Benchmarking the next phase of the North American Land Data Assimilation System (NLDAS) using the Land Verification Toolkit (LVT)

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This work is funded in part by the NOAA Climate Program Office's Modeling, Analysis, Predictions, and Projections (MAPP) Program

Acknowledgements:
Kristi Arsenault, Gabrielle De Lannoy, Ben Livneh, Yudong Tian, Yuqiong Liu, Rolf Reichle, Sarith Mahanama, Qing Liu, Mike Cosh

Presentation Outline

- Introduction to NLDAS project and the new/ upgraded LSMs for the next phase on NLDAS
  - **Noah-3.3, Catchment/Fortuna-2.5 (completed); SAC-HTET-3.5.6/SNOW-17, VIC-4.1.2 (in devel.)**
- Simulations with the Land Information System (LIS)
  - **Introduction to the LIS software framework**
  - **Data assimilation of surface soil moisture (SM), SWE, and terrestrial water storage (TWS)**
- Evaluations/benchmarks using the Land Verification Toolkit (LVT)
  - **Soil moisture; Surface fluxes; Snow; Drought**

NLDAS Land Surface Models (LSMs)

- NLDAS Phase 2 is currently running routinely in near-real time (~3.5-day lag) to drive a suite of LSMs from the meteorological (**Noah-2.8 and Mosaic**) and hydrological (**Sacramento [SAC/SNOW-17] and VIC-4.0.3**) communities.
- The NLDAS-2 LSMs have been extensively evaluated in several papers by Xia et al. for soil moisture/temps, streamflow, fluxes, etc.
- For the next phase of NLDAS, new and upgraded LSMs are run using the NASA-developed Land Information System (LIS) software framework.
- All LSMs are run on a 1/8th deg. resolution CONUS domain, including parts of Canada/Mexico (25-53° N; 125-67° W).
- A 60-year spin-up of the soil states was performed, followed by 34-year simulations from Jan 1979 – Dec 2012.

Reference(s): Xia et al. (2012a&b) – NLDAS-2 introduction and streamflow evaluation – JGRa; Xia et al. (2013) – soil temp. evaluation – *J. Appl. Meteor. Climatol.*; numerous others in review.

NLDAS Land Surface Models (LSMs)

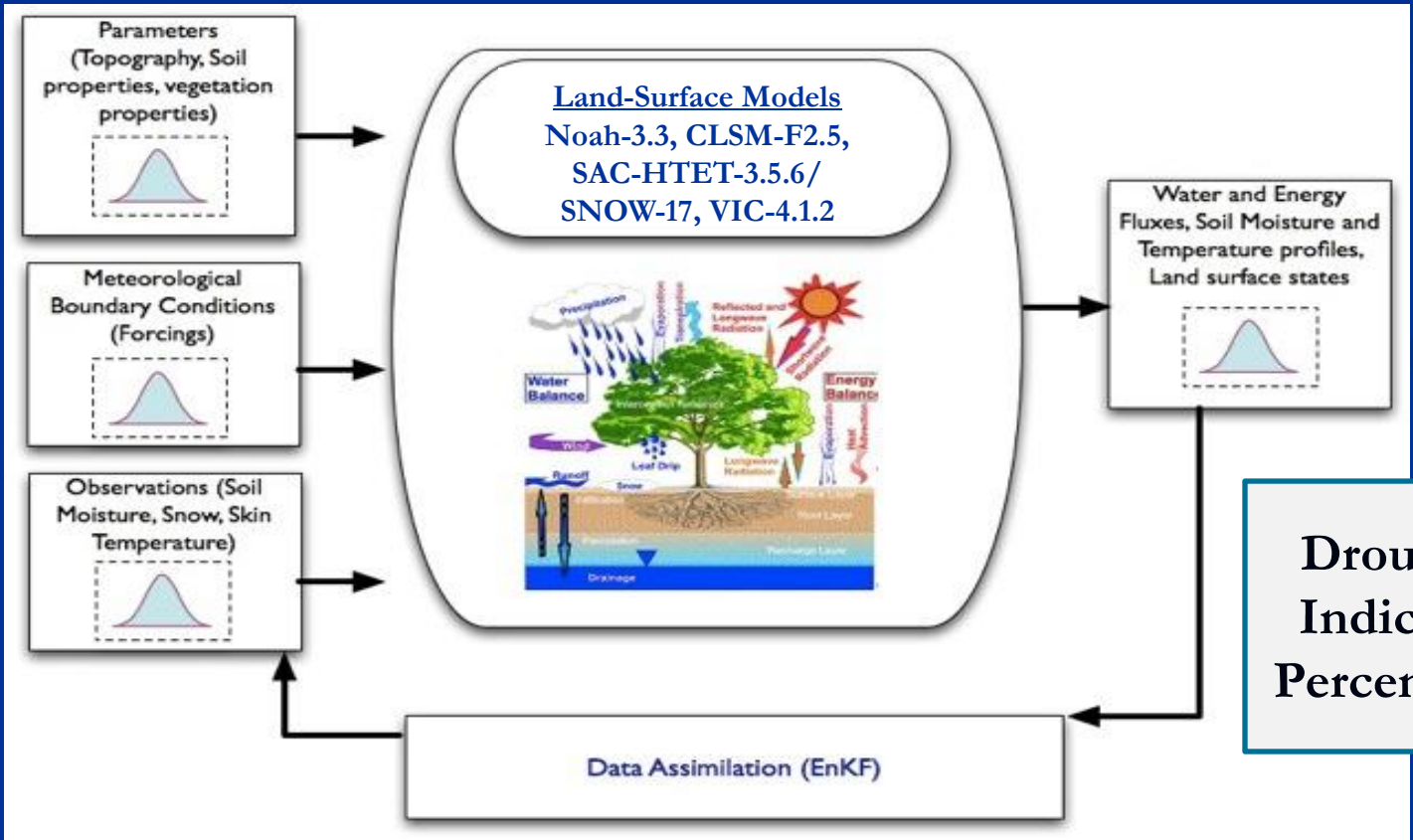
NLDAS-2	Major LSM changes	Next phase of NLDAS	References
Noah-2.8	• Common code by NCAR/NCEP • Warm season updates • Snow physics upgrade	Noah-3.3	Chen et al. (1996, JGR); Ek et al. (2003, JGR); Wei et al., 2012, HP); Livneh et al., 2010, J. Hydromet.)
Mosaic	• Topographic catchments instead of 1-D soil 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-4.1.2	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-3.5.6/ 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.

