Evaluation of New and Upgraded Land-Surface Models in the North American Land Data Assimilation System (NLDAS)

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Presentation Outline

- Introduction of the new/upgraded LSMs to be used in the next phase of NLDAS
  - Noah-3.3, Catchment/Fortuna-2.5, SAC-HTET/SNOW-17, VIC-4.1.1
- Simulations using the Land Information System (LIS) software framework
  - Introduction to LIS
  - Comparison of model climatologies against NLDAS-2
- Comparisons to independent observations
  - Soil Moisture
  - Streamflow
  - Surface Fluxes

NLDAS Land Surface Models (LSMs)

- For NLDAS Phase 2, NLDAS-2 forcing is used to drive a suite of LSMs from the meteorological (Noah and Mosaic) and hydrological (Sacramento [SAC/SNOW-17] and VIC) communities.
- For this project, all LSMs will be brought under the Land Information System (LIS) software framework, in place of their default drivers
- The GMAO's Catchment LSM will replace Mosaic, and the other LSMs will be upgraded to their latest model versions
- All LSMs were run on a 1/8th deg. resolution CONUS domain, including parts of Canada/Mexico (25-53° N; 125-67° W)
- A 15-year spin-up of the soil states was performed, followed by 33-year simulations from Jan 1979 – Dec 2011

NLDAS Land Surface Models (LSMs)

NLDAS-2	Major LSM changes	Next phase of NLDAS	References
Noah-2.8	• Common code by NCAR/NCEP • Warm season updates • Snow physics upgrade	Noah-3.3	Chen et al. (1996, JGR); Ek et al. (2003, JGR); Wei et al., 2012, HP); Livneh et al., 2010, J. Hydromet.)
Mosaic	• Topographic catchments instead of 1-D soil moisture layers • 3 soil moisture regions: saturated, sub-saturated, and wilting	Catchment/ Fortuna-2.5 (CLSM-F2.5)	Koster et al. (2000, JGR); Reichle et al. (2011, J. Climate)
VIC-4.0.3	• Canopy energy balance • Snowpack improvements	VIC-4.1.1	Liang et al. (1994, JGR); Gao et al. (2010, book chapter)
SAC/ SNOW-17	• Distinct soil layers for soil moisture/temps (HT) • Includes the Noah LSM's evapotranspiration physics (ET)	SAC-HTET/ SNOW-17	Burnash et al., (1973); Anderson (1973); Koren et al. (2007, 2010, NOAA Tech Memos)

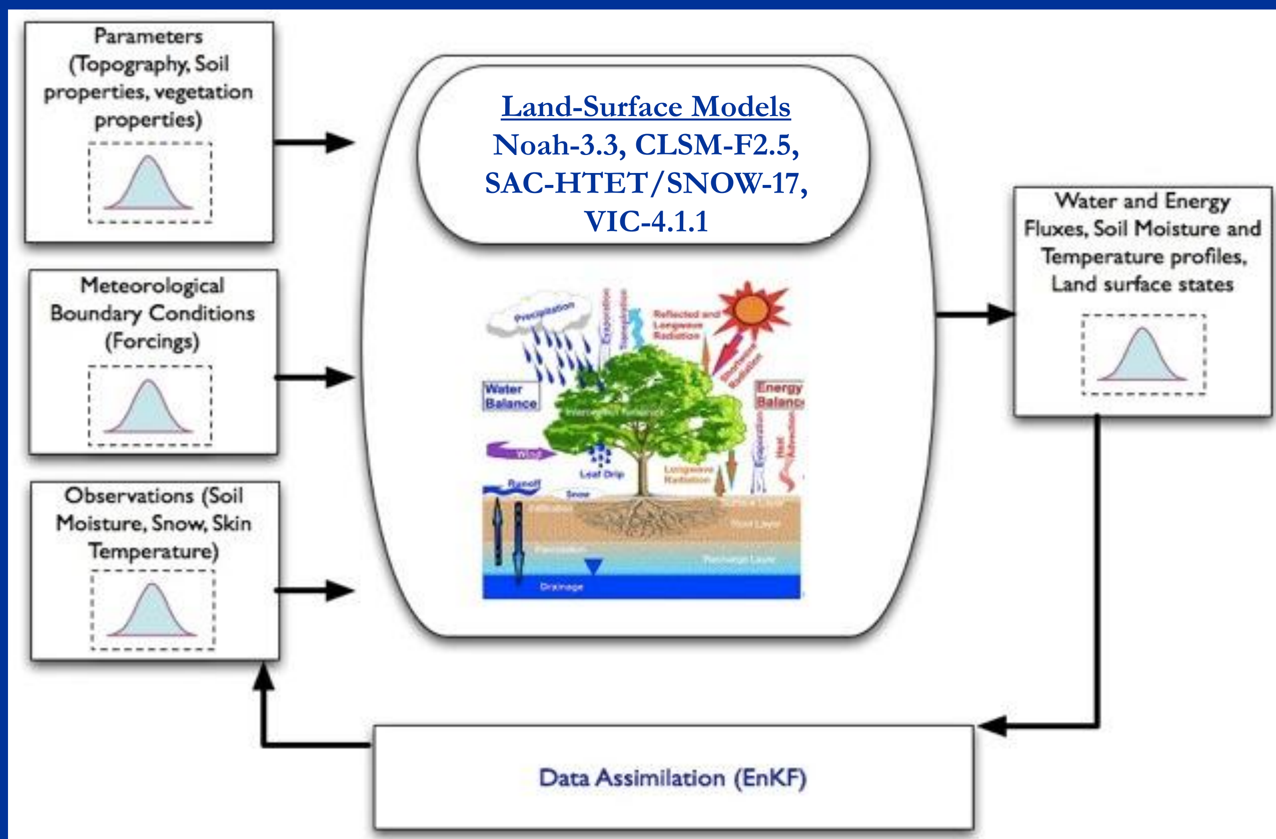
The Land Information System (LIS)

- LIS is a flexible land-surface modeling and data assimilation framework developed with the goal of integrating satellite- and ground-based observed data products with land-surface models

Next phase of NLDAS under LIS

1979-present NLDAS2 Forcing and Parameters

Soil Moisture, SWE



Drought Indices/ Percentiles

Current status of experiments

- Noah-3.3 and CLSM-F2.5 simulations completed in the latest version of the LIS software, and evaluated using datasets available in the Land surface Verification Toolkit (LVT) – Kumar et al. (2012)
- VIC-4.1.1 simulation very recently completed and initial evaluation underway
- SAC-HT/SNOW-17 has been implemented in LIS, and work is underway to update to SAC-HTET/SNOW-17
- The results presented here should be considered to be preliminary. Based on these initial evaluations, new and test simulations will be made to examine the effects of various model parameters/options on simulated results.

