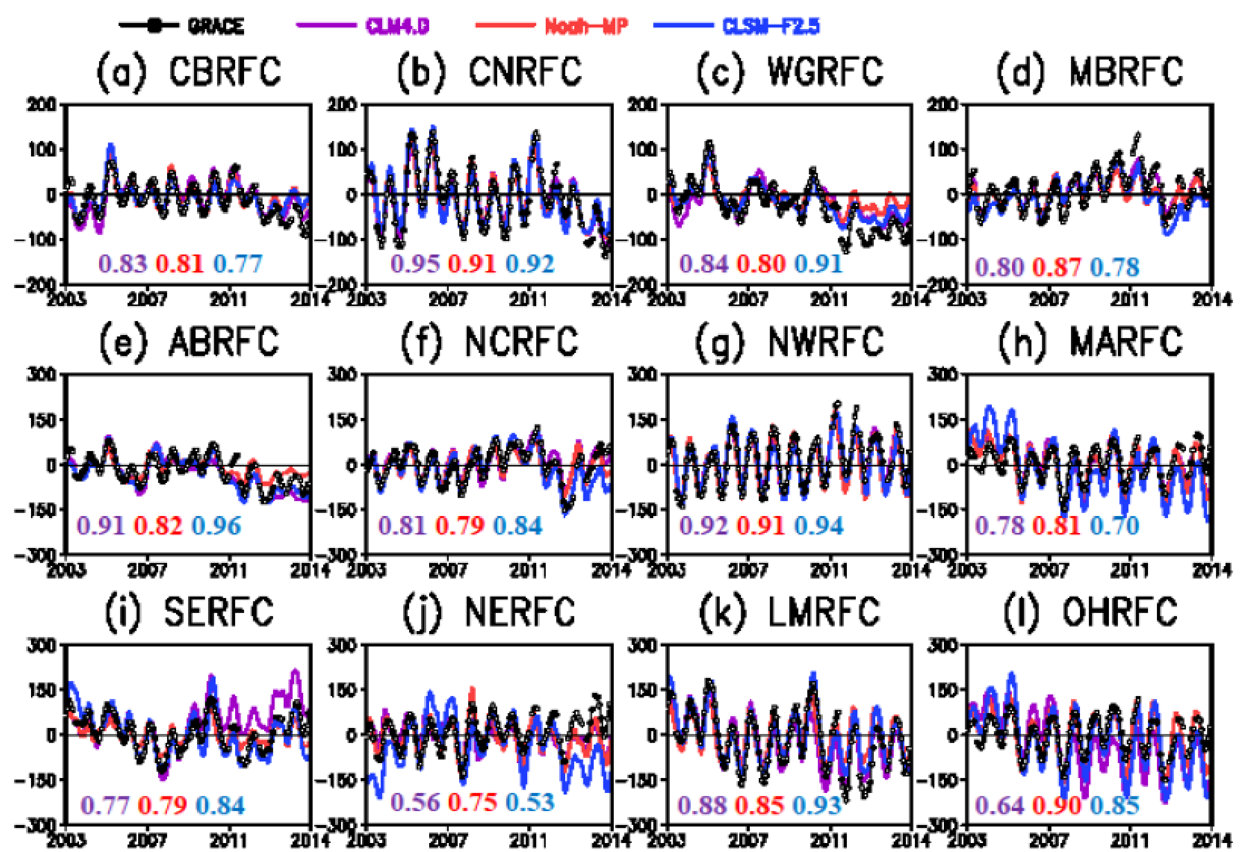


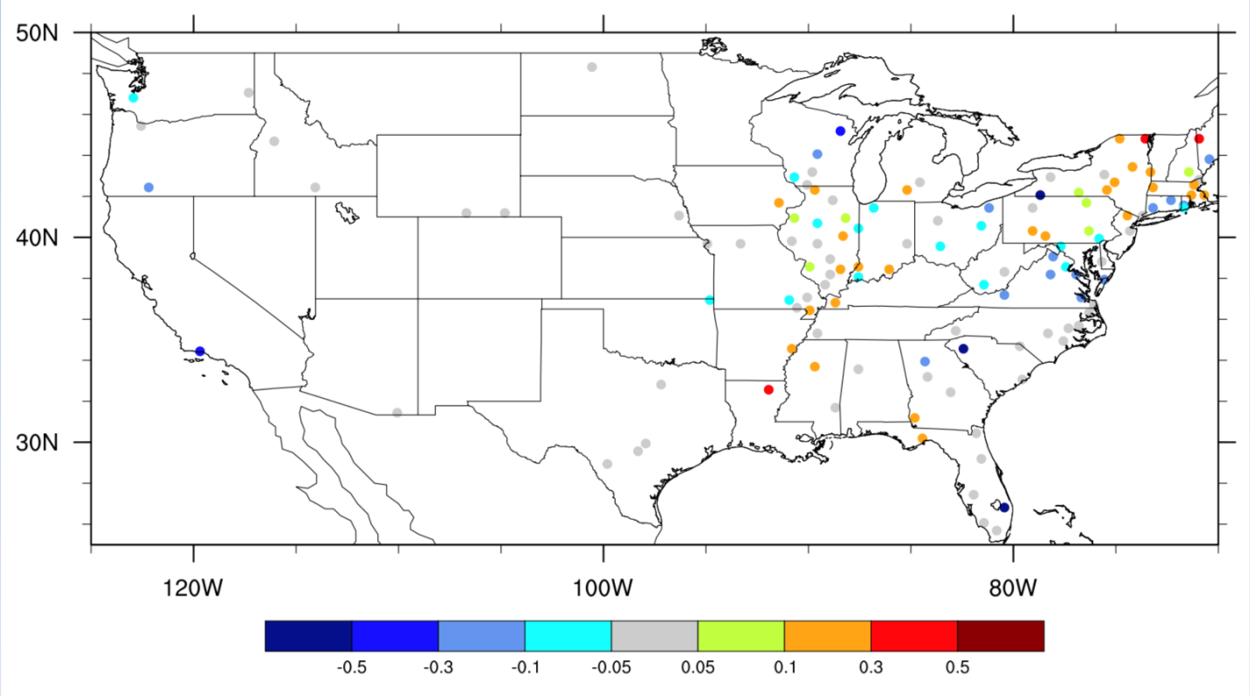


Groundwater evaluations show: 1) CLSM-F2.5 does better than Noah-MP; and 2) Noah-MP dynamic vegetation does slightly worse than default Noah-MP.

CLSM-F2.5 improvement experiments

CLSM-F2.5 does well in simulating total water storage anomaly (Xia et al., JHM, in revision, left). GRACE DA shown to improve CLSM-F2.5's ability to simulate groundwater variability (Kumar et al., 2016, JHM, right). However, the runoff consistently is too low (especially the baseflow) and the ET is too high.

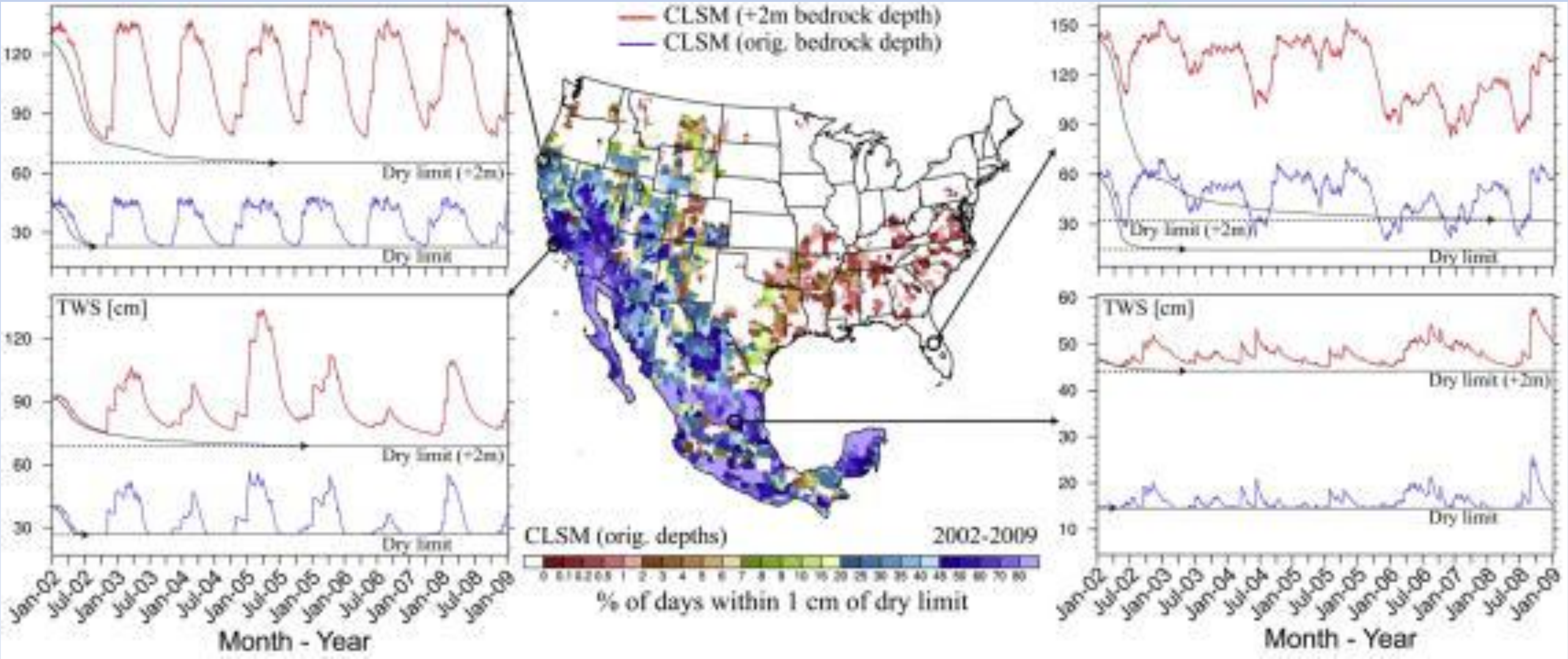




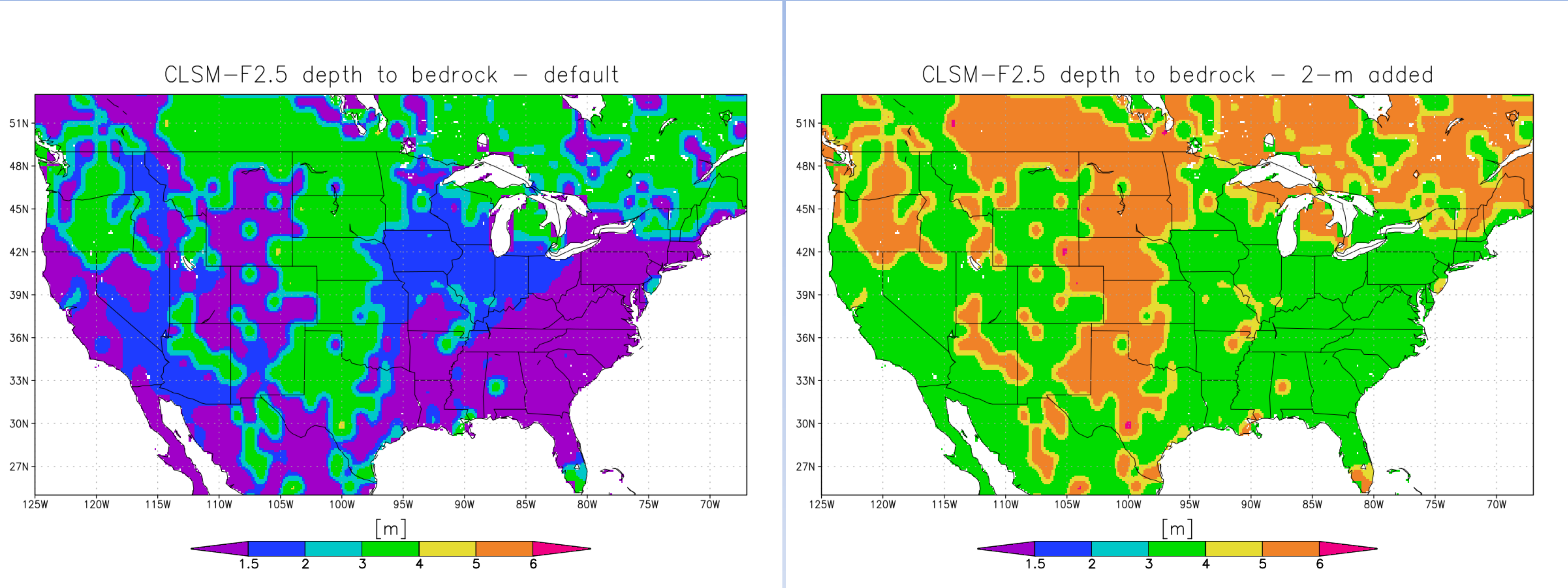
LEFT) Total water storage anomaly for 12 River Forecast Centers (RFCs) from Xia et al. The values indicate the AC as compared to GRACE. **RIGHT**) AC differences of groundwater between GRACE DA and Open Loop from Kumar et al. Warm colors indicate locations with improvement, cool colors indicate locations with degradation, and grey shading locations are not statistically significant.