1979-present NLDAS-2 Forcing and Parameters

Soil Moisture, SWE, TWS

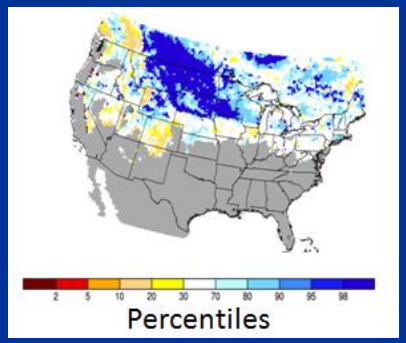


Drought Indices/ Percentiles

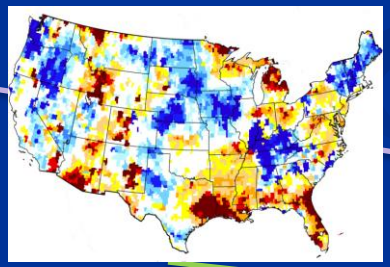
Reference(s): Kumar et al. (2006) in *Environmental Modelling & Software*
Peters-Lidard et al. (2007) in *Innovations in Systems and Software Engineering*

Data assimilation for the next phase of NLDAS

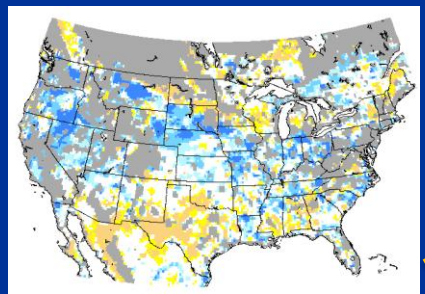
- In addition to running the LSMs in the standard way for NLDAS (Open Loop), we are adding data assimilation of remotely-sensed surface soil moisture (SM) and SWE (from a variety of platforms) and of TWS (from GRACE)
- Noah-3.3 OL, DA SM, and DA SWE simulations, and CLSM-F2.5 OL and DA TWS are being presented here.



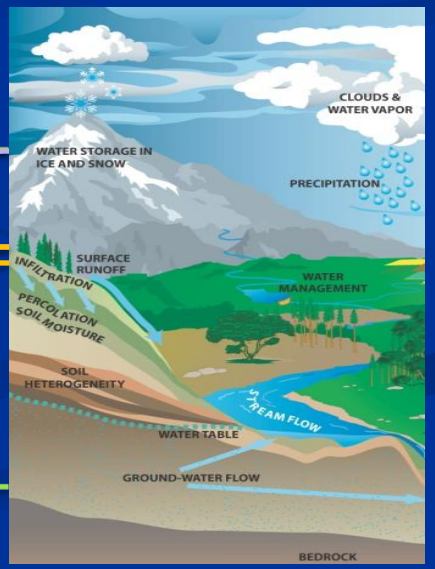
March 2011 SWE Mean Percentile from LPRM v5 – NASA Aqua/AMSR-E EDR (2003-2011).



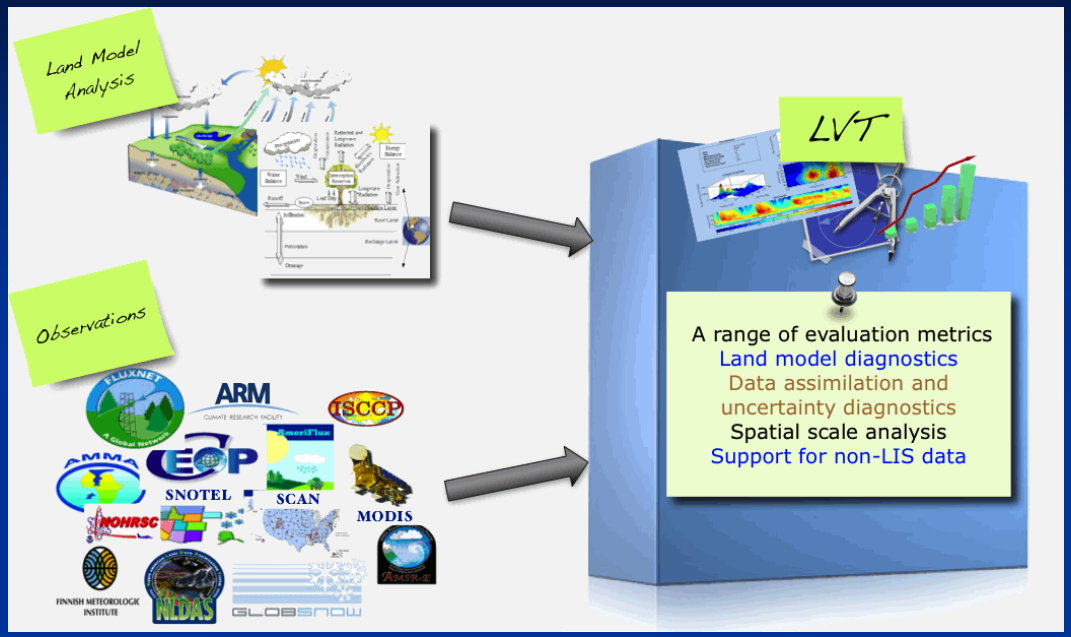
March 2011 GRACE-based Groundwater Percentile from GRACE TWS EDR (2002-present).



