The North American Land Data Assimilation System (NLDAS) Science Testbed: An Environment for the Systematic Evaluation and Benchmarking of NLDAS Outputs

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Poster 97

NLDAS Description and Forcing Data Generation

NLDAS Phase 2 is run operationally with a daily update (3.5-day lag) by NOAA/NCEP:
- 37-years (from January 1979 to present), with hourly and monthly datasets available
- 1/8th-degree surface meteorology and hydrology dataset over CONUS (25-53 North)
- Most of the forcing fields are derived from NARR, with an elevation lapse-rate adjust.
- CPC daily gauge precipitation analysis is temporally disaggregated into hourly using Stage II radar precipitation estimates (or other sources, if the radar is not available)
- The SW downward radiation is bias-corrected using a GOES climatology.
- The NLDAS-2 forcing drives four (4) LSMs: Noah, Mosaic, VIC, and SAC
- NLDAS Drought Monitor webpage is updated daily. NLDAS datasets are available.

Land Information System (LIS) and Land Verification Toolkit (LVT)

NASA's LIS software framework (Fig. 1, left) includes many LSMs (Fig. 2, below), and will be used for new/upgraded model versions for the next phase of NLDAS. LIS also allows the data assimilation of satellite-based observations to improve modeled states/fluxes. LVT (Fig. 3, right) is designed for evaluation and benchmarking of LIS outputs and multiple observation datasets (in situ, remotely-sensed, model/reanalysis).

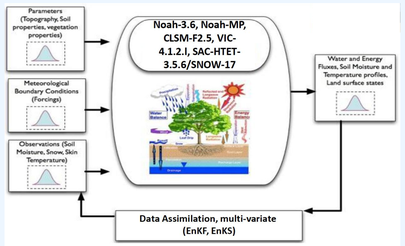


Figure 1 (left): Land Information System (LIS) software framework for the next phase of NLDAS

Figure 3 (right): Land Verification Toolkit (LVT)

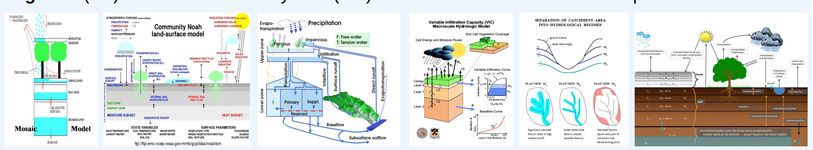
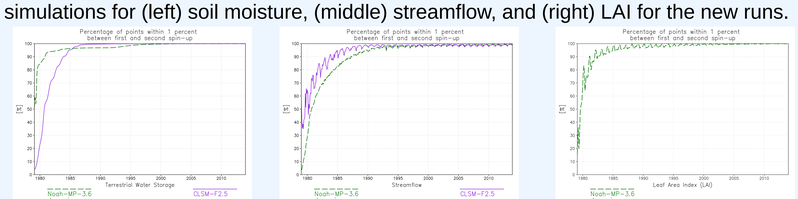


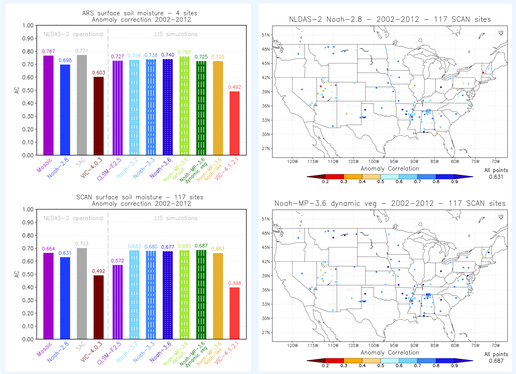
Figure 2: Schematics of the NLDAS-2 LSMs (four left panels) and new LSMs (two right panels)

Experimental Design and Spin-up

The new/upgraded LSMs were simulated in LIS using the NLDAS Phase 2 forcing for a 35-year period (1979-2013). Two passes were performed, for a total of 70 years of spin-up, before a third 35-year simulation to be compared against the NLDAS-2 LSMs and against observations. No data assimilation was performed for the runs in this study. LVT was used to perform the evaluations over an 11-year period (2002-2012) with multiple high-quality observations of water and energy balance observations. **Figure 4** shows the percentage of points in the NLDAS domain within 1% between the 1st and 2nd spin-up simulations for (left) soil moisture, (middle) streamflow, and (right) LAI for the new runs.