Evaluation of simulated output

Soil moisture:

USDA Soil Climate Analysis Network (SCAN); 123 stations chosen after careful quality control – data used for evaluations between 2000-2011

Four USDA ARS experimental watersheds ("CalVal" sites) – data used for evaluations between 2001-2011

Streamflow:

Gauge measurements from 961 unregulated USGS streamflow stations (1981-2011).

Naturalized streamflow at major basin outlets (Koster et al., 2010) – varies by basin

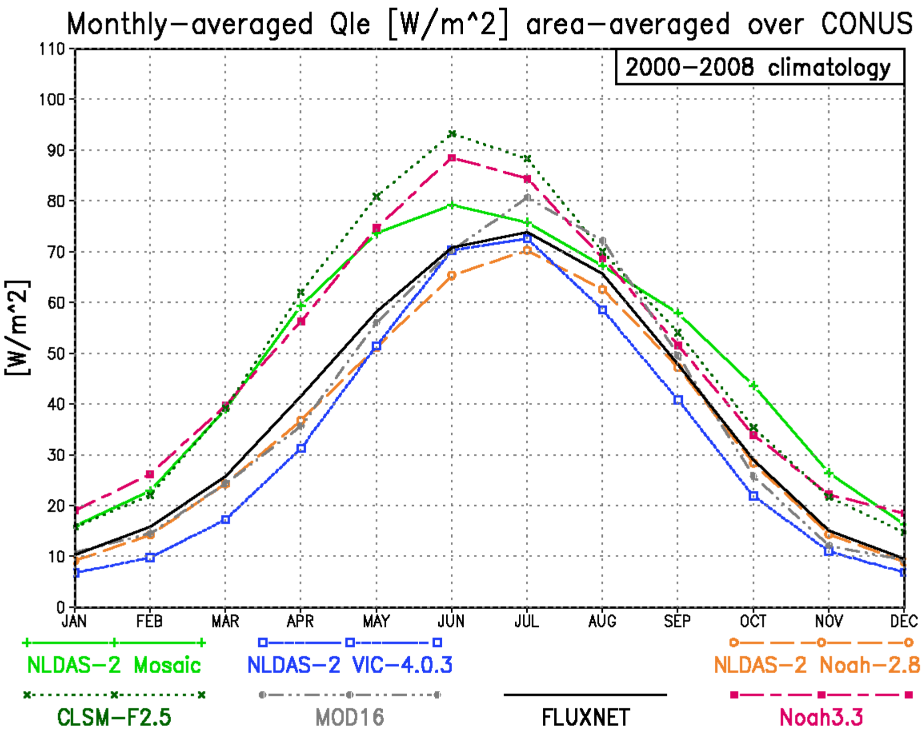
Fluxes:

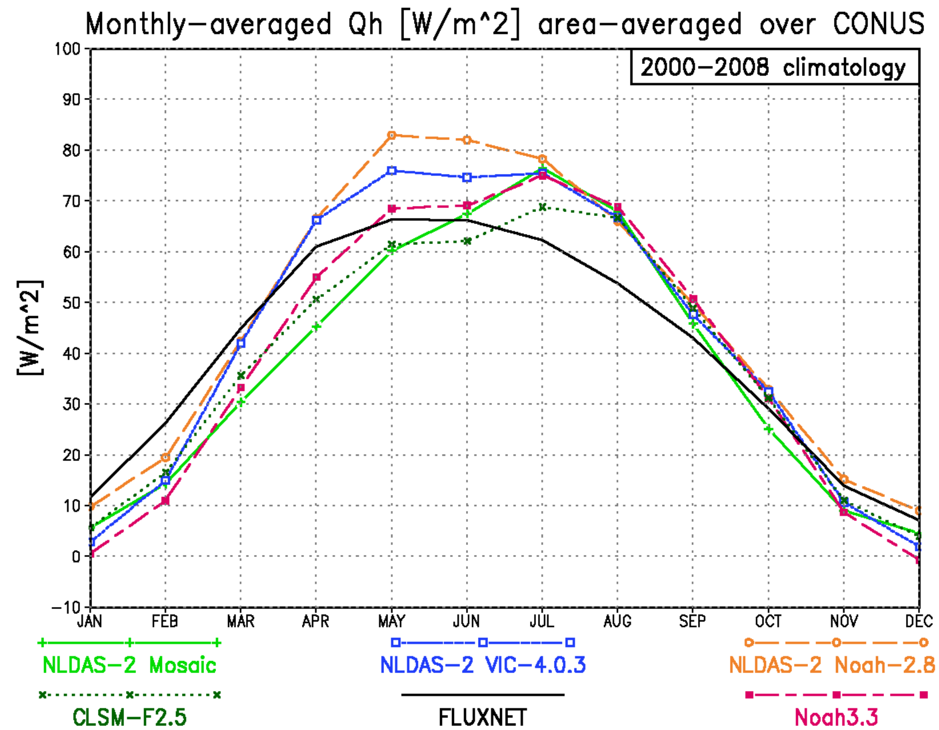
Gridded analysis of latent and sensible heat fluxes using FLUXNET stations from Jung et al. (2009) – data used for evaluations between 1982-2008

Gridded global monthly 1-km MOD16 ET estimates based on MODIS satellite retrievals from Mu et al. (2011) – data used for evaluations between 2000-2010

All model verifications and analysis generated using the Land surface Verification Toolkit (LVT) – Kumar et al., (2012, Geosci. Model Dev.)