March 2011 Surface SM Percentile from LPRM v5 – NASA Aqua/AMSR-E EDR (2003-2011).



The Land Verification Toolkit (LVT)

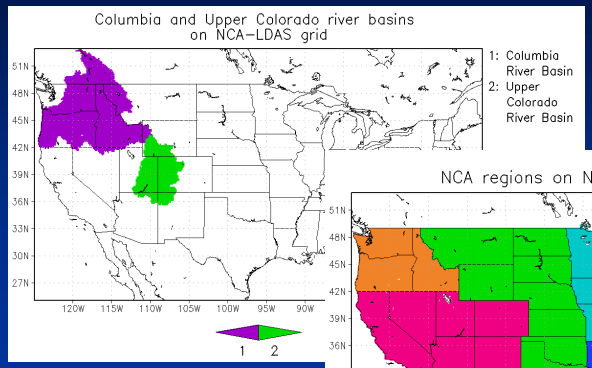


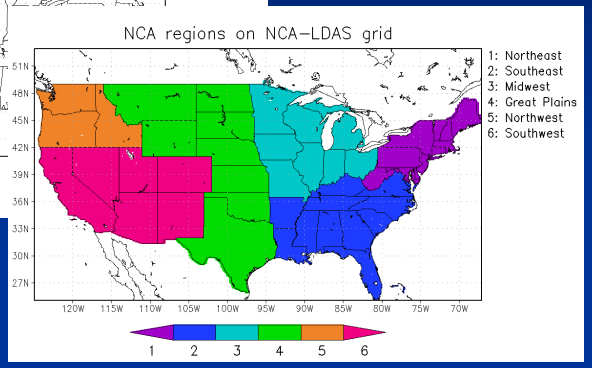
Metric Class	Examples
Accuracy	RMSE, Bias, Correlation
Ensemble	Mean, Standard deviation, Likelihood
Uncertainty	Uncertainty importance
Information theory	Entropy, Complexity
Data assimilation	Mean, variance, lag correlations of innovation distributions
Spatial similarity	Hausdorff distance
Scale decomposition	Discrete wavelet transforms

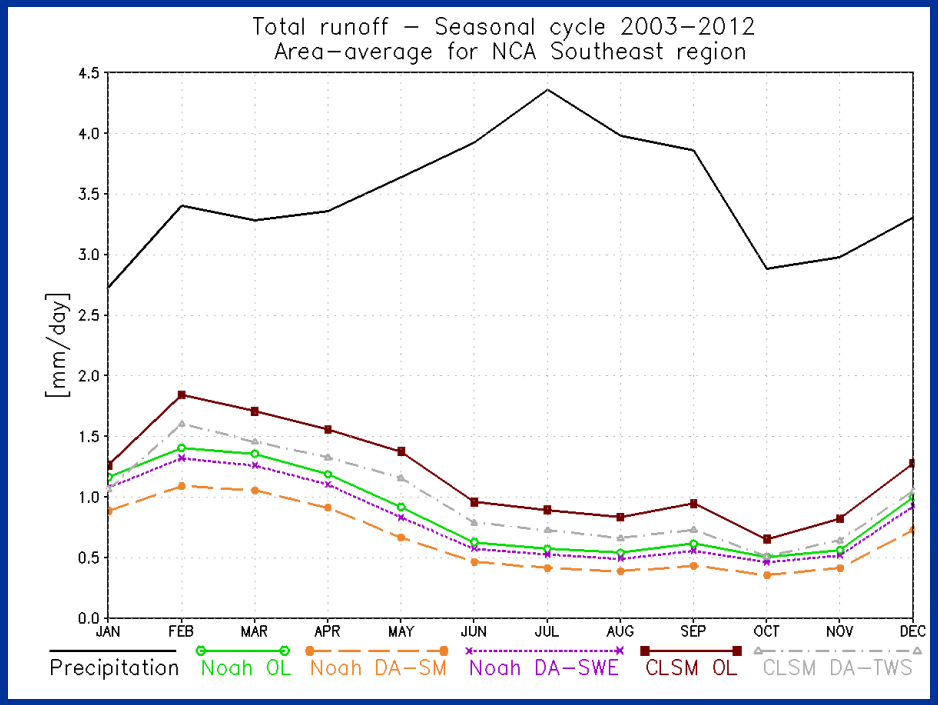
- LVT is a NASA-developed open-source software framework developed to provide an automated, consolidated environment for systematic land surface model evaluation and benchmarking
- Includes support for a range of in-situ, remote-sensing, and other model and reanalysis products in their native formats