CLSM-F2.5 improvement experiments

The CLSM experiments in both papers add 2-meters to the depth to bedrock. The below figure from [Houborg et al., 2012, WRR] (Figure 2) introduced this concept, to prevent the model from hitting an artificial dry limit every year. Although the 2-m addition is generally done within LIS as well as for the GRACE data assimilation product (led by Rodell) used in the U.S. Drought Monitor, the GMAO does not add 2-m to CLSM in their simulations (MERRA-2, SMAP L4, etc).



CLSM-F2.5 depth to bedrock



CLSM-F2.5 depth to bedrock (from 1-deg. GSWP-2 data)

Left) original bedrock depth

Right) with 2-m added

CLSM-F2.5 improvement experiments

Two complete sets of runs were done – one with the **original bedrock depth** and one with **2-m added to bedrock depth**. Five runs were done for both sets of the depths to bedrock, and indicate the changes over the previous experiment:

1) LIS code:
   - Current CLSM-F2.5 code as in LIS-7.1 public
2) “Baseline”:
   - Same as “LIS code”, but with code similar to the “BL” baseline GMAO internal experiment
   - The only difference is that these two lines are re-commented out in the subroutine SRUNOFF (surface runoff calculation)

```
!          frun=frun+ar2(n)*(srfexc(n)/(srfmx(n)+1.e-20))**2
!          frun=frun+ar4(n)*(srfexc(n)/(srfmx(n)+1.e-20))**4
```

   - In the “LIS code” run, the lines are used (aka, _NOT_ commented out)

CLSM-F2.5 improvement experiments

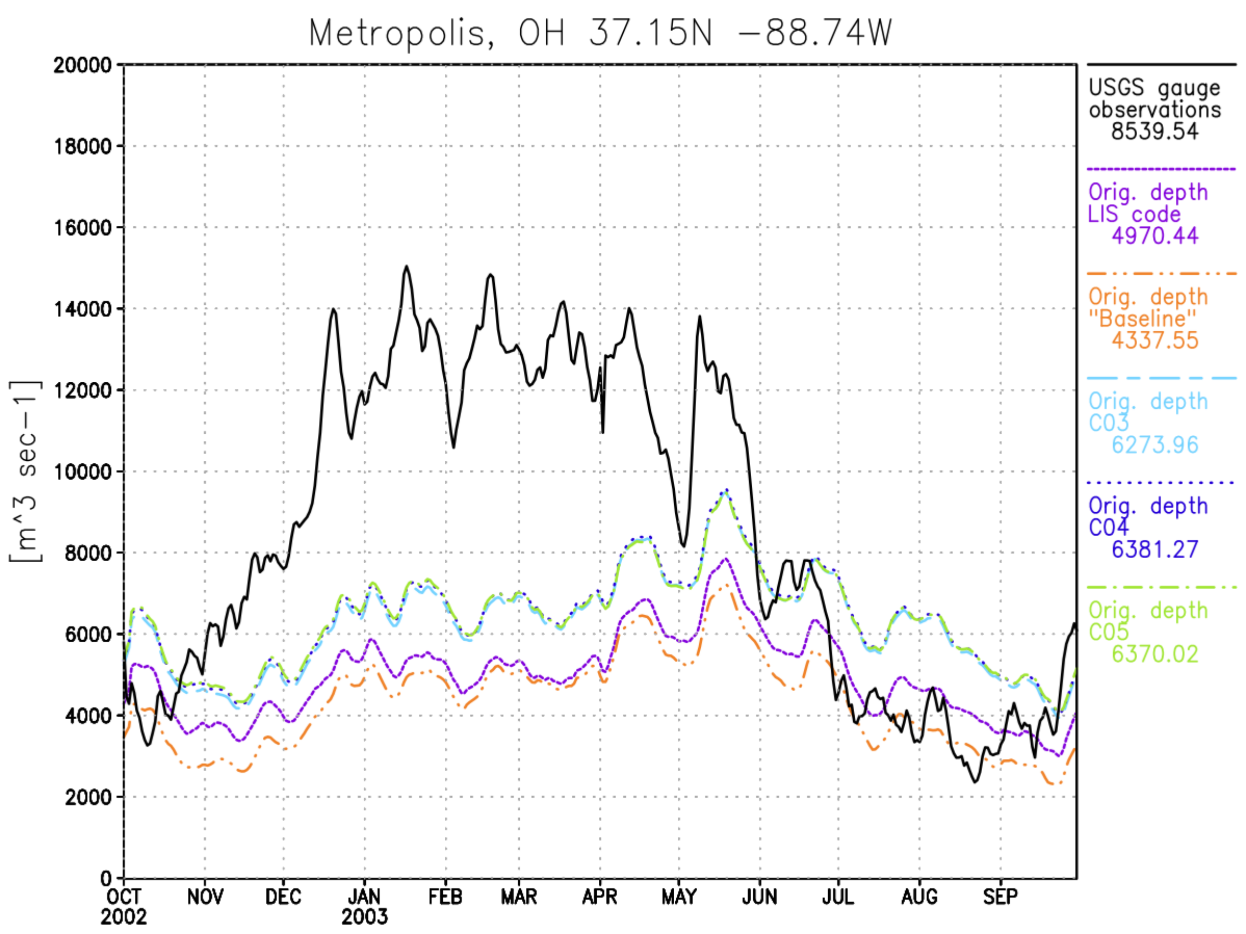
Experiment descriptions:

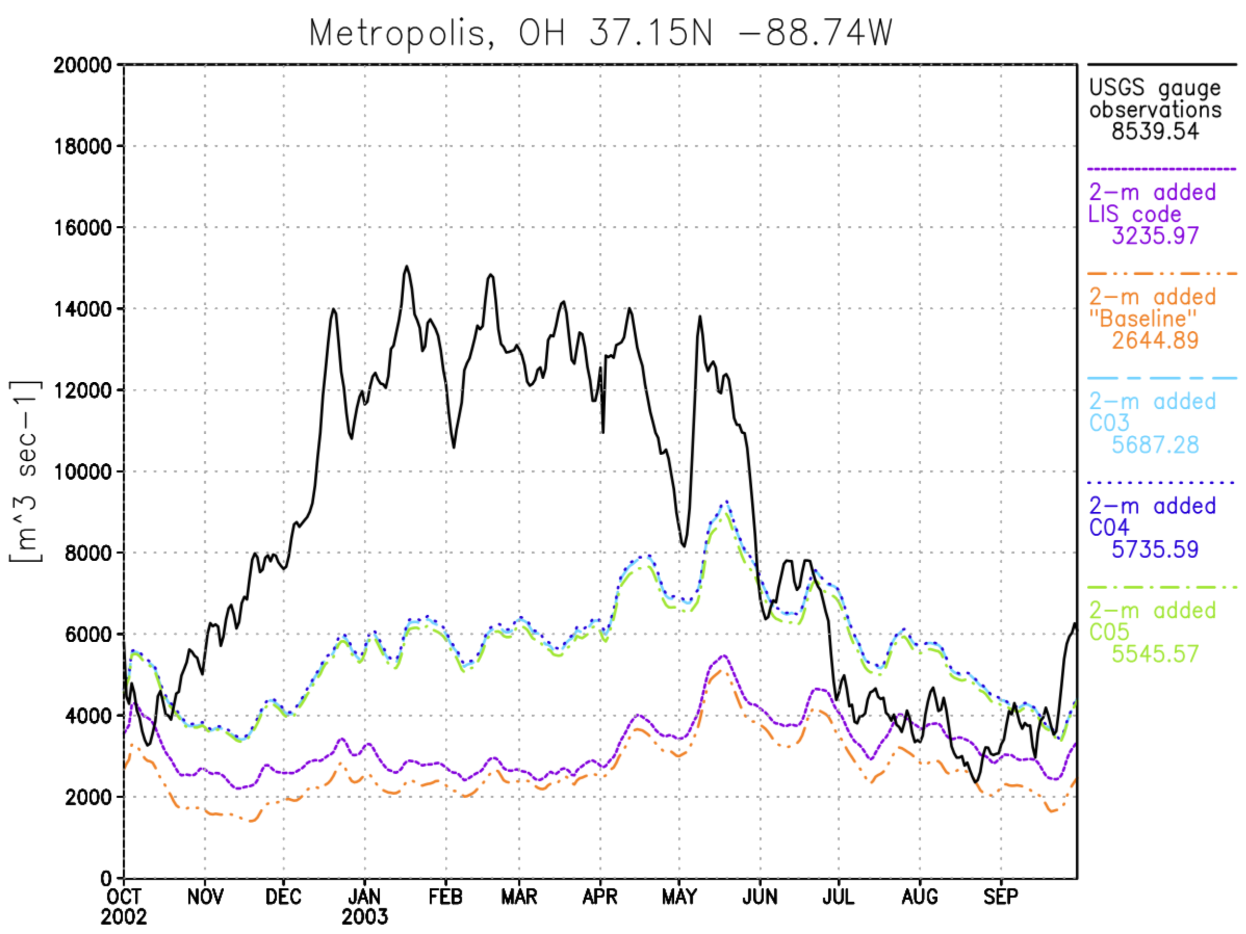
3) C03 (GMAO internal experiment label):
   - ASTRFR = 1.0 (stress transition point) & STEXP = 2.0 (stress ramping)
   - RSWILT = 2000.0 (wilting point resist.) & RSSAT = 300.0 (saturation resist.)
   - "Baseline" values, respectively: 0.333, 2.0 (thus, no change), 500.0, 25.0
4) C04 (GMAO internal experiment label):
   - The following equation was added to reduce the recovery of surface deficits associated with bare soil evap

     IF(SRFLW < 0.) SRFLW = 0.05 * SRFLW
5) C05 (GMAO internal experiment label):
   - Further reduction of the recovery of surface deficits from bare soil evap

     IF(SRFLW < 0.) SRFLW = 0.01 * SRFLW
   - RSSAT = 25.0 (saturation resistance) – thus, no change from "Baseline"