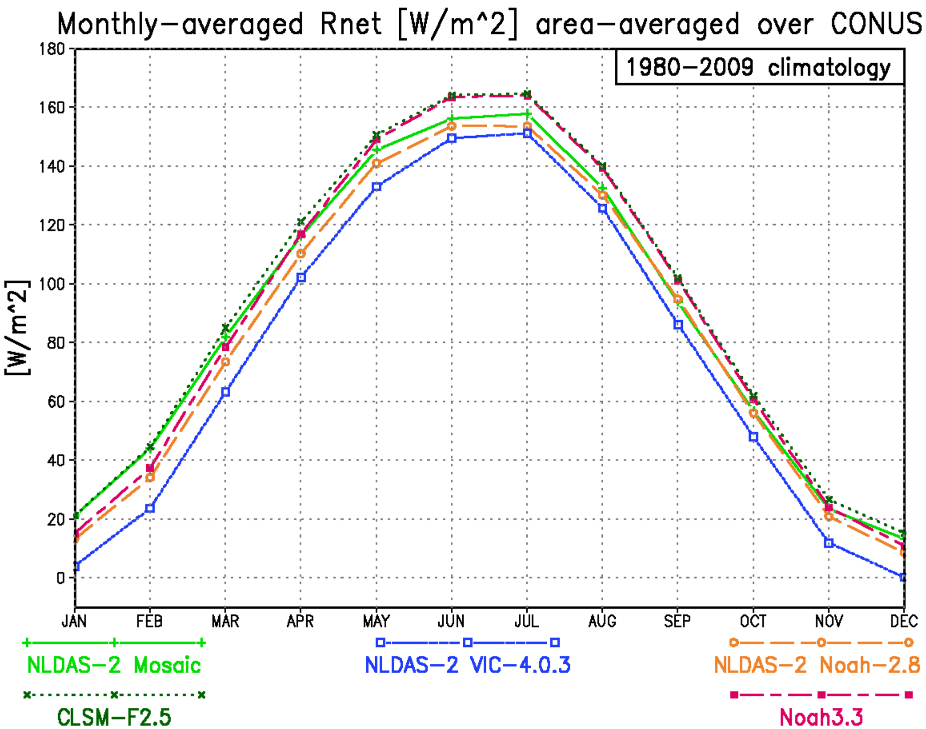
Climatology of Latent/Sensible Fluxes

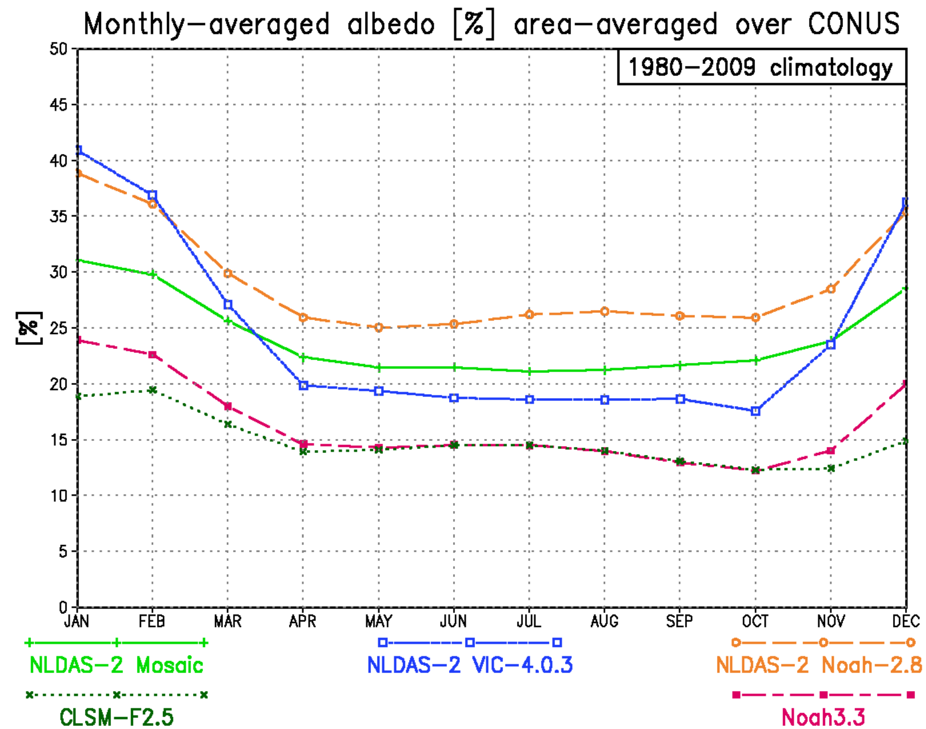




These figures show the latent/sensible heat fluxes for 2000-2008 (inclusive), which is the overlapping period of the FLUXNET and MOD16 flux estimates. Noah-3.3 has much higher latent heat flux than NLDAS-2 Noah-2.8, FLUXNET, and MOD16 in the winter and spring. CLSM-F2.5's latent heat flux is generally similar to NLDAS-2 Mosaic and Noah-3.3, but is higher during May-July. NLDAS-2 VIC and Noah have lower latent heat flux, particularly in the spring. Conversely, NLDAS-2 VIC and Noah have the highest sensible heat flux in the spring. Again, CLSM-F2.5 is generally similar to NLDAS-2 Mosaic. Noah-3.3 and FLUXNET have lower sensible heat flux compared to NLDAS-2 Noah-2.8.

Climatology of Net Radiation/Albedo





For a 30-year climatology (1980-2009, inclusive), there are consistent differences in the net radiation and albedo between the results. All LSMs were forced with the same NLDAS-2 downward SW & LW. There is more available net radiation at the surface in the Noah-3.3 and CLSM-F2.5 results, which could be contributing to the higher latent heat fluxes. The albedos are lower in Noah-3.3 and CLSM-F2.5, most notably during the summer. Both Noah-3.3 and CLSM-F2.5 used Noah-3.3's AVHRR background surface albedo datasets. Test will be run using NLDAS-2 Noah-2.8's background surface albedo dataset within Noah-3.3, as well as using Catchment's albedo dataset within CLSM-F2.5.