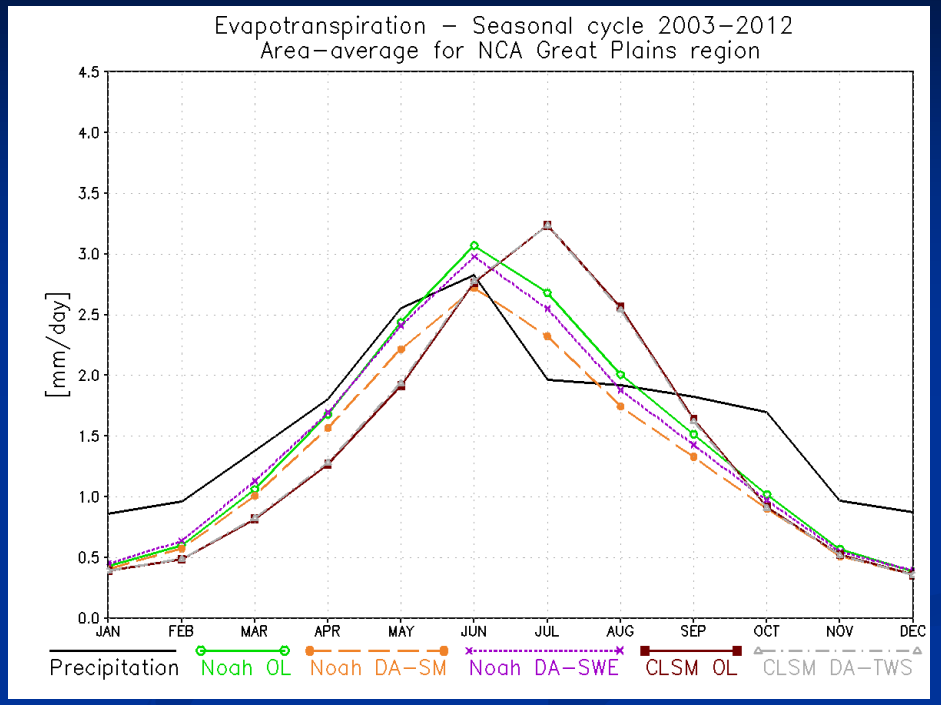
Reference(s): Kumar et al. (2012): Land surface Verification Toolkit (LVT) – A generalized framework for land surface model evaluation. ***Geosci. Model. Dev.***