Streamflow – WY2002-2010 9-year ave. for Ohio River Basin

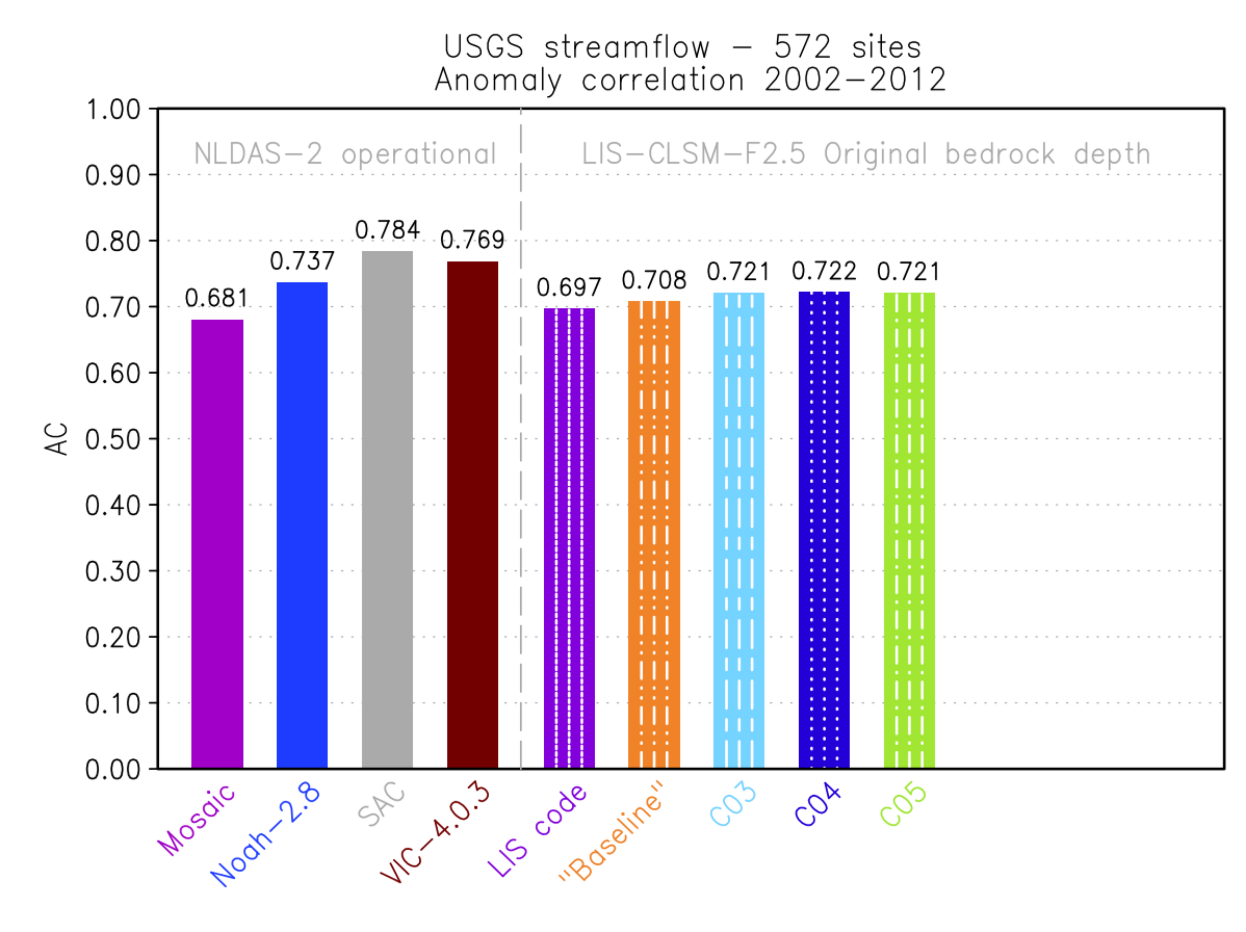


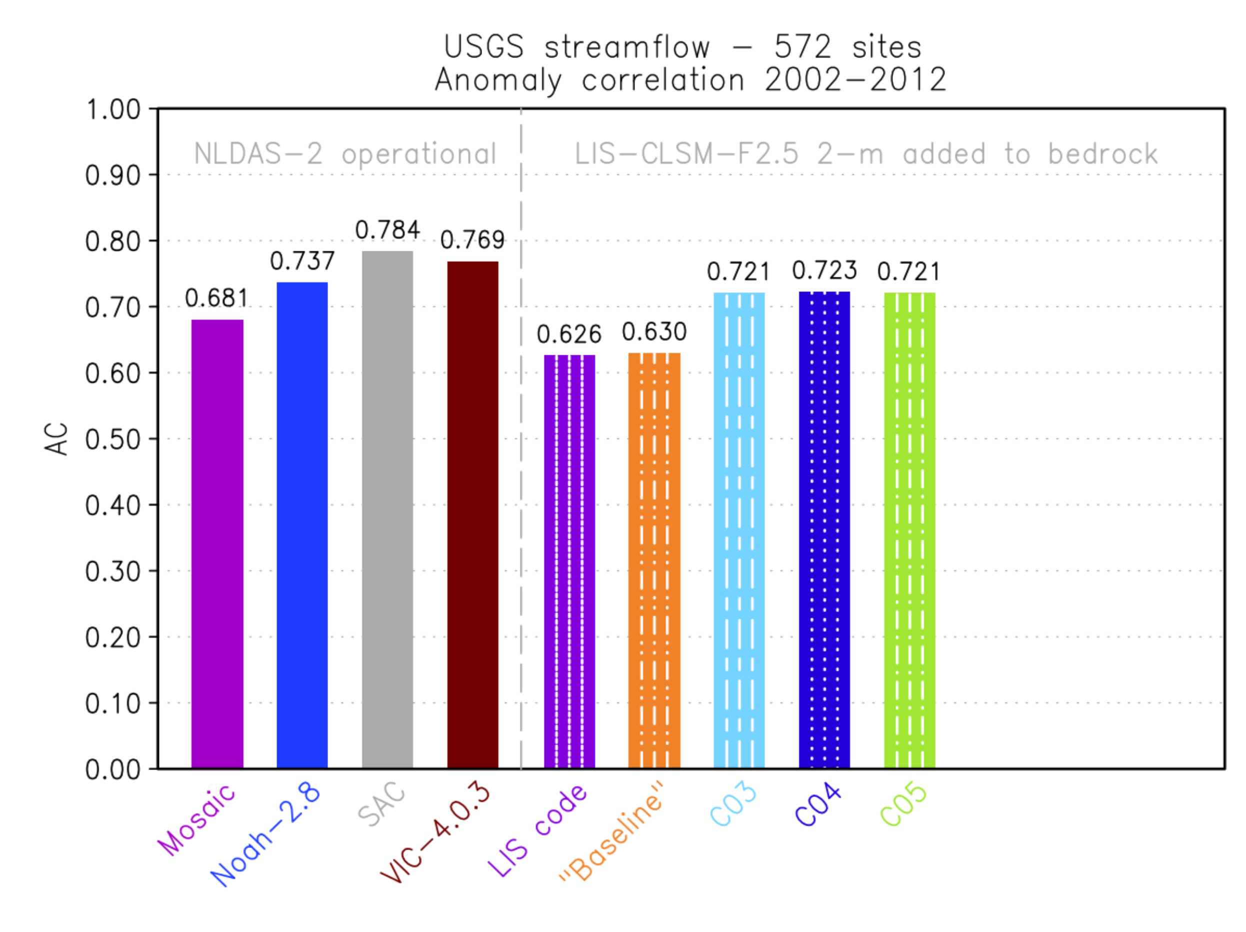


LEFT) Experiments with original bedrock depth RIGHT) Experiments with 2-m added to depth

No run produces enough streamflow (this basin is worst example). Adding 2-m significantly lowers the streamflow. C03 increases the streamflow somewhat. All simulations used the HyMAP router. NLDAS router shows similar amounts for this basin.

Streamflow – USGS – Anomaly correlation

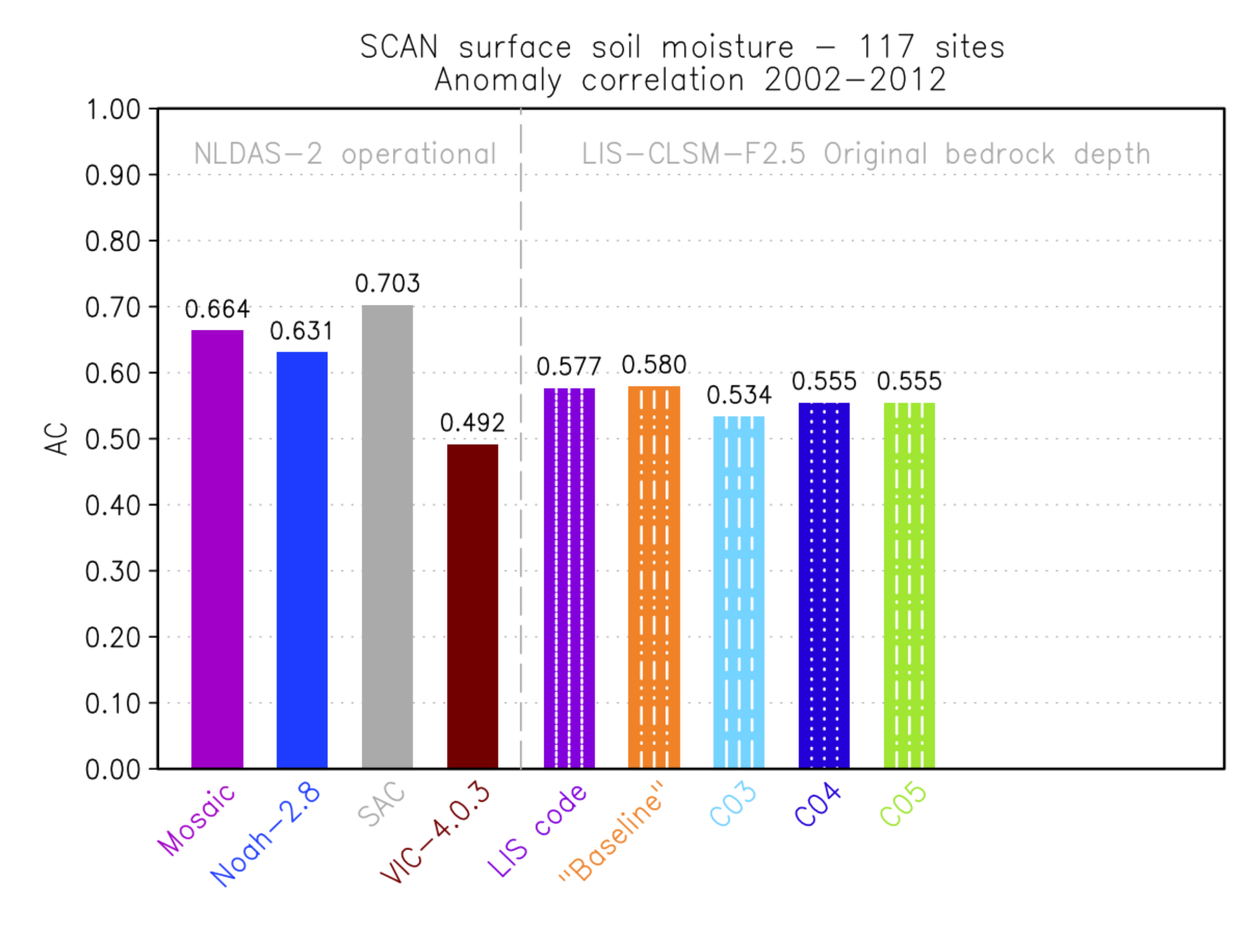


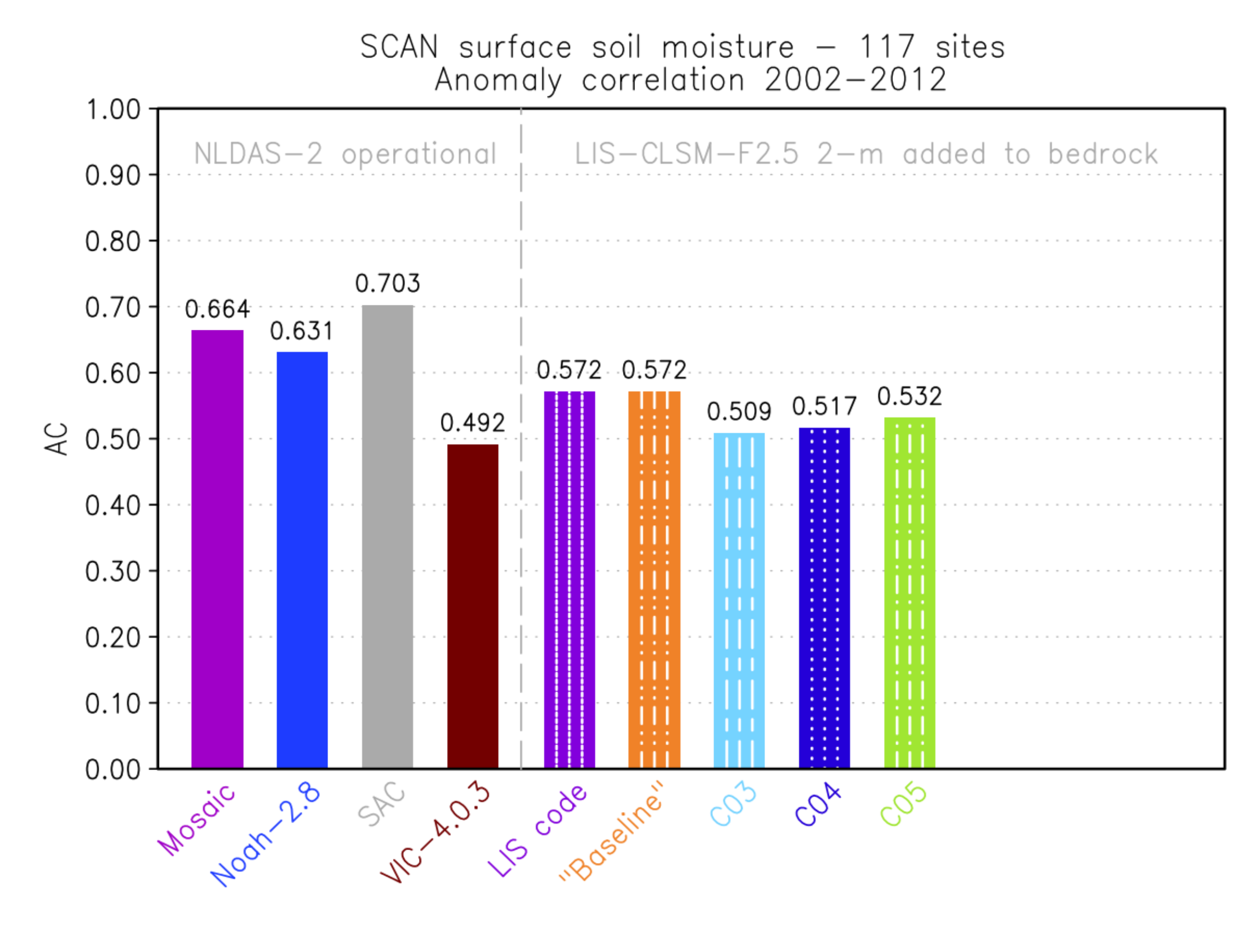


LEFT) Experiments with original bedrock depth RIGHT) Experiments with 2-m added to depth

C03-C05 perform similarly for streamflow monthly AC. These experiments show a large improvements over “Baseline” for the 2-m added runs, in particular.