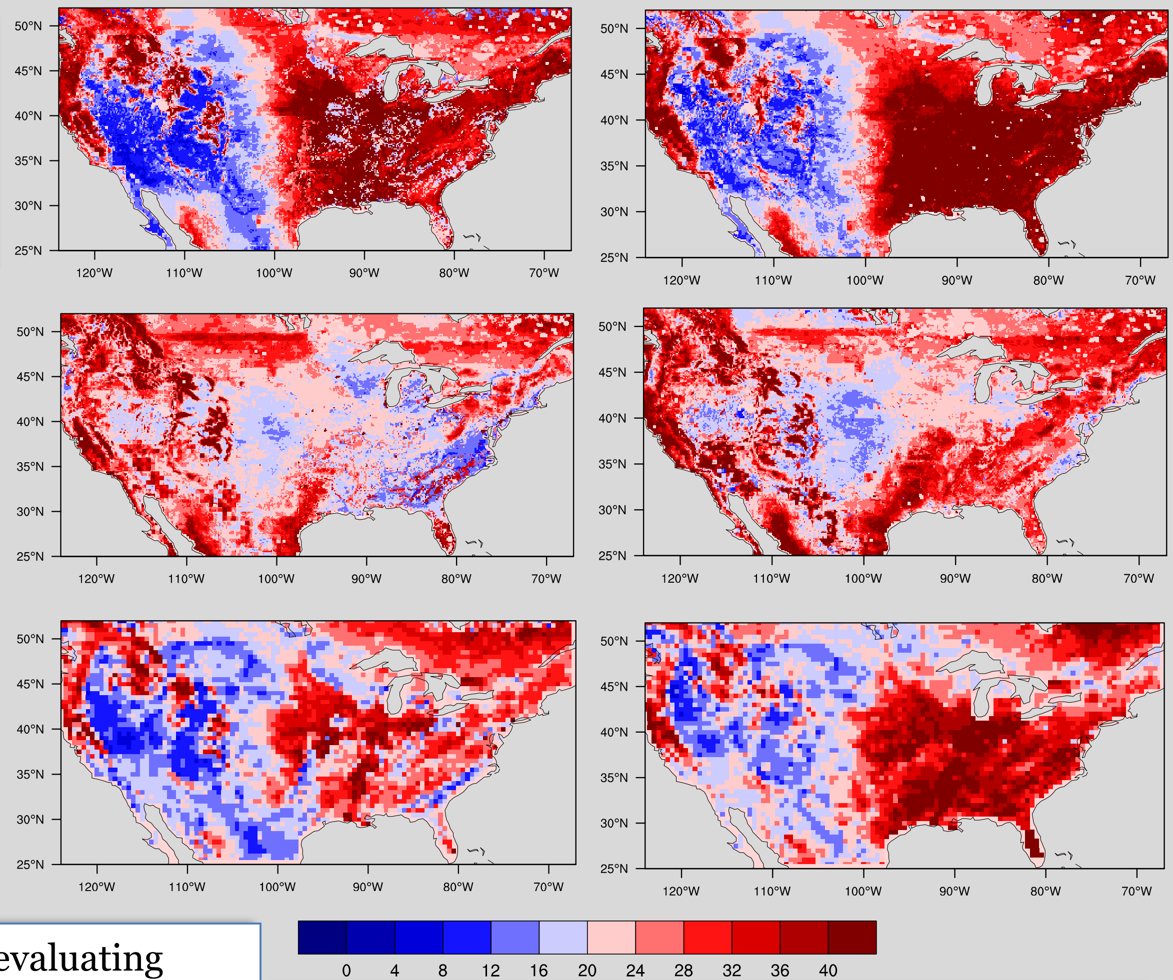
Evaluation of Fluxes

FLUXNET (Latent Heat)	Noah-3.3	CLSM-F2.5
RMSE (W/m2)	27.5 +/- 1.0	29.6 +/- 1.0
Bias (W/m2)	11.9 +/- 1.0	11.0 +/- 1.0

FLUXNET (Sensible Heat)	Noah-3.3	CLSM-F2.5
RMSE (W/m2)	26.3 +/- 1.0	27.4 +/- 1.0
Bias (W/m2)	-1.7 +/- 1.0	-8.0 +/- 1.0

MOD16 (Latent Heat)	Noah-3.3	CLSM-F2.5
RMSE (W/m2)	23.2 +/- 1.0	26.3 +/- 1.0
Bias (W/m2)	12.2 +/- 1.0	11.8 +/- 1.0

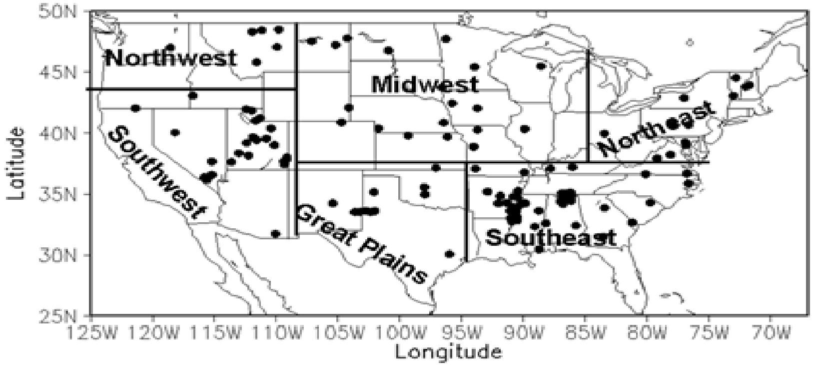
Noah-3.3 (RMSE) CLSM-F2.5 (RMSE)



Both LSMs had similar statistics when evaluating against both the FLUXNET and MOD16 gridded flux products. Notably high RMSE values are found in cropland areas in Midwest and along the Miss. River.