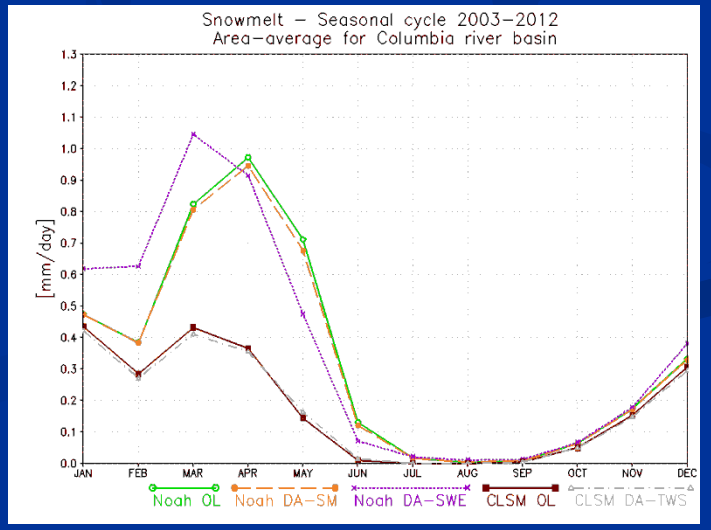
Water budgets for the new simulations



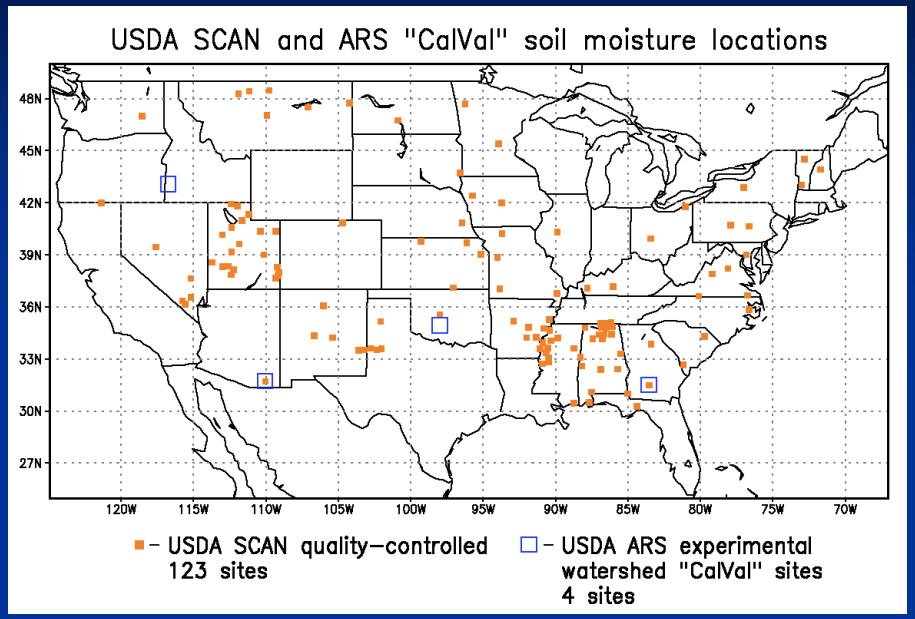








Evaluation of soil moisture fields



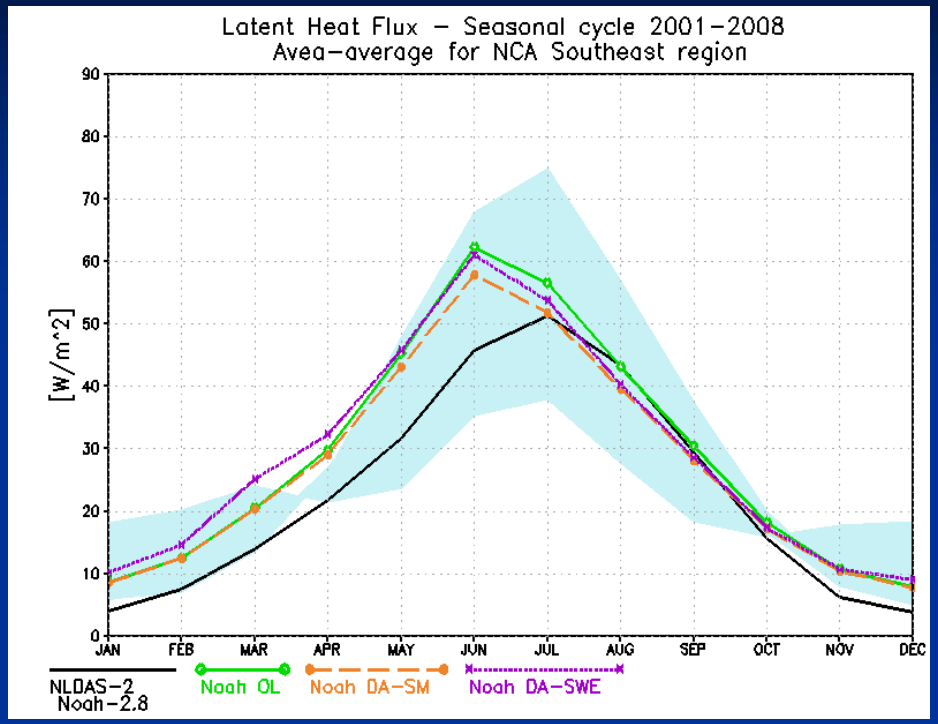
LSM (version)	ARS	SCAN
NLDAS-2 Noah-2.8	0.694	0.611 +/- 0.029
NLDAS-2 Mosaic	0.758	0.656 +/- 0.023
NLDAS-2 SAC	0.757	0.694 +/- 0.024
NLDAS-2 VIC-4.0.3	0.592	0.493 +/- 0.027
Noah-3.3 OL	0.733	0.667 +/- 0.025
Noah-3.3 DA SM	0.738	0.662 +/- 0.028
Noah-3.3 DA SWE	0.723	0.663 +/- 0.023
CLSM-F2.5 OL	0.637	0.513 +/- 0.031
CLSM-F2.5 DA TWS	0.679	0.550 +/- 0.028

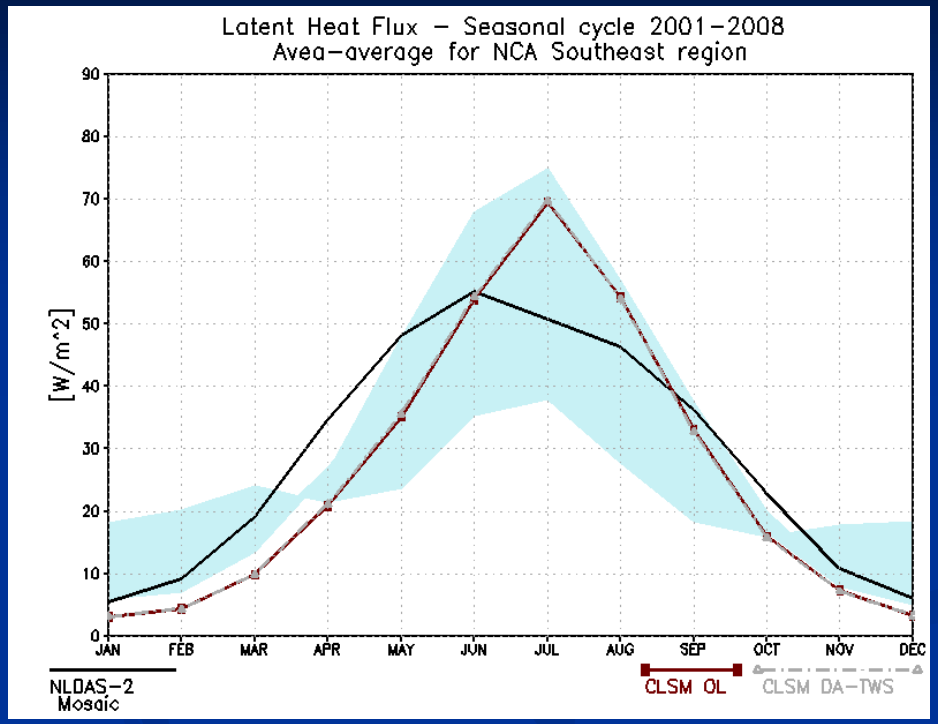
Anomaly R values

The surface soil moisture was evaluated against quality-controlled soil moisture observations at 5-cm depth from the USDA SCAN (123 sites) and ARS "CalVal" networks (4 sites). Noah-3.3 OL shows an improvement over NLDAS-2's Noah-2.8 for these sites. Noah-3.3 DA SM & DA SWE show small changes from the OL. CLSM-F2.5 OL has a lower R than Noah-3.3, but the DA of TWS from GRACE shows an improvement over the OL. Note that the top soil moisture level in Noah-3.3 is 10-cm, while in CLSM-F2.5 the top soil moisture level is 2-cm.

Reference(s): Jackson et al. (2012) – ARS – *IEEE TRGS*; Schaefer et al. – SCAN – *J. Atmos. Oceanic Technol.*; Liu et al. (2011) – soil moisture skill with land DA – *JHM*

Evaluation of gridded surface fluxes





Gridded monthly surface fluxes based on either FLUXNET surface observations (FLUXNET) or on MODIS retrievals (both MOD16 and UW ET) are used to evaluate the surface fluxes from the NLDAS-2 LSMs and the new simulations. Shown is the seasonal cycle for the **NCA Southeast** region for 2001-2008 of the gridded reference ET products, with the range of the three shown **in light blue**. The left panel shows the Noah-3.3 LSM with higher Qle in the spring compared to NLDAS-2's Noah-2.8, with an earlier peak of the seasonal cycle. DA of SM helps to reduce this peak. The right panel shows CLSM-F2.5 with a later peak compared to NLDAS-2's Mosaic.