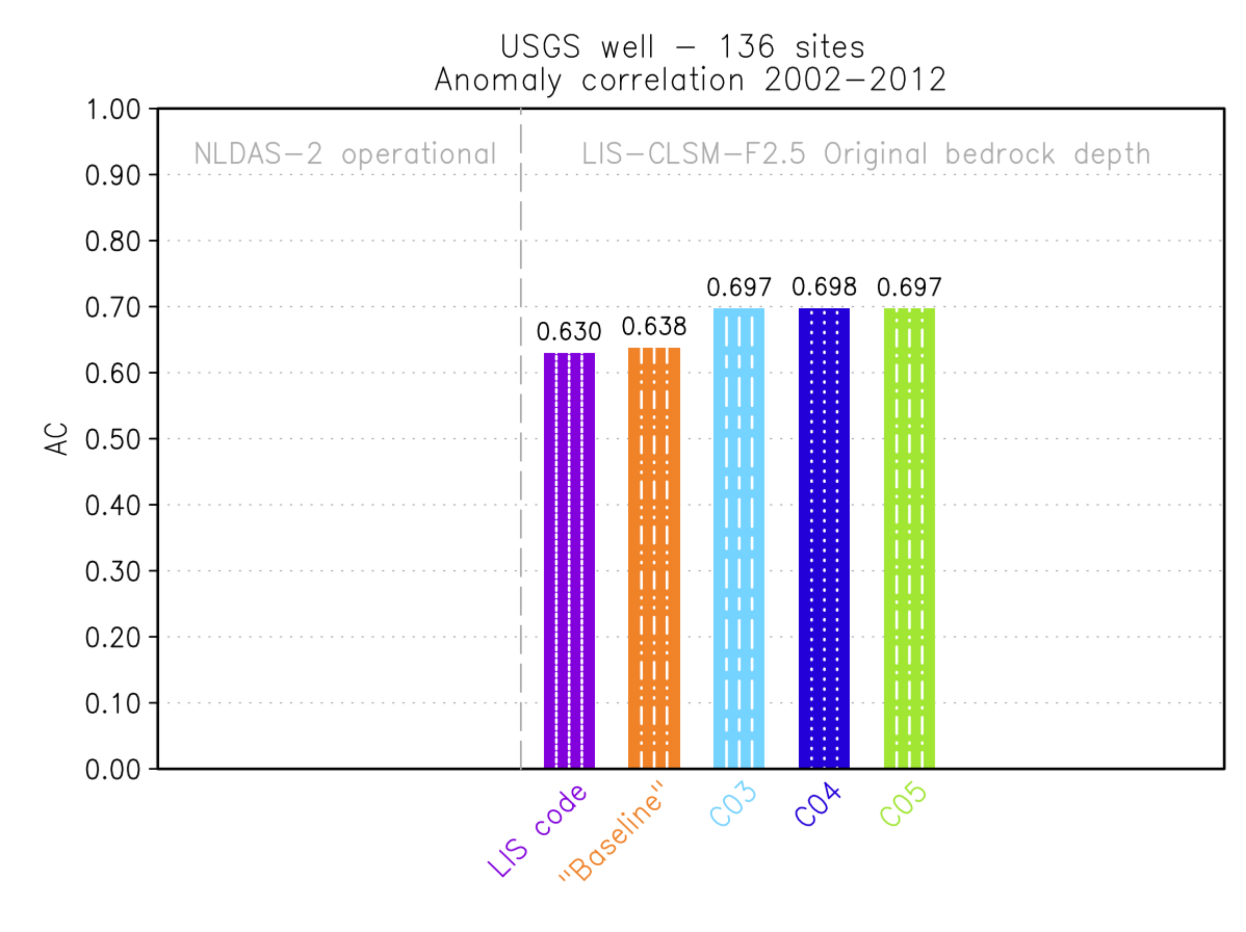
Soil Moisture – SCAN – Anomaly correlation

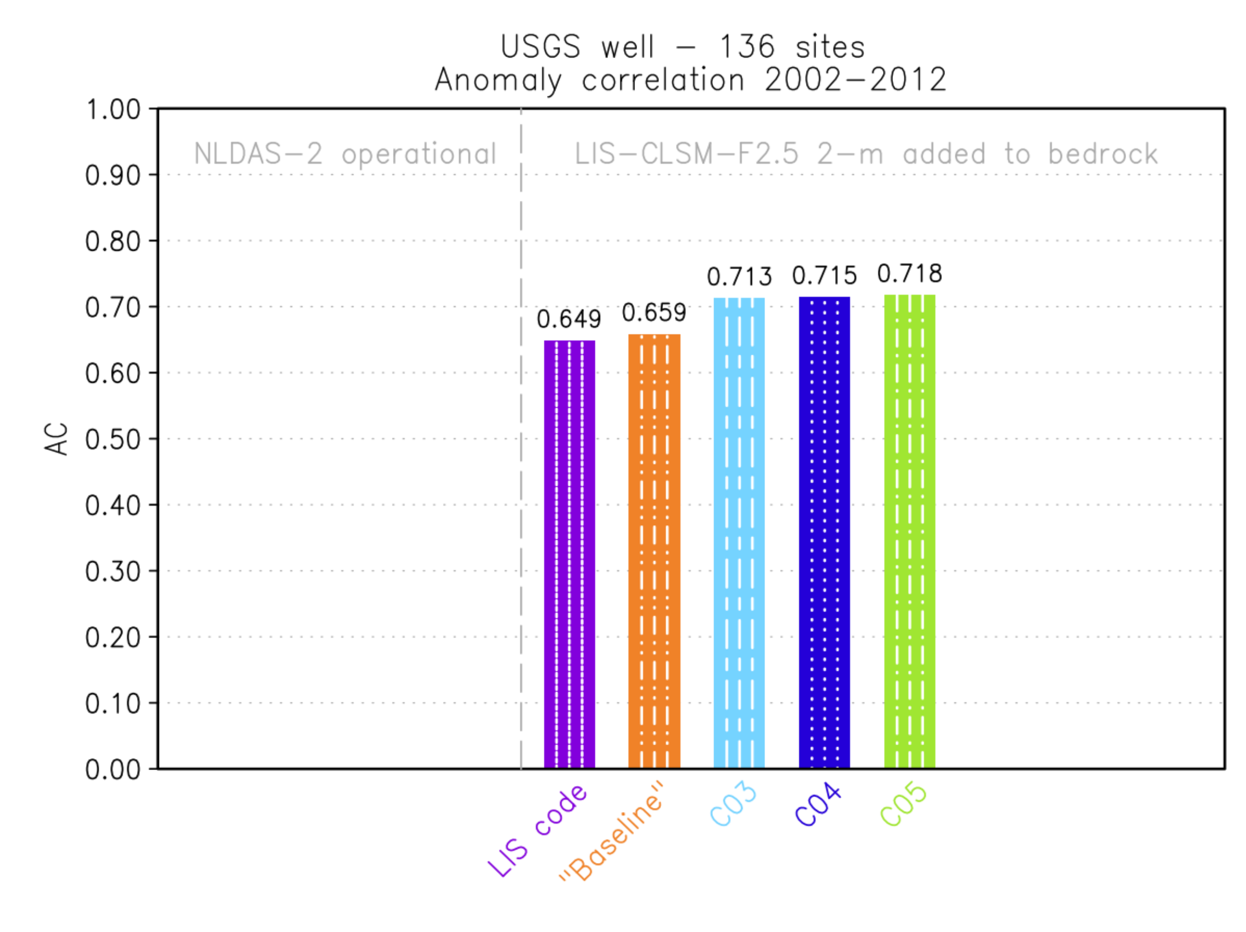




LEFT) Experiments with original bedrock depth RIGHT) Experiments with 2-m added to depth
C03 reduces soil moisture skill compared to "Baseline". C04/C05 restores some of this skill, but not all. The AC values are a little lower when adding 2-m to bedrock depth.