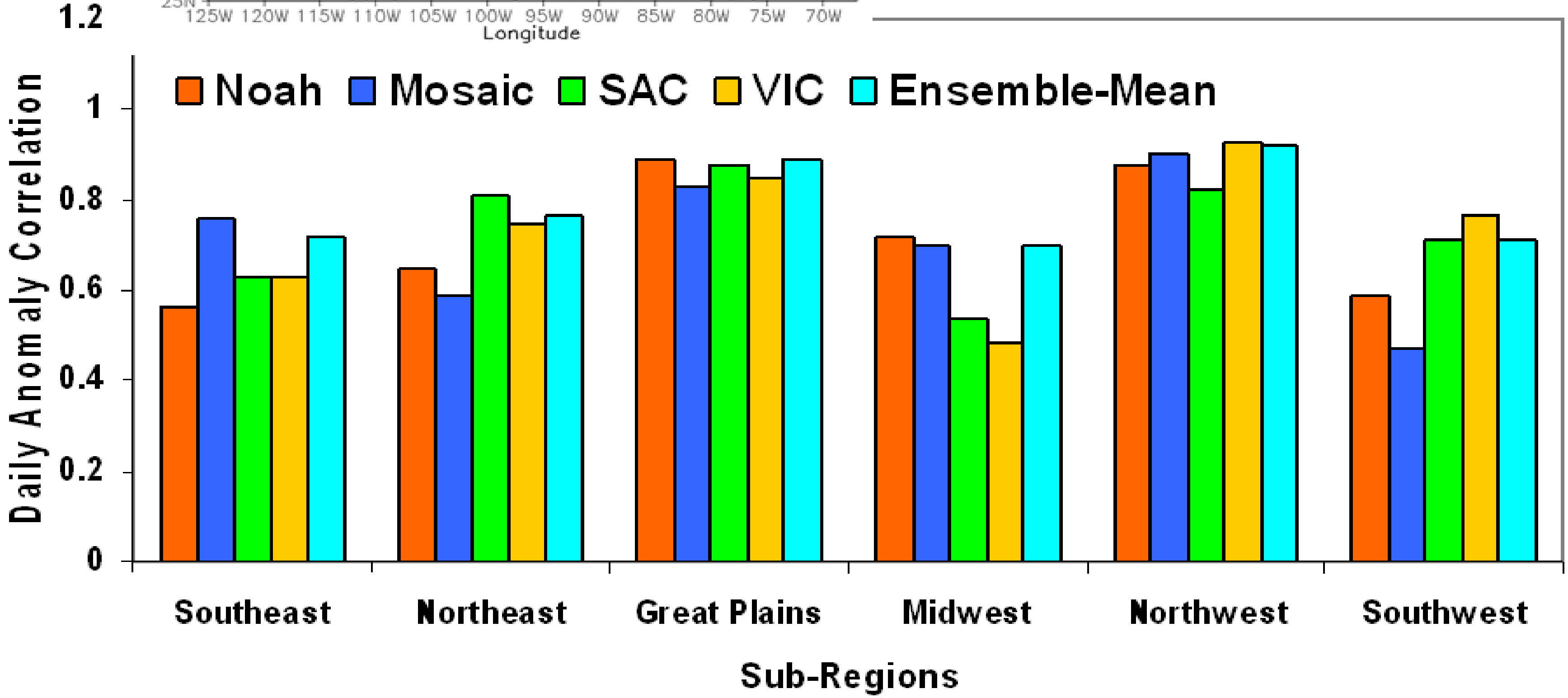
For more on this evaluation of ET in an NLDAS-like framework, see Peters-Lidard et al. (2011, HP)

Evaluation of soil moisture fields

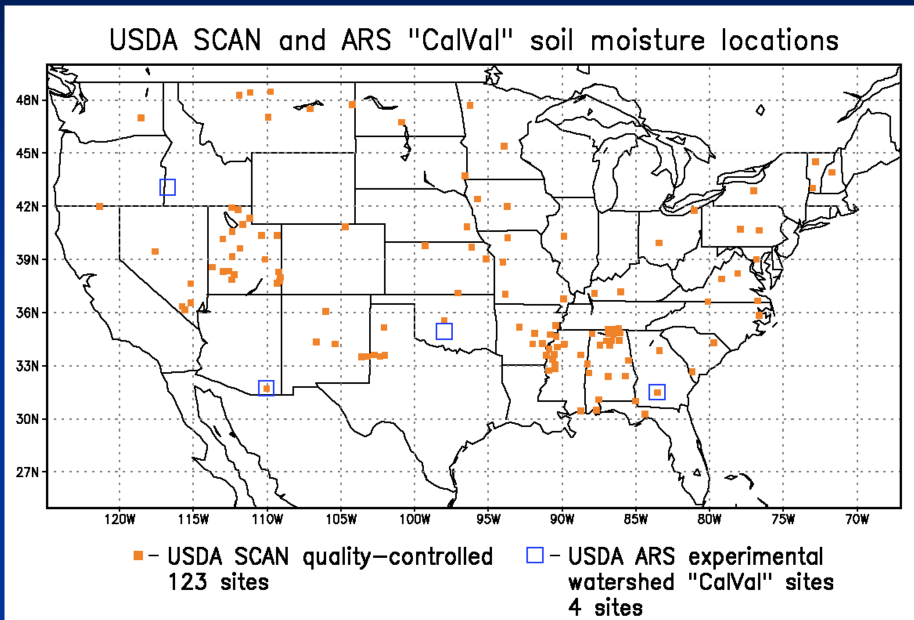


Spatial averaged daily top 1m soil moisture anomaly correlation over continental United States