Reference(s): Jung et al. (2009) – FLUXNET – *Biogeosci.*; Mu et al. (2011) – MOD16 – *Rem. Sens. Environ.*; Tang et al. (2009) – UW ET – *JGR*; Peters-Lidard et al. (2011) – ET evaluations

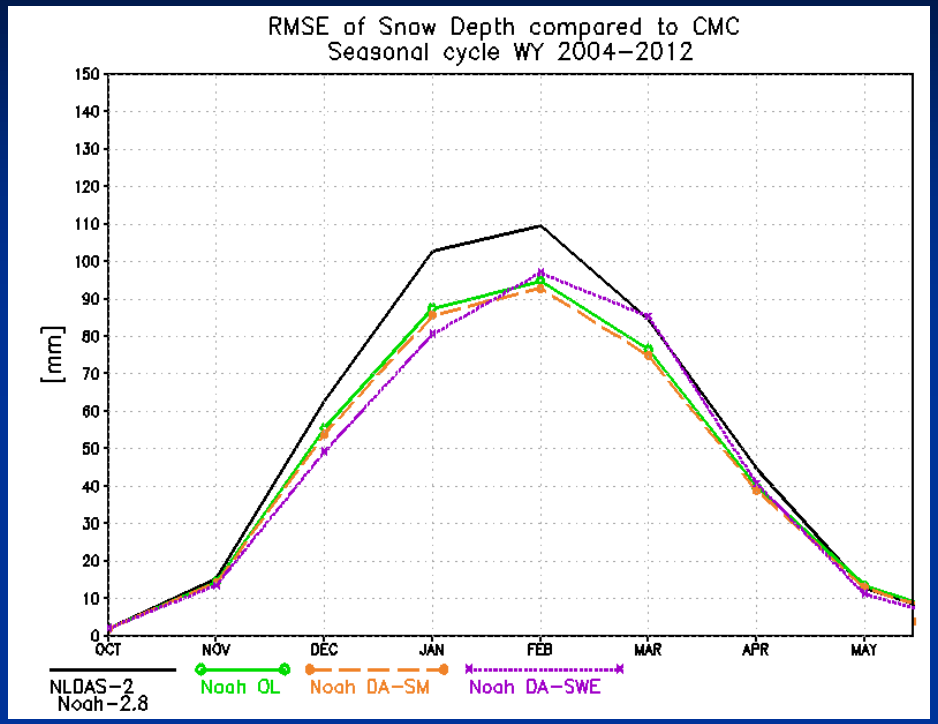
Evaluation of gridded surface fluxes

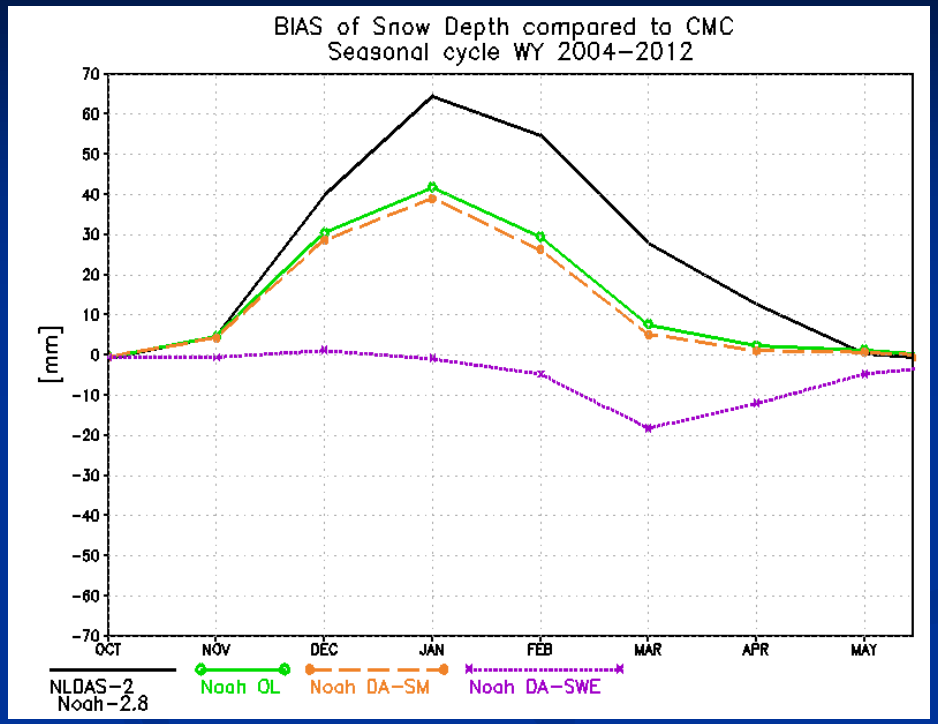
LSM (version)	FLUXNET Qh		FLUXNET Qle		MOD16 Qle		UW ET Qle	
[W/m^2]	Bias	RMSE	Bias	RMSE	Bias	RMSE	Bias	RMSE
NLDAS-2 Noah-2.8	7.5	21.5	-2.3	12.1	-3.1	17.6	-9.2	20.0
NLDAS-2 Mosaic	-3.2	22.0	11.0	20.6	10.1	22.0	4.0	24.3
NLDAS-2 VIC-4.0.3	4.7	23.6	-3.7	14.3	-4.5	18.9	-10.7	19.8
Noah-3.3 OL	3.0	21.2	10.0	18.4	9.2	18.7	3.0	21.6
Noah-3.3 DA SM	4.5	22.2	8.1	17.7	7.3	17.3	1.0	22.1
Noah-3.3 DA SWE	3.5	21.7	9.1	17.8	8.3	17.8	-1.1	21.8
CLSM-F2.5 OL	7.0	21.2	1.7	12.4	0.9	18.3	-5.2	15.5
CLSM-F2.5 DA TWS	6.9	21.1	1.6	12.2	0.7	18.2	-5.4	15.5