Groundwater – USGS – Anomaly correlation

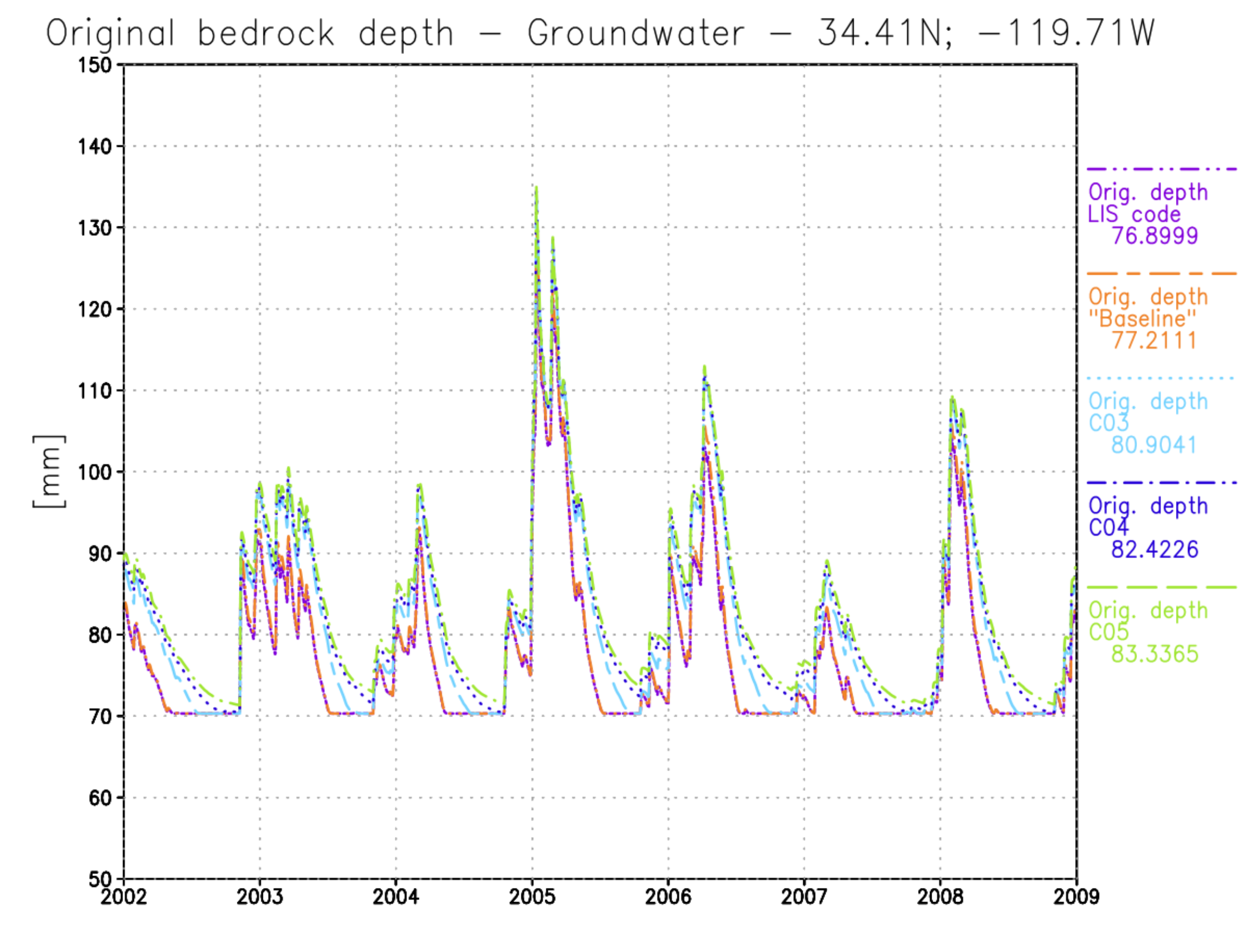


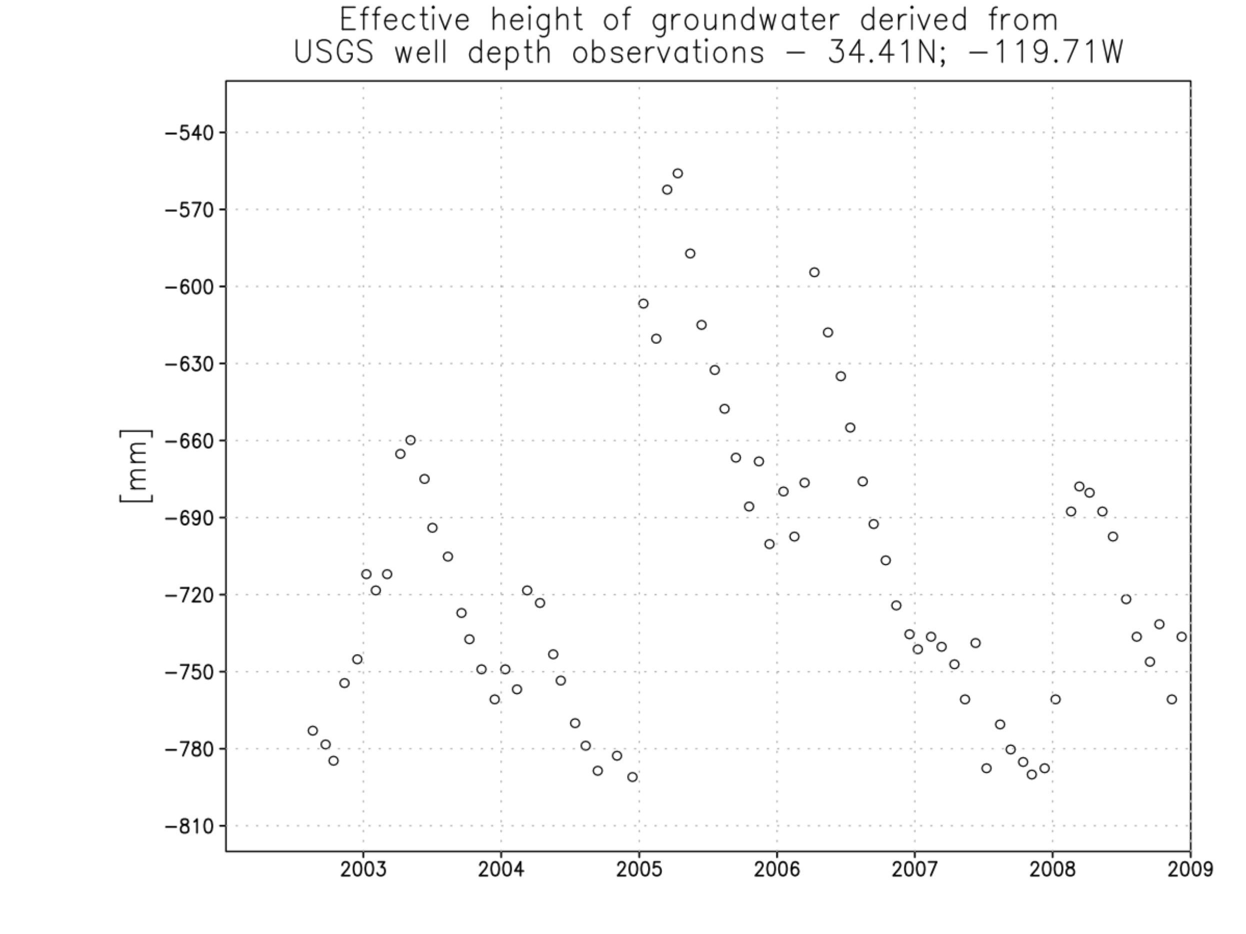


LEFT) Experiments with original bedrock depth   RIGHT) Experiments with 2-m added to depth

C03-C05 increase the AC over "Baseline". Adding 2-m to bedrock depths slightly increases the groundwater AC for all experiments.

GWS – CA point – original bedrock depth

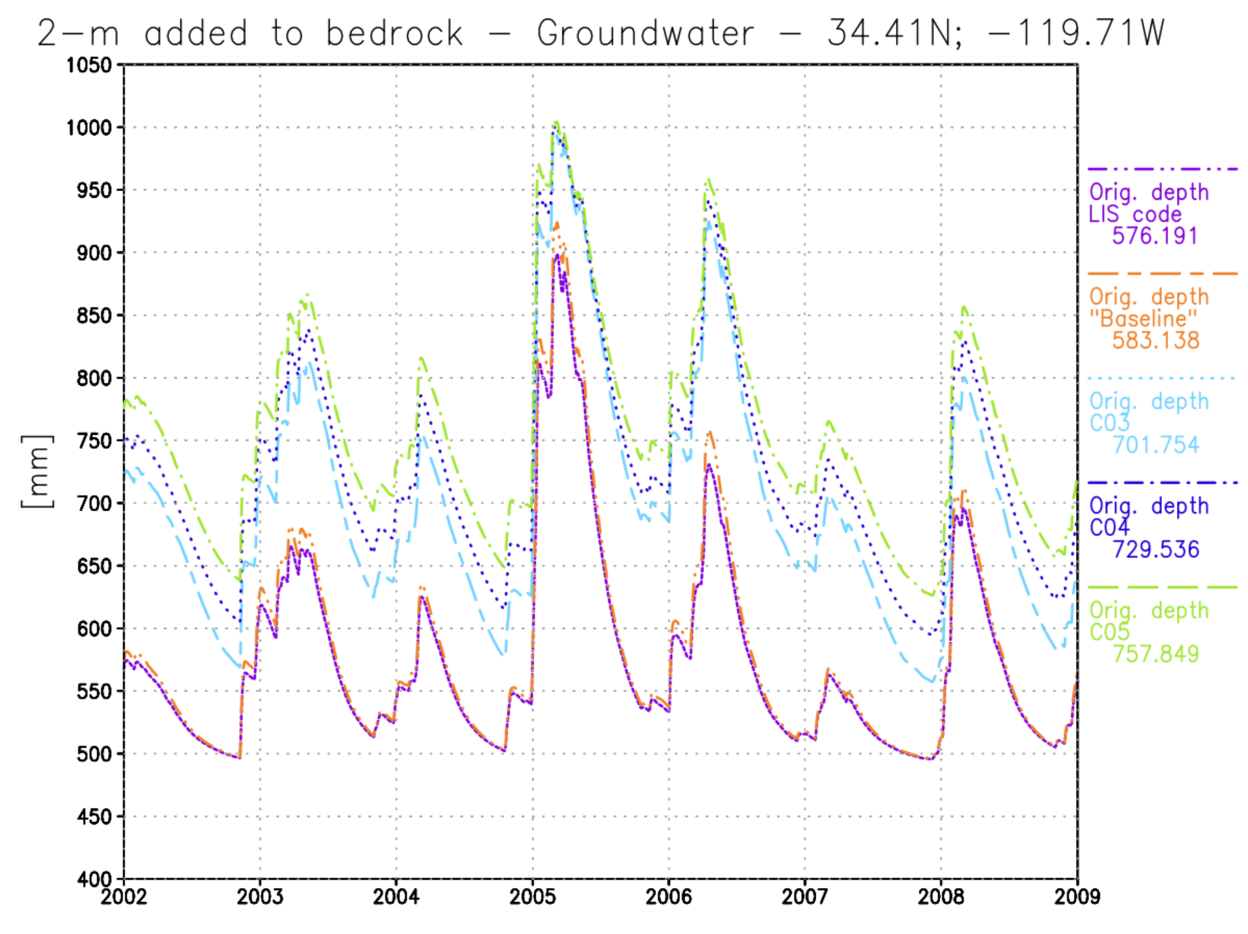


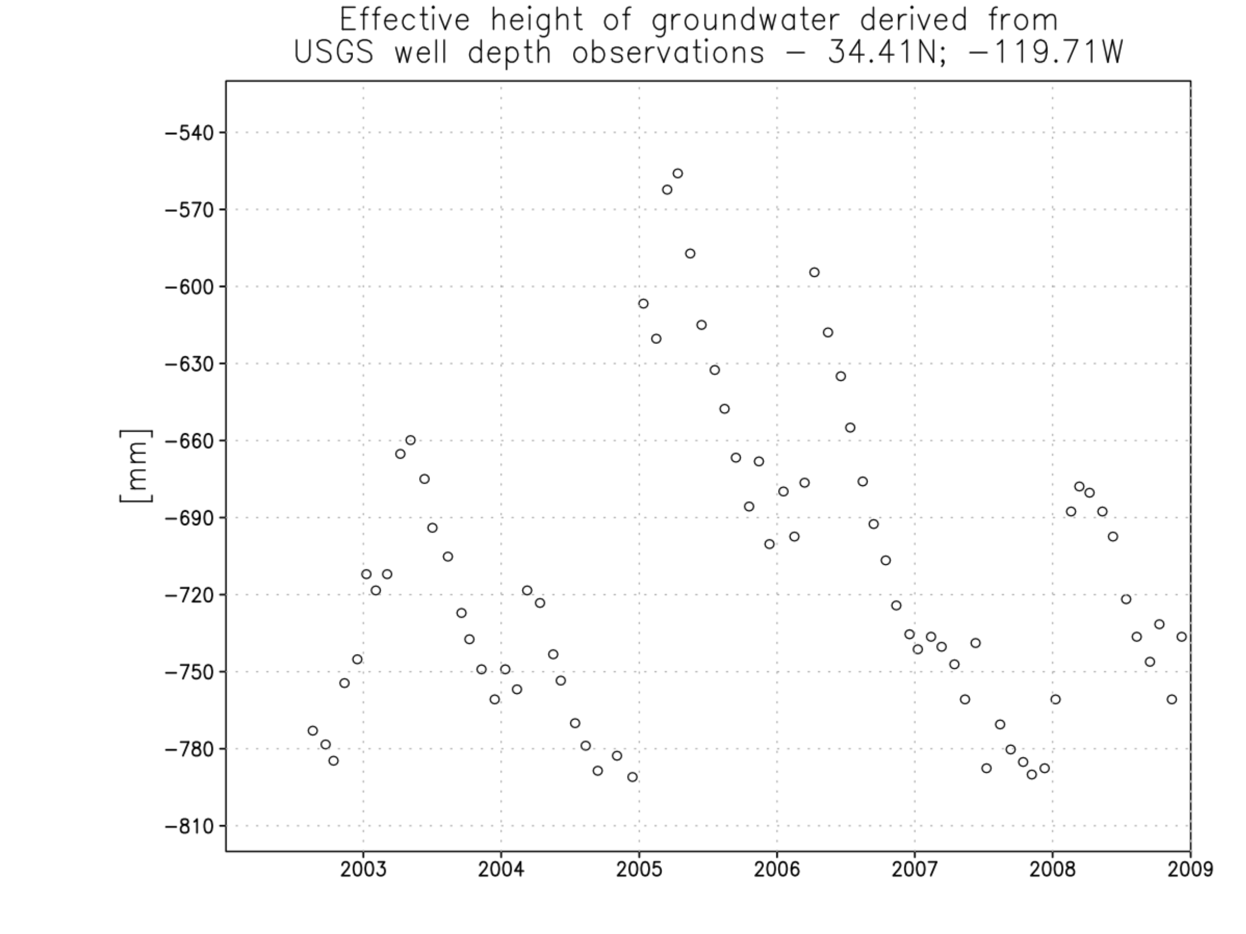


AC: LIS code: 0.588; “Baseline”: 0.582; C03: 0.651; C04: 0.677; C05: 0.676

LIS code and “Baseline” clearly hit the dry limit every year. C03 to C05 show some improvement through reduction of ET and increase of runoff, but may come close to dry limit each fall.

GWS – CA point – 2-m added to bedrock





AC: LIS code: 0.868; "Baseline": 0.871; C03: 0.959; C04: 0.954; C05: 0.947

AC is much higher from adding 2-m to bedrock. C03-C05 further increase the AC.

There is not much evidence of hitting a wet or dry limit between years.

Testing Noah-MP physics options

The Noah-MP LSM contains numerous physics options. The following slides show some preliminary evaluations of individually changing options from the "WRF default" set of options, typically recommended.

Dynamic vegetation:

1) FVEG = SHDFAC prescribed from input
2) Dynamic vegetation turned on
3) FVEG calculated
4) FVEG maximum (*WRF default*)

Canopy stomatal resistance:

1) Ball-Berry (*WRF default*)
2) Jarvis

Runoff and groundwater:

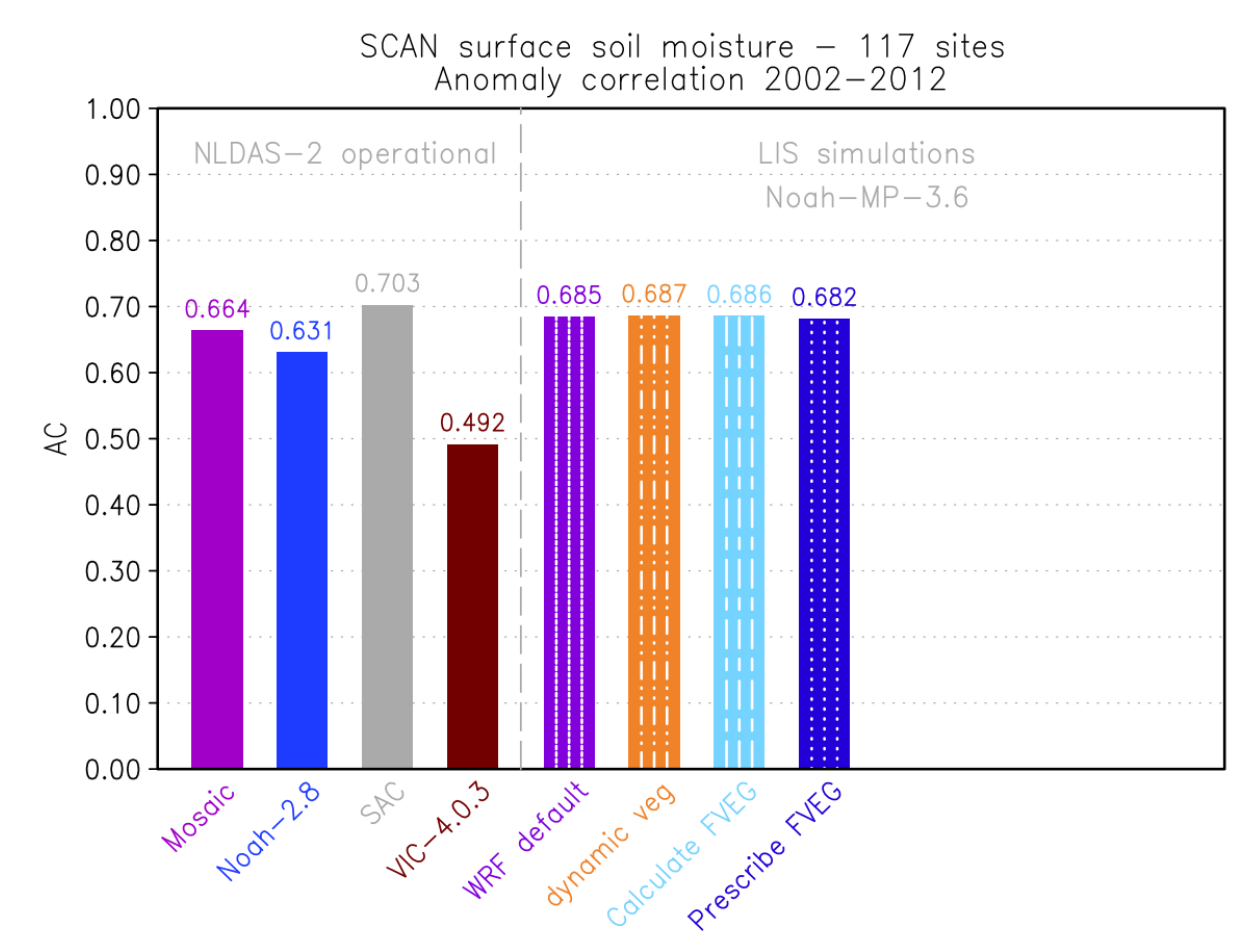
1) TOPMODEL w/ groundwater (Niu et al., 2007, JGR) (*WRF default*)
2) TOPMODEL w/ an equilibrium water table (Niu et al., 2005, JGR)
3) Noah (original) surface and sub-surface runoff (free drainage)
4) BATS surface and sub-surface runoff (free drainage)