U.S. Soil Climate Analysis Network (SCAN), 1 January 2002 - 31 December 2009



Evaluation of soil moisture fields



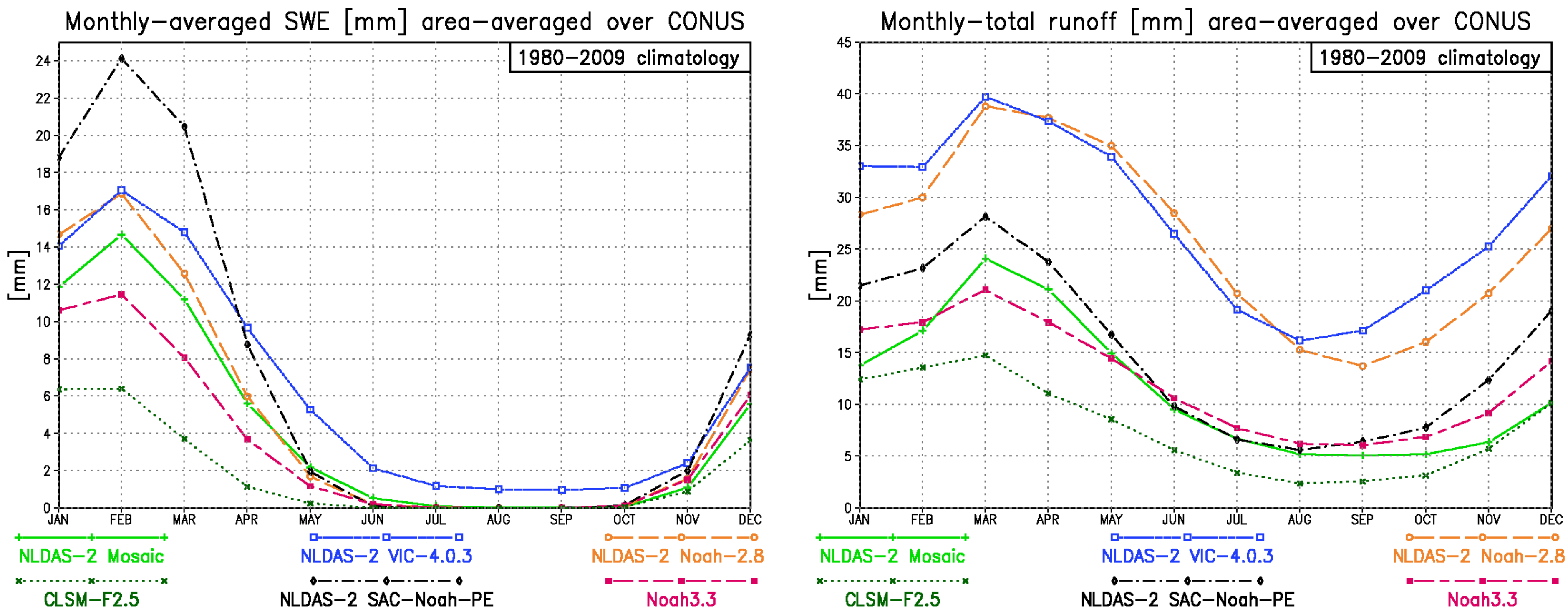
ARS CalVal (surface soil moisture)	Noah-3.3	CLSM-F2.5
Anomaly R	0.74 +/- 0.01	0.63 +/- 0.01
Anomaly RMSE (m3/m3)	0.034 +/- 0.001	0.033 +/- 0.001
ubRMSE (m3/m3)	0.041 +/- 0.002	0.042 +/- 0.002

SCAN (surface soil moisture)	Noah-3.3	CLSM-F2.5
Anomaly R	0.60 +/- 0.02	0.59 +/- 0.03
Anomaly RMSE (m3/m3)	0.044 +/- 0.002	0.048 +/- 0.002
ubRMSE (m3/m3)	0.054 +/- 0.003	0.056 +/- 0.002

SCAN (root zone soil moisture)	Noah-3.3	CLSM-F2.5
Anomaly R	0.60 +/- 0.02	0.55 +/- 0.02
Anomaly RMSE (m3/m3)	0.037 +/- 0.002	0.037 +/- 0.002
ubRMSE (m3/m3)	0.048 +/- 0.003	0.047 +/- 0.002

Both Noah-3.3 and CLSM-F2.5 perform reasonable well for both surface and root zone soil moisture at these locations, although there is some indication that Noah-3.3 performs slightly better. Similar analyses using LVT will be performed with the NLDAS-2 LSM simulated output.

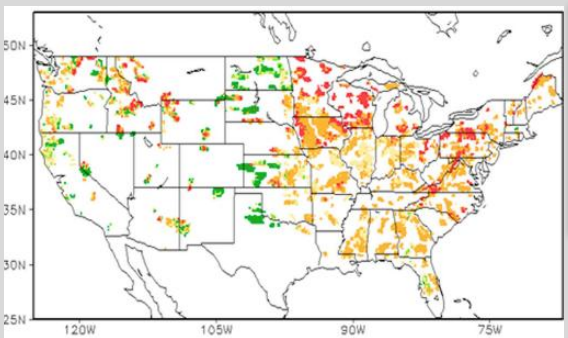
Climatologies of SWE and Runoff



Noah-3.3 has lower peak winter SWE than NLDAS-2 Noah, while CLSM-F2.5 has even lower peak SWE. Both LSMs simulate lower SWE than all four NLDAS-2 LSMs for almost all months. Noah-3.3 runoff is much lower than NLDAS-2 Noah as well. CLSM-F2.5's runoff is generally similar to that from NLDAS-2 Mosaic, but slightly lower for most months, to significantly lower during spring melt.