Shown in this table are summary bias and RMSE values for the entire CONUS domain, again for 2001-2008, for all months. Noah-3.3 OL has a high bias of Qle and higher RMSE as compared to NLDAS-2's Noah-2.8 (consistent with shown in Peters-Lidard et al., 2011). Both DA SM and DA SWE in Noah-3.3 generally help to reduce both bias and RMSE of Qle. CLSM-F2.5 LSM has lower Qle and tends to have the lowest RMSE, especially as compared to NLDAS-2's Mosaic. DA TWS has a very small effect to slightly reduce both bias and RMSE in CLSM-F2.5.

Reference(s): Jung et al. (2009) – FLUXNET – *Biogeosci.*; Mu et al. (2011) – MOD16 – *Rem. Sens. Environ.*; Tang et al. (2009) – UW ET – *JGR*; Peters-Lidard et al. (2011) – *Hydro. Proc.*

Evaluation of snow depth





Gridded snow depth observations/analyses are used to evaluate the simulated snow depths in NLDAS. The reference products are Canadian Meteorological Centre's (CMC) daily snow depth analysis, the NWS's NOHRSC SNOw Data Assimilation System (SNODAS), and the Global Historical Climatology Network (GHCN). These figures show a reduction in bias and RMSE from NLDAS-2's Noah-2.8 to Noah-3.3, using CMC as the reference for an average seasonal cycle of Water Years (WY) 2004-2012. SWE DA reduces the bias as well. CLSM-F2.5 (not shown) also has a significantly lower bias and RMSE when compared to NLDAS-2's Mosaic.

Reference(s): Menne et al. (2012) – GHCN – *J. Atmos. Oceanic Technol.*; Brown and Brasnett (2010) – CMC – *Environ. Canada*; Barrett (2009) – SNODAS – *NSIDC, Boulder, CO*