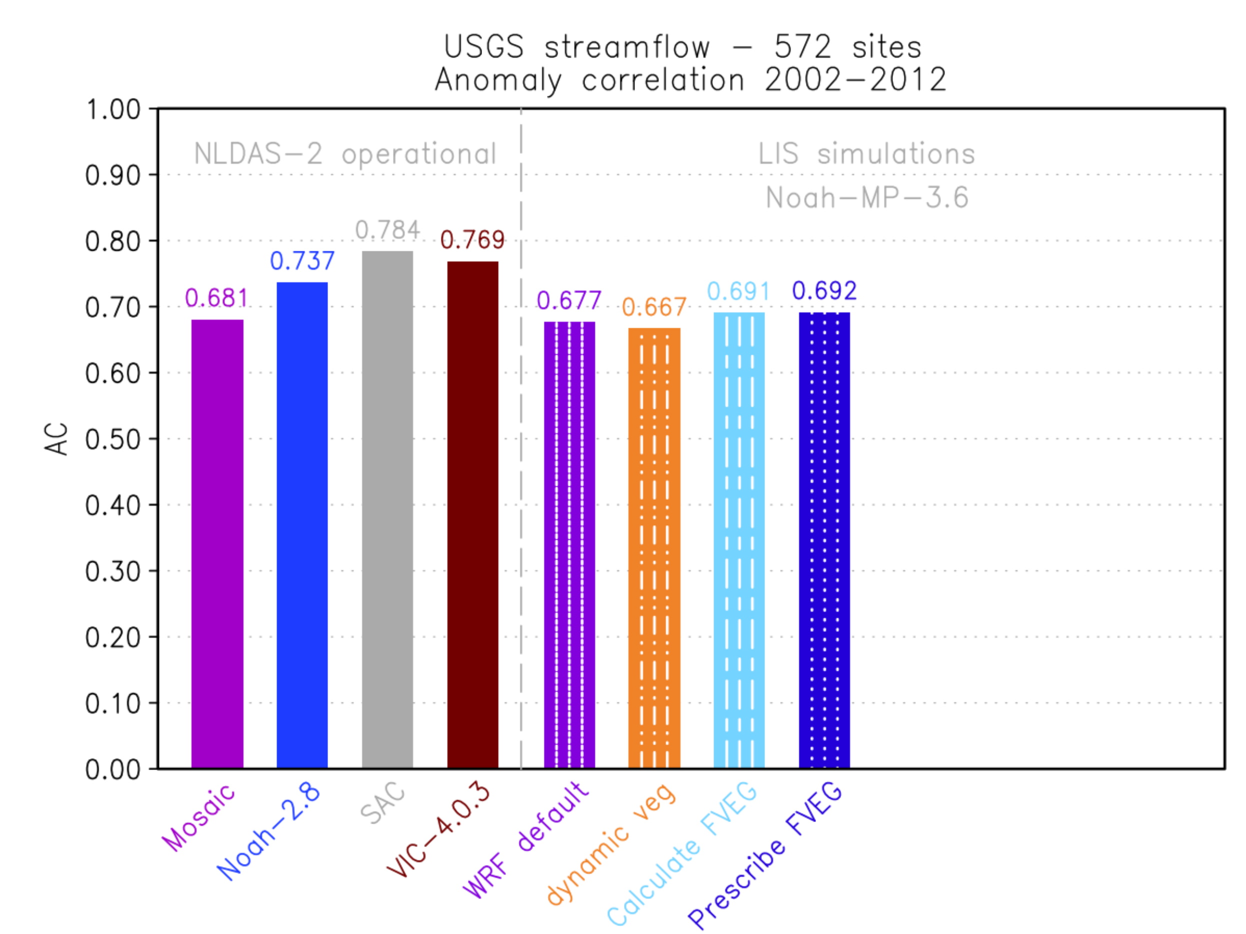
Surface layer drag coefficient:

1) Monin-Obukhov (*WRF default*)
2) Original Noah (Chen et al., 1997, BLM)

No firm conclusions should be taken from these experiments yet, as evaluation and refinement of the simulations is on-going. Additional physics options have been tested, and evaluations are in progress.

Noah-MP vegetation physics options



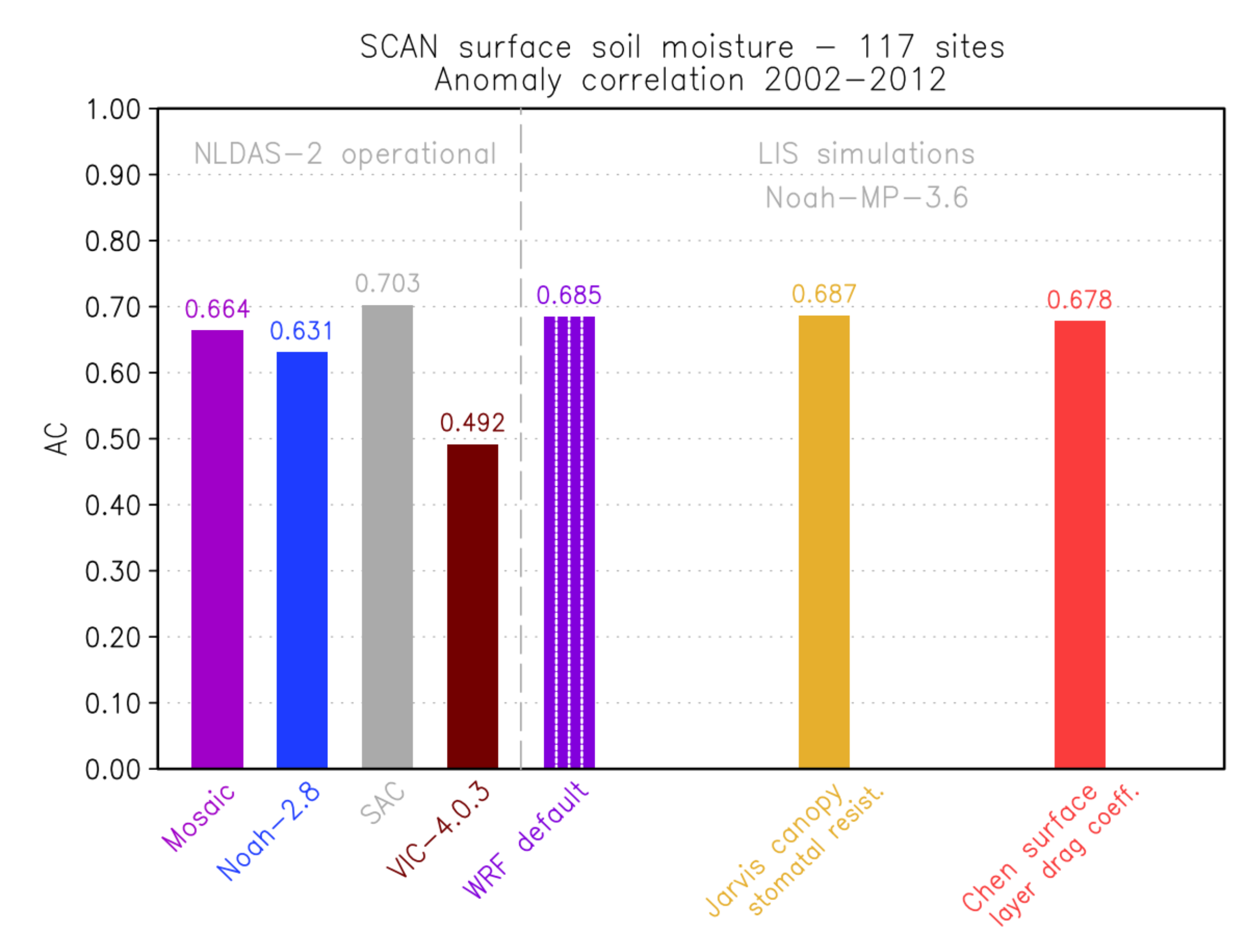


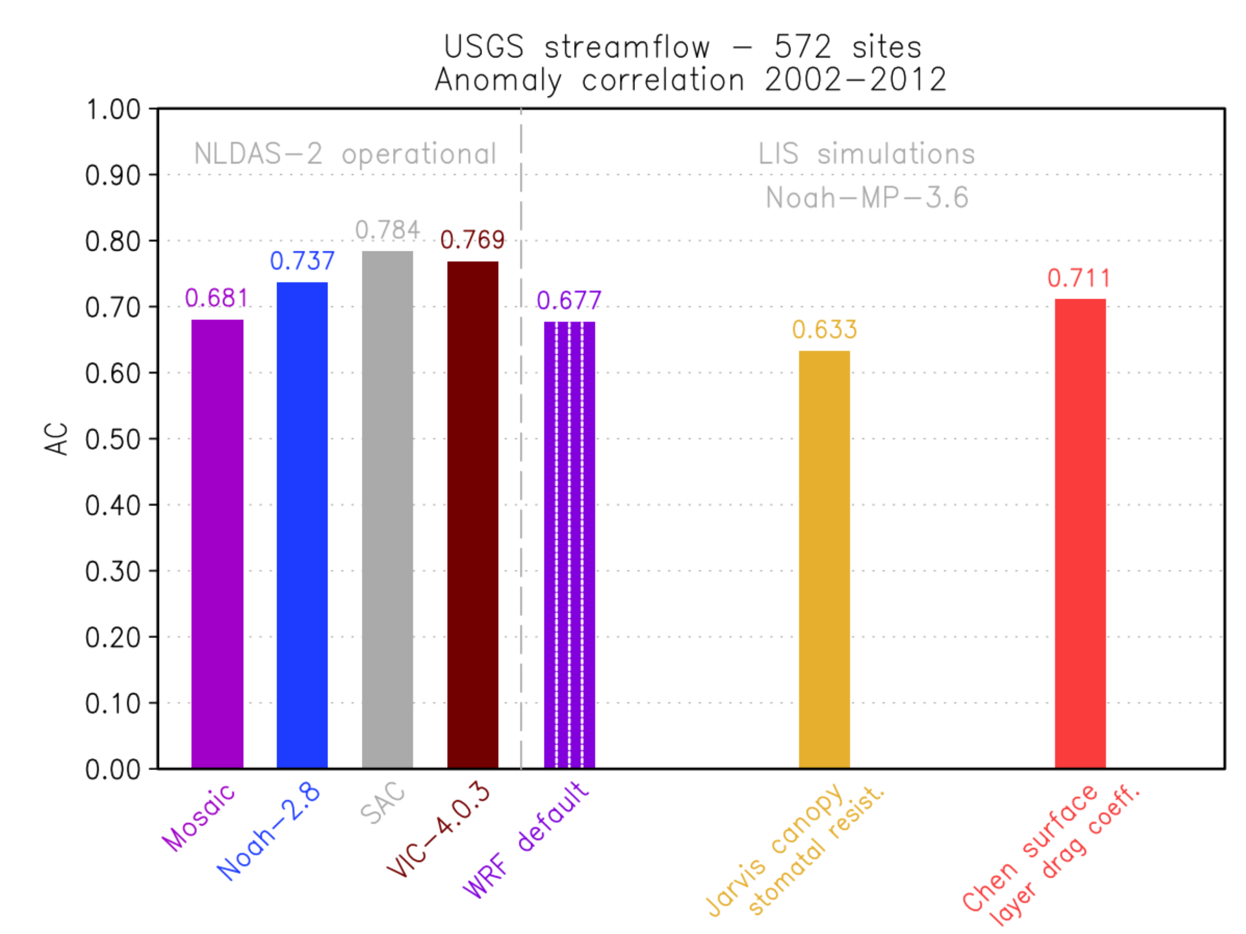
LEFT) SCAN surface SM anomaly correlations RIGHT) USGS streamflow anomaly correlations

Noah-MP vegetations options perform similarly for soil moisture.