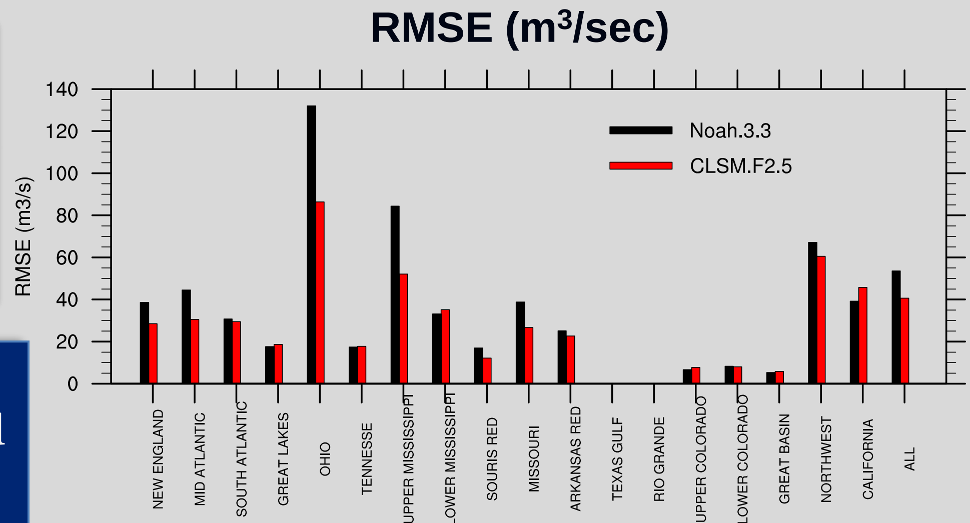
Evaluation against USGS Streamflow

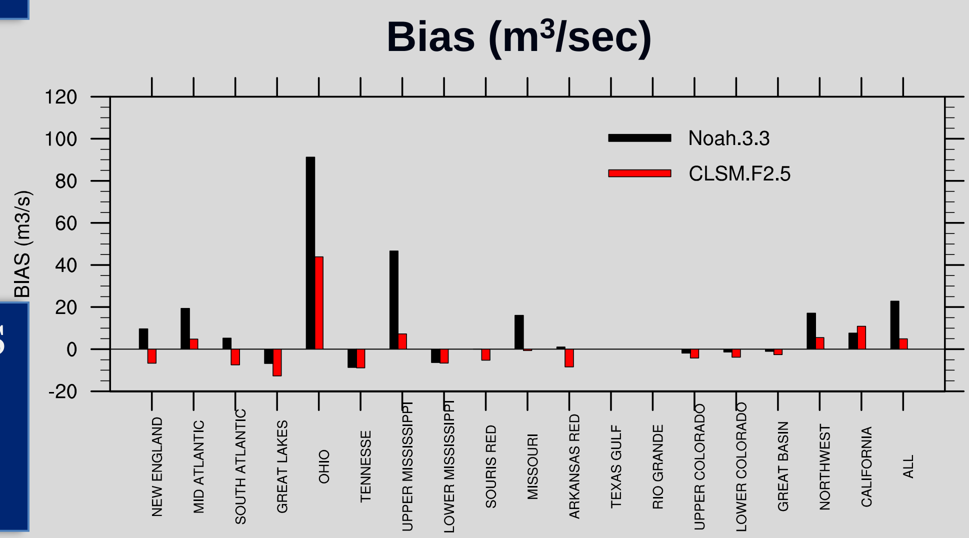
Streamflow (USGS)	Noah-3.3	CLSM-F2.5
RMSE (m^3/s)	**51.8 +/- 1.0**	**40.6 +/- 1.0**
Bias (m^3/s)	**20.1 +/- 1.0**	**4.94 +/- 1.0**



(Left) 961 unregulated USGS basins

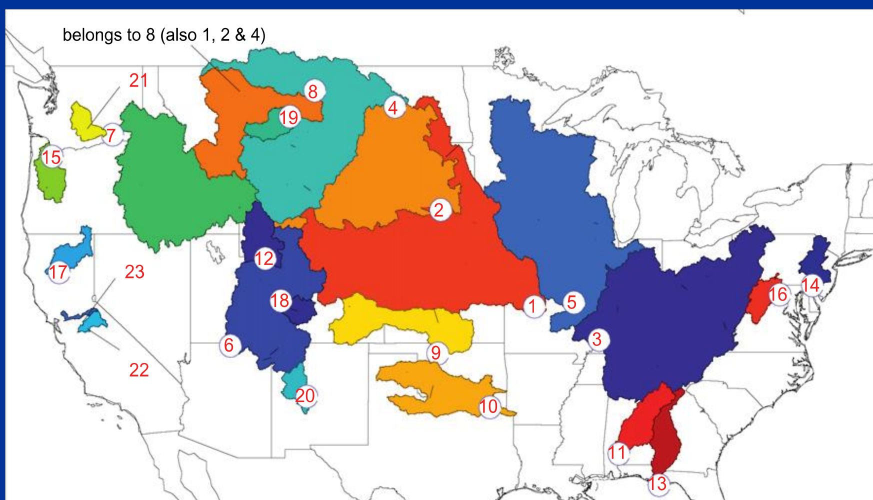
(Left) USGS Water Resource Regions





CLSM-F2.5 performed better for the NLDAS streamflow evaluation after Lohmann et al. (2004)

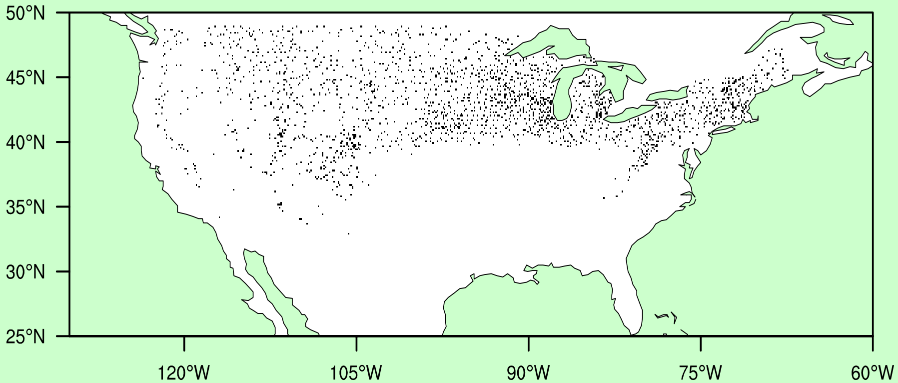
Evaluation against Naturalized streamflow data at major basin outlets



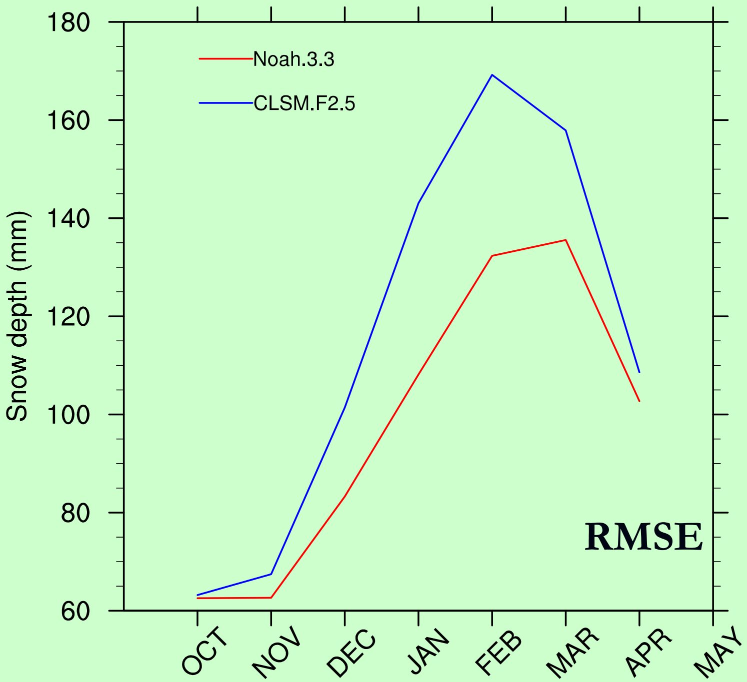
CLSM-F2.5 and Noah-3.3 performed about the same, with large errors for the Ohio and Upper Mississippi. Interestingly, the biases from the naturalized streamflow tend to be negative for both LSMs; in the 961 small basins, Noah-3.3 was primarily positively biased.