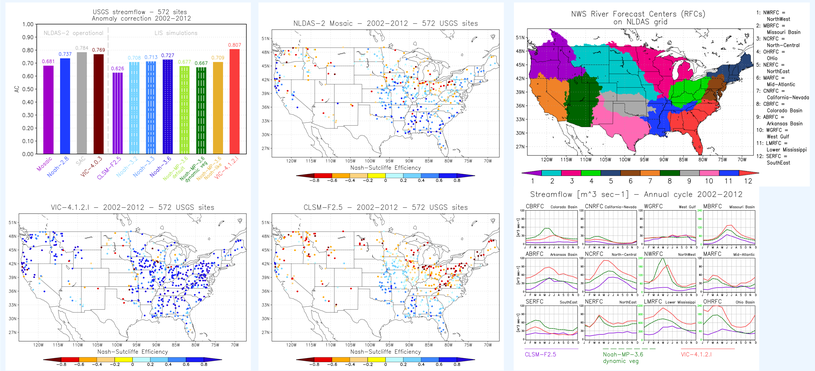


Evaluation against in situ soil moisture (SCAN and ARS)



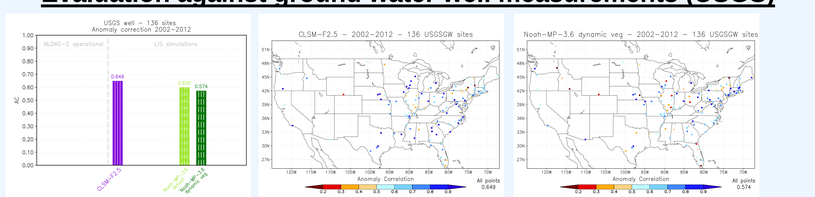
Evaluations were done against in situ quality-controlled surface soil moisture USDA SCAN and ARS networks. The bar graphs show anomaly correlations for all LSMs. The example maps show lower skills in mountain areas where the precipitation quality is lower. Later versions of Noah and Noah-MP LSMs show some improvements over NLDAS-2, while CLSM-F2.5 and VIC-4.1.2.l have lower AC values compared to NLDAS-2 Mosaic and VIC-4.0.3 LSMs.

Evaluation against small streamflow gauges (USGS)



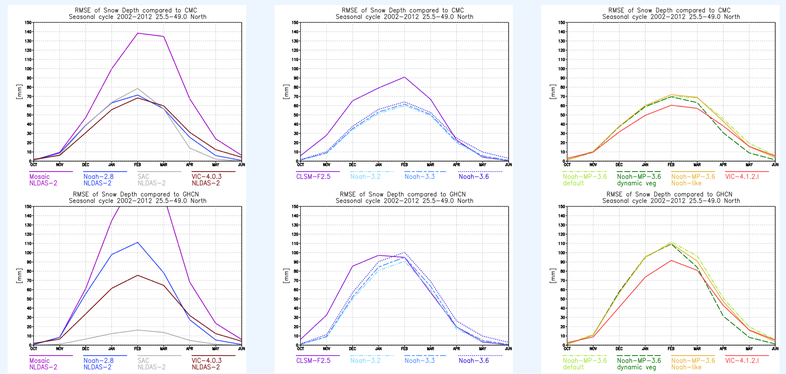
The HyMAP router in LIS was used to route modeled runoff into streamflow in the new LSMs. The NLDAS-2 LSMs used the NLDAS router. Evaluations were made against 572 small unregulated USGS streamflow gauges with monthly comparisons. VIC-4.1.2.l has a high AC (upper left), with many sites (bottom left) also having a high Nash-Sutcliffe Efficiency (NSE). CLSM-F2.5 has lower AC and NSE compared to NLDAS-2 Mosaic (