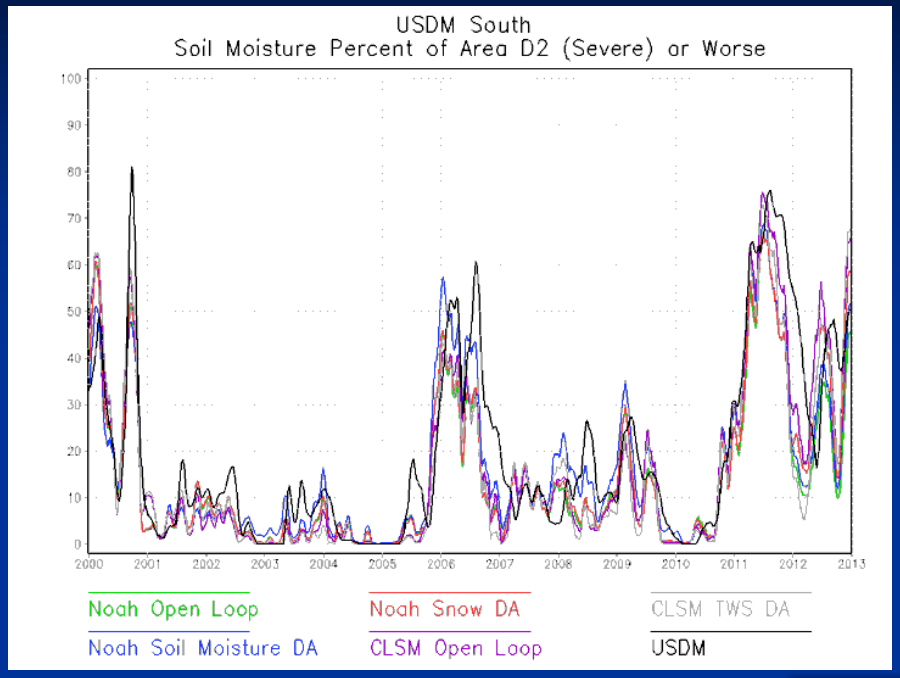
Evaluation of snow depth

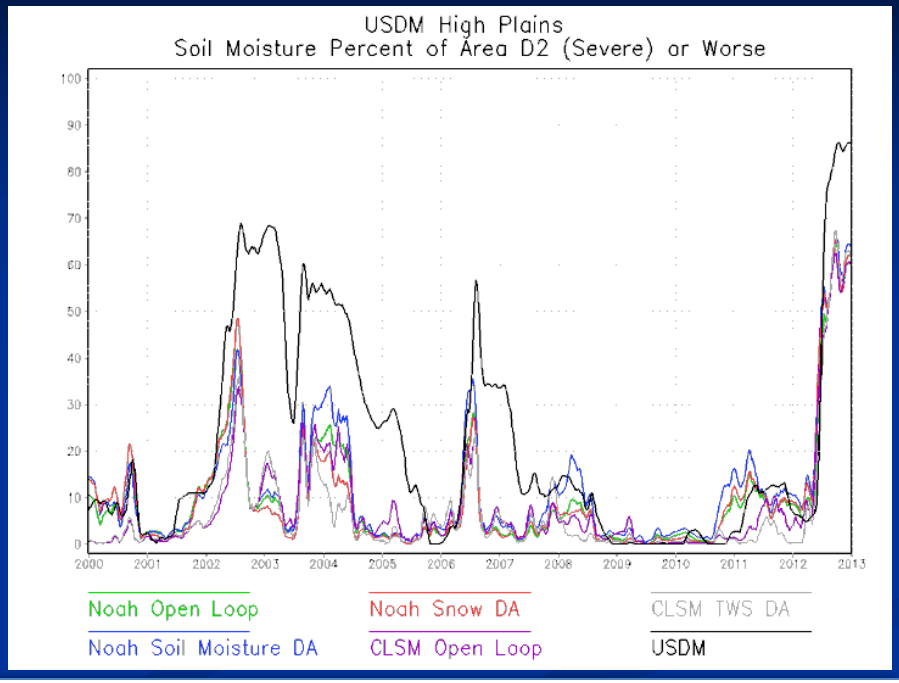
LSM (version)	CMC		GHCN		SNODAS	
[mm]	Bias	RMSE	Bias	RMSE	Bias	RMSE
NLDAS-2 Noah-2.8	29.0	60.3	-61.7	91.5	-30.1	56.8
NLDAS-2 Mosaic	106.9	132.8	-16.7	121.3	15.9	82.5
NLDAS-2 SAC	-68.1	69.2	-124.2	124.4	-81.4	82.1
Noah-3.3 OL	16.6	53.0	-69.8	88.6	-37.3	56.6
Noah-3.3 DA SM	14.9	51.8	-72.4	88.5	-39.3	57.0
Noah-3.3 DA SWE	-5.1	52.6	-59.8	75.1	-42.0	59.3
CLSM-F2.5 OL	-4.5	69.5	-35.5	85.6	-25.6	81.1
CLSM-F2.5 DA TWS	-4.4	69.3	-35.5	85.5	-25.7	81.2

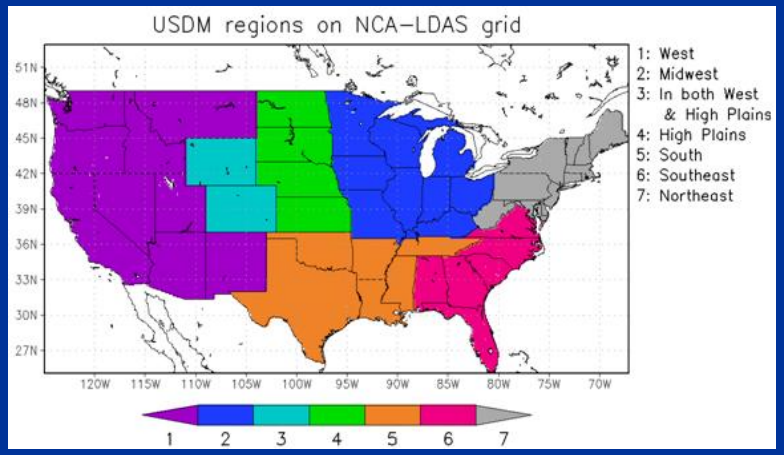
Shown in this table are summary bias and RMSE values independently against CMC, GHCN, and SNODAS averaged over the months of Oct-Apr for WY 2004-2012 for the entire NLDAS domain. Generally, lower bias and RMSE values are found with the new Noah-3.3 and CLSM-F2.5 simulations. Noah-3.3 DA SWE helps to primarily lower the Bias against the OL, with little change to RMSE. CLSM-F2.5 has lower bias and RMSE than NLDAS-2.5's Mosaic, with little changes from the addition of DA TWS.

Reference(s): Jung et al. (2009) – FLUXNET – *Biogeosci.*; Mu et al. (2011) – MOD16 – *Rem. Sens. Environ.*; Tang et al. (2009) – UW ET – *JGR*; Peters-Lidard et al. (2011) – *Hydro. Proc.*

Evaluation against USDM area extent







Since 2000, the U.S. Drought Monitor (USDM) has published weekly drought extent/severity maps. Using LVT, we can calculate percentiles over the NLDAS record, and then calculate the percentage of each USDM region undergoing different drought categories. These figures show weekly soil moisture percent area for the new simulations as compared to the USDM for drought category (D2) or worse.

Reference(s): Svoboda et al. (2002) – The Drought Monitor – *BAMS*;
Available at: http://droughtmonitor.unl.edu/

More NLDAS evaluation/development

- Please come to the Drought Analysis and Prediction session on Wednesday morning!
- Xia et al. (2014, JHM) developed an objective blended NLDAS drought index using multiple water balance variables (top 1-m and total soil moisture, ET, runoff, SWE, SPI, etc.)
- Kumar et al. (2014, submitted to JHM) show a detailed evaluation of the Noah-3.3 DA SM and DA SWE simulations, including an evaluation of routed streamflow and drought estimation
- Next steps for this work:
  - Finish adding VIC-4.1.2 and SAC-HTET-3.5.6/SNOW-17 into LIS and test with the effects of DA
  - Simultaneous DA of multiple water balance variables

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.
- LSMs from NLDAS Phase 2 and from the next phase of NLDAS were evaluated against observations using the Land Verification Toolkit (LVT). The effects of data assimilation of soil moisture, SWE, and TWS were also evaluated.
- Generally, data assimilation improves the simulation of surface fluxes, soil moisture, and snow depth in Noah-3.3 & CLSM-F2.5.
- Noah-3.3 has higher Qle than NLDAS-2's Noah-2.8 and is typically higher than the reference products; Anomaly R soil moisture is improved with Noah-3.3.
- The new NLDAS LSMs show improvements in snow depth.

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/
- LVT website at NASA:
  http://lis.gsfc.nasa.gov/LVT/