For streamflow, the AC skills are also generally similar.

Canopy stomatal resistance & Surface layer drag





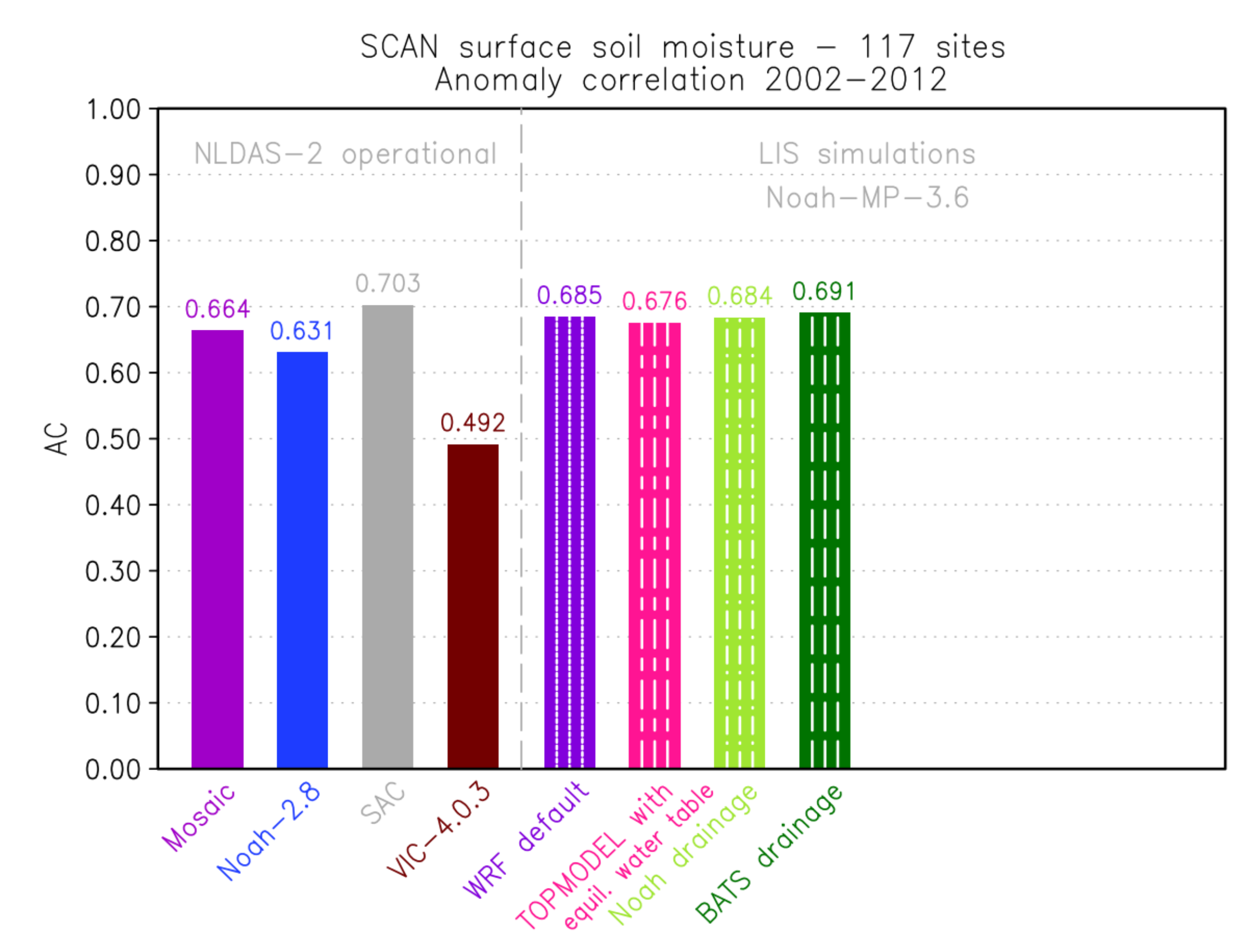
LEFT) SCAN surface SM anomaly correlations RIGHT) USGS streamflow anomaly correlations

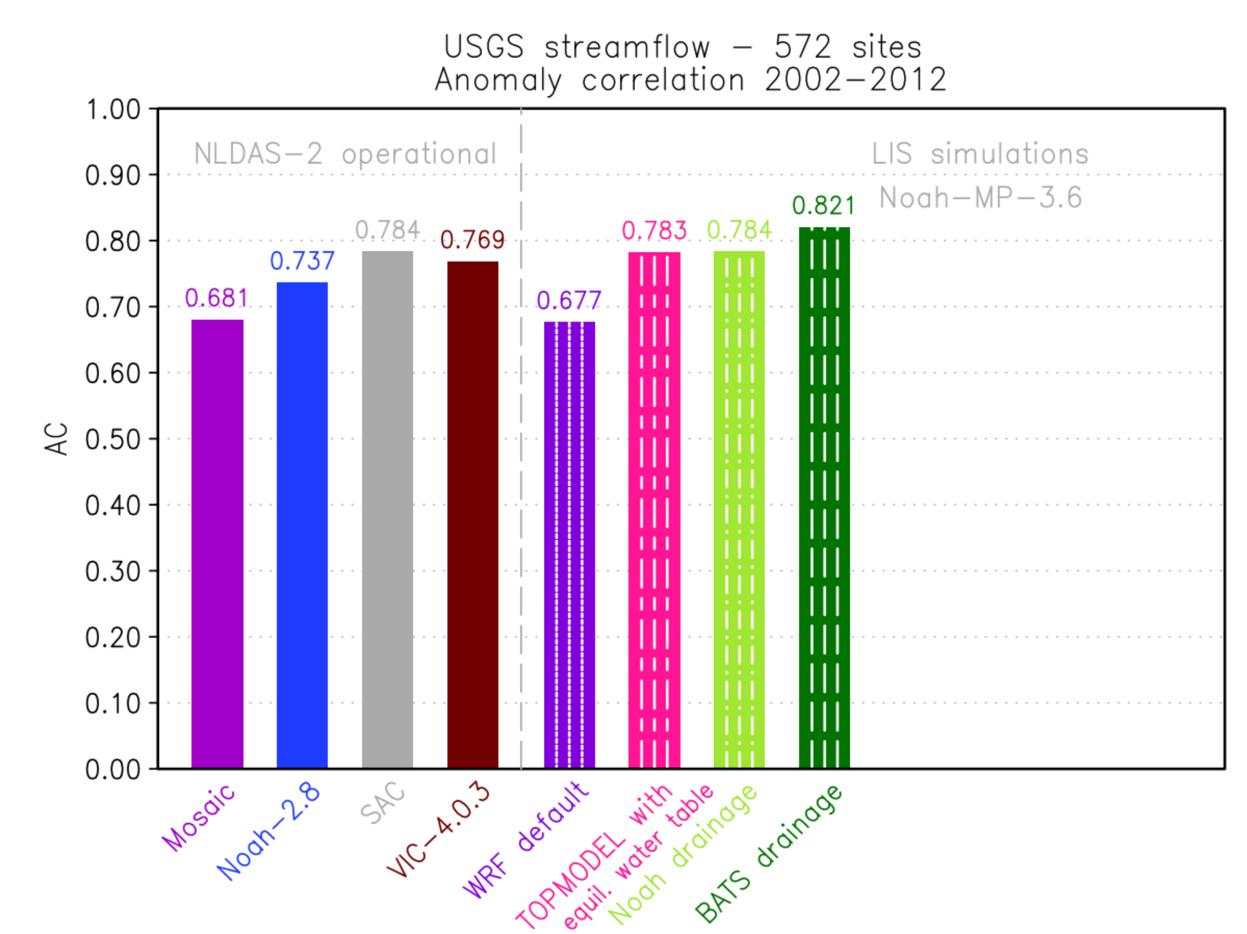
Noah-MP options perform similarly for soil moisture.

Perhaps using Ball-Berry in place of Jarvis has improved streamflow AC.

Chen surface layer drag has higher streamflow AC, however.

Noah-MP runoff and baseflow options





LEFT) SCAN surface SM anomaly correlations RIGHT) USGS streamflow anomaly correlations

Again, surface soil moisture generally behaves the same with the different options.

Not quite sure yet why the streamflow AC increases from not using the groundwater module, particularly the options with free drainage. Will continue to evaluation these simulations.