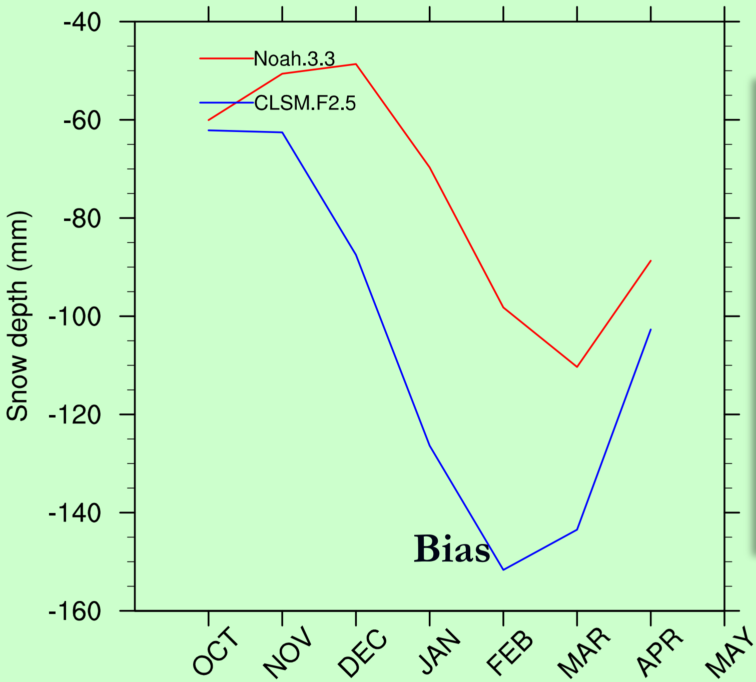
	RMSE (m^3/s)		Bias (m^3/s)	
	Noah.3.3	CLSM-F2.5	Noah.3.3	CLSM-F2.5
Alabama(11)	1080.0	1100.0	-277.0	-455.0
Apalachicola(13)	646.0	724.0	-217.0	-479.0
Missouri(8)	238.0	276.0	-144.0	-200.0
Missouri(4)	641.0	695.0	-346.0	-449.0
Green(12)	94.8	102.0	-46.8	-62.4
Gunnison(18)	132.0	133.0	-82.0	-85.4
Snake(7)	1630.0	1770.0	-1000.0	-1330.0
Colorado(6)	728.0	793.0	-372.0	-498.0
San Joaquin(23)	35.8	39.9	-5.49	-4.02
Musselshel(19)	13.4	12.5	0.7	-3.23
Ohio(3)	7420.0	8190.0	-4310.0	-5690.0
Potomac(16)	340.0	350.0	-196.0	-218.0
Rio Puerco(20)	50.6	28.7	43.4	22.3
Arkansas(9)	299.0	299.0	-193.0	-193.0
Missouri(2)	735.0	822.0	-348.0	-509.0
Arkansas-Red(10)	408.0	489.0	-165.0	-286.0
Sacramento(17)	379.0	367.0	-138.0	-87.5
Tuolumne (22)	86.6	78.2	-32.9	-27.5
Upper Mississippi(5)	2410.0	3210.0	-603.0	-2250.0
Willamette(15)	992.0	962.0	-210.0	-266.0
Yakima(21)	101.0	121.0	-63.0	-90.4

Evaluation of Snow depth



GHCN (snow depth)	Noah-3.3	CLSM-F2.5
RMSE (mm)	**149.0 +/- 5.0**	**179.0 +/- 5.0**
Bias (mm)	**-78.6 +/- 5.0**	**-121.0 +/- 5.0**





Both LSMs had less snow depth than observed at the GHCN stations. Noah-3.3 performed somewhat better than CLSM-2.5.

Next Steps

- Perform evaluations with the VIC-4.1.1 simulation
- Finish adding SAC-HTET/SNOW-17 into LIS and run the NLDAS experiment and compare against NLDAS-2 SAC
- Continue to evaluate NLDAS-2 LSMs and the newest versions of these LSMs against each other and using available observations
- Add and test the effects of data assimilation of remotely-sensed soil moisture and SWE products, as well as MODIS snow-covered area (SCA), GRACE terrestrial water storage, and irrigation intensity from MODIS
- Compare drought indices and percentiles to other datasets, such as the U.S. Drought Monitor archive and a newly-developed optimal NLDAS-2 drought index under development by Xia et al.

Summary

- NLDAS is a successful collaboration project that has produced nearly 34 years of hourly 1/8th-degree surface forcing and land-surface model output over CONUS and parts of Canada/Mexico
- The next NLDAS phase continues with the use of new/upgraded LSMs as well as data assimilation of additional data products
- The Noah-3.3 and CLSM-F2.5 simulations showed increased latent heat flux over the NLDAS domain compared to most of the NLDAS-2 results and to the reference gridded datasets
- The new model versions performed well as compared to in situ soil moisture, but generally had too much runoff compared to 961 small USGS basins and too little runoff compared to a naturalized streamflow dataset; further evaluation is needed

NLDAS & LIS websites

- NLDAS at NASA:
  http://ldas.gsfc.nasa.gov/nldas/
- NLDAS datasets at the NASA GES DISC:
  http://disc.gsfc.nasa.gov/hydrology/
- NLDAS at NOAA/NCEP/EMC:
  http://www.emc.ncep.noaa.gov/mmb/nldas/
- LIS website at NASA:
  http://lis.gsfc.nasa.gov/