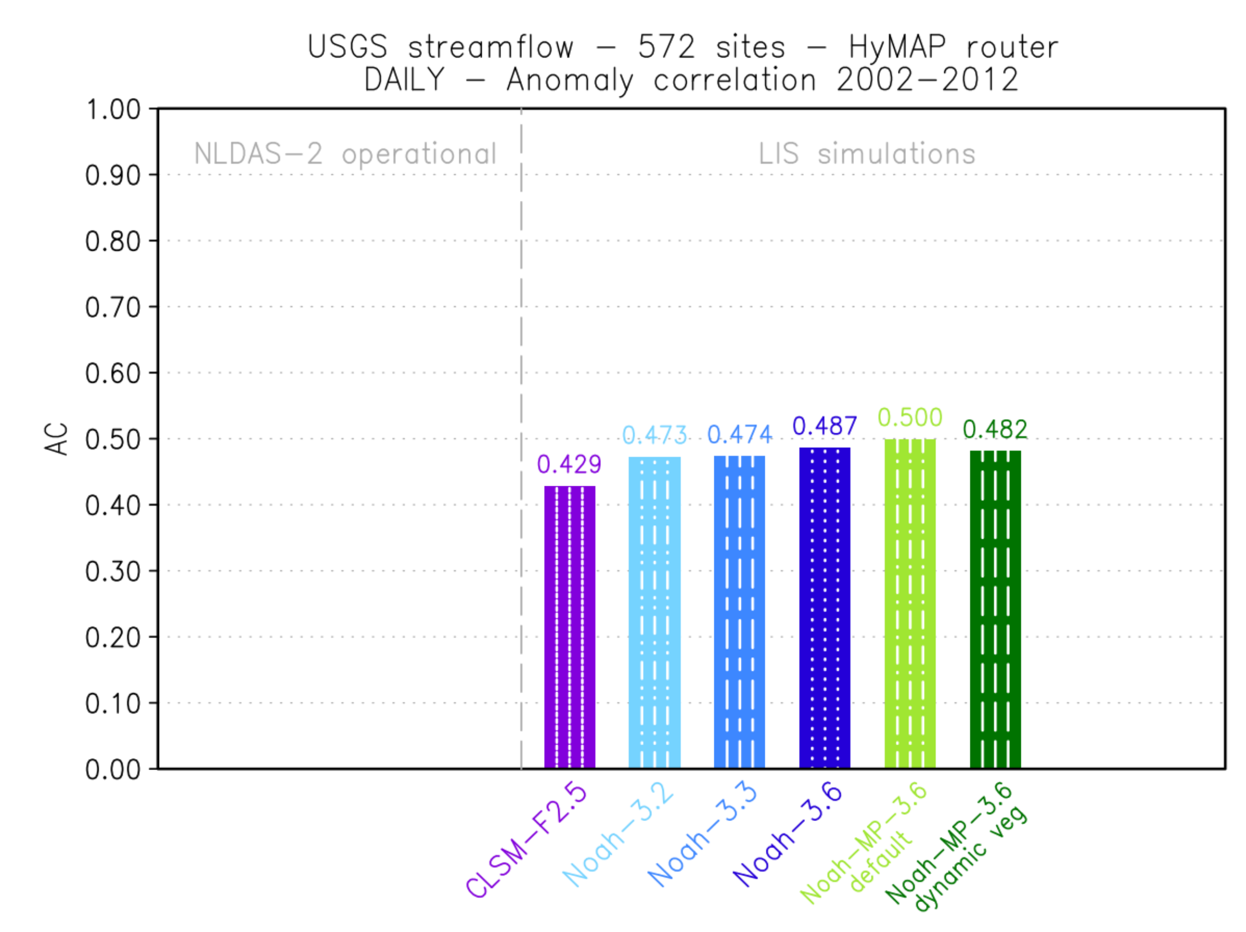
Comparing HyMAP vs. NLDAS router

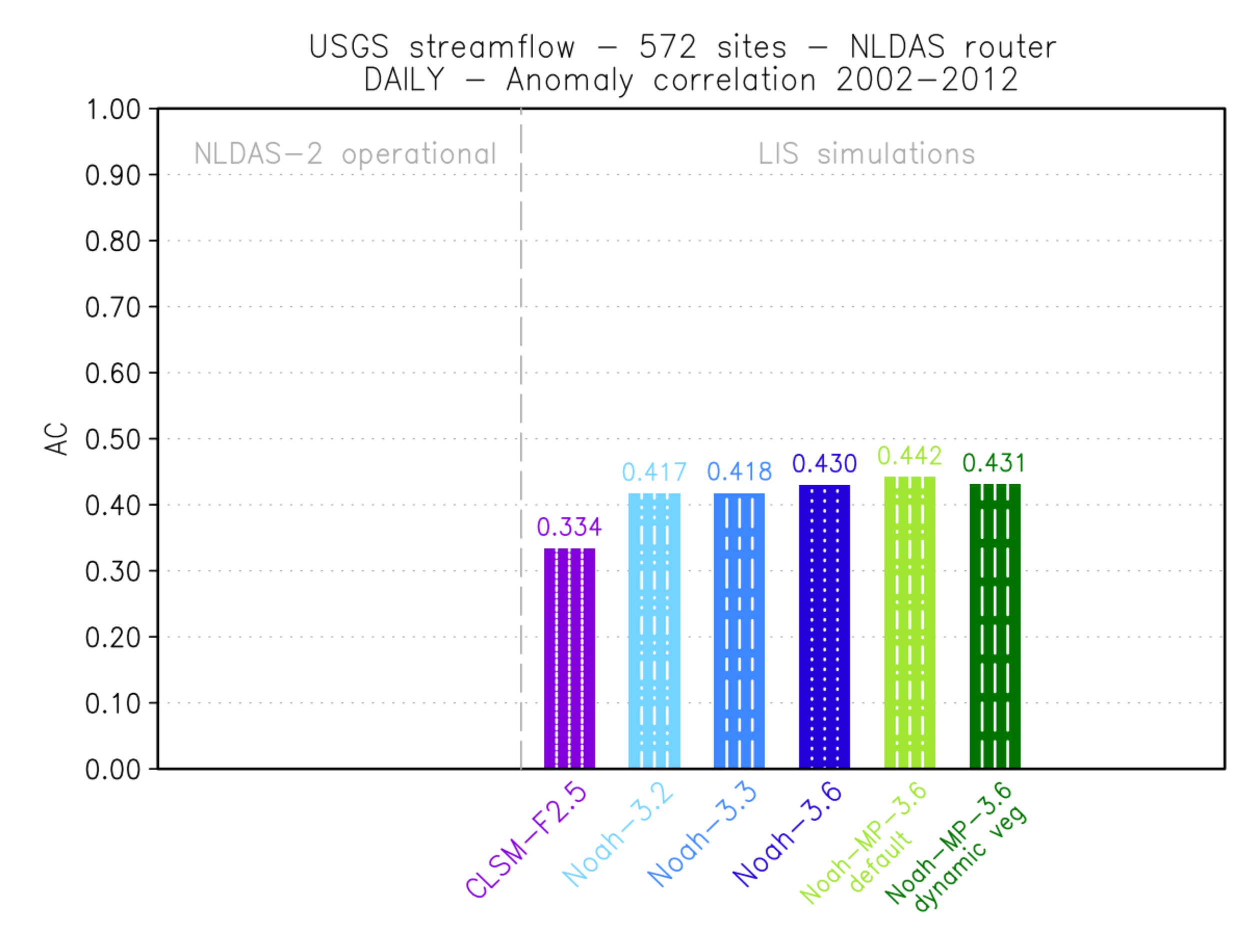
As part of our just-started MAPP Climate Test Bed project for operational transition for the next phase of NLDAS, we are implementing the HyMAP streamflow router, in place of the current NLDAS router.

Both the HyMAP router (Getirana et al., 2012) and the NLDAS router (Lohmann et al., 2004) are included within LIS. However, the NLDAS router is tied to the current NLDAS grid, while HyMAP supports finer-scale and global domains. Also, HyMAP provide river stage in addition to river discharge, and is being actively developed/improved within the LIS group, including consideration of floodplains.

The results on the next two slides show daily evaluations using the two routers. Simulated runoff/ET/etc. are identical. Monthly evaluations did not show any significant difference between the routers. The NLDAS-2 operational LSMs will also be tested with the HyMAP router in an offline mode (work in progress).

Daily streamflow anomaly correlation



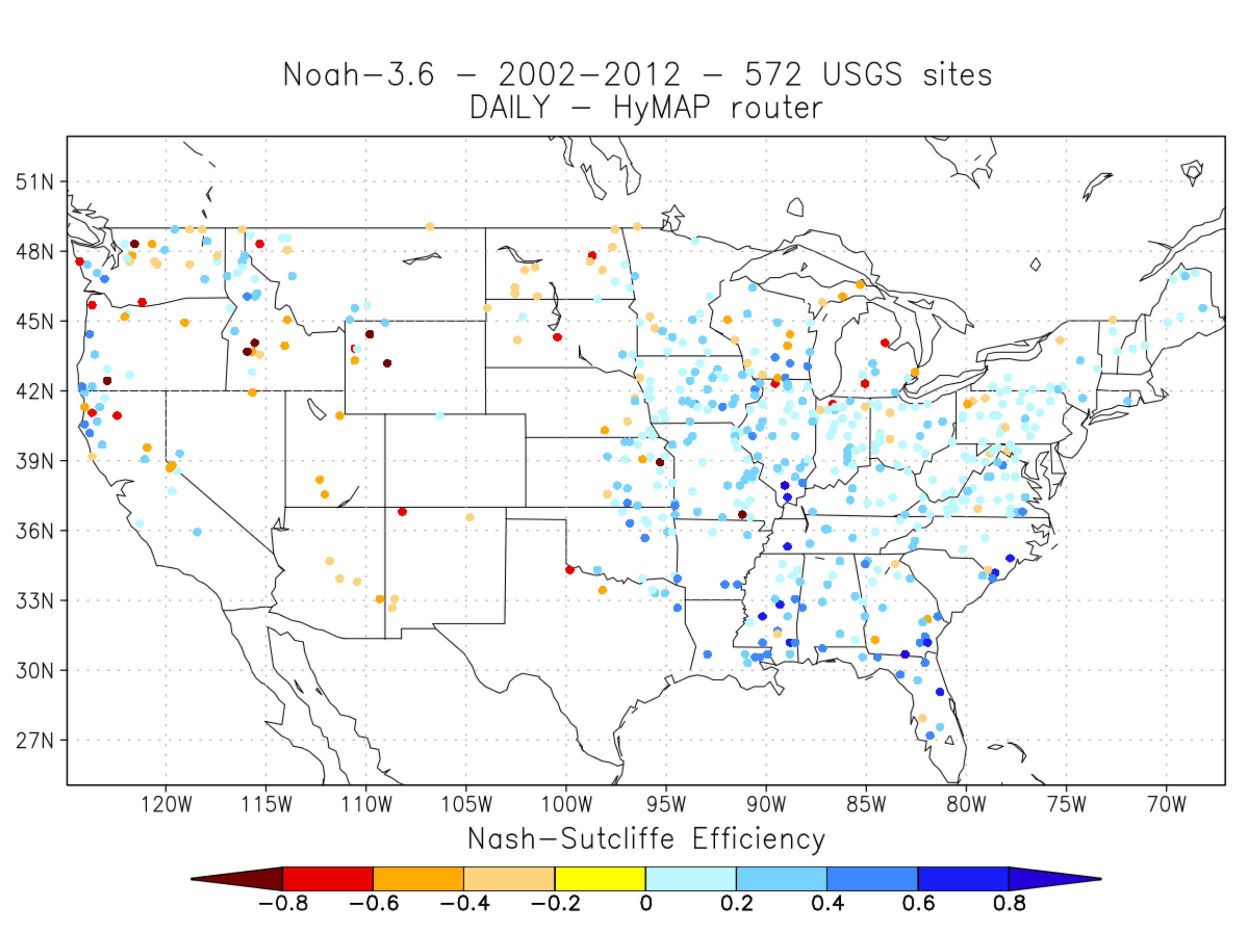


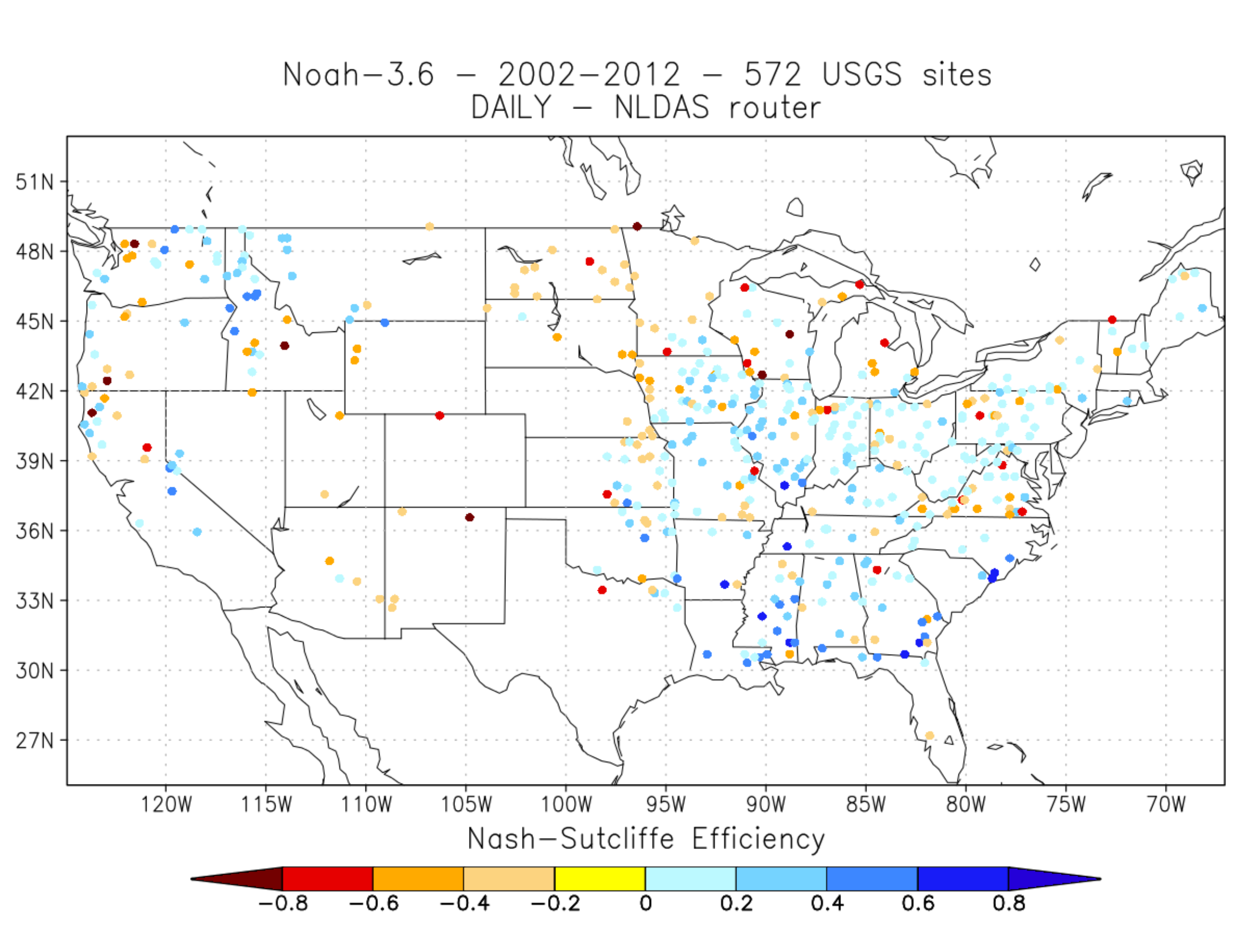
LEFT) Experiments with HyMAP router RIGHT) Experiments with NLDAS router

The daily AC values are higher using the HyMAP router for all LSMs.

Noah-3.6 and Noah-MP default tend to have the highest AC values.

Daily Nash-Sutcliffe Efficiency (NSE)





LEFT) Experiments with HyMAP router RIGHT) Experiments with NLDAS router

NSE values tend to be higher with the HyMAP router, especially in the Midwest and Mid-Atlantic.

We expect further improvement with HyMAP after additional parameter/physics refinement.

Conclusions

- CLSM-F2.5 experiments have somewhat increased the runoff, but it is still lower than it should be, particularly in the Ohio River Basin. The experiments have reduced the soil moisture AC, while improving the streamflow and the groundwater AC. The addition of 2-m to the depth to bedrock lowers the runoff, but helps significantly with the groundwater simulation for GRACE DA.
- Noah-MP physics options evaluations are in progress.
- Initial HyMAP vs. NLDAS router comparisons show improved skill in daily evaluations.

http://ldas.gsfc.nasa.gov/nldas/ David.Mocko@nasa.gov

On-going development and evaluation

- CLM-4.5 LSM has been integrated into the LIS software and will be evaluated in the NLDAS environment
- RUC LSM is also in LIS and is being evaluated for NLDAS
- Adding new evaluations to the Testbed (updated North American Soil Moisture Database, GLEAM ET and soil moisture, etc.)
- Testing additional Noah-MP physics options
- A few more CLSM-F2.5 experiments are planned (baseflow)
- Additional HyMAP router improvements and evaluations

http://ldas.gsfc.nasa.gov/nldas/   David.Mocko@nasa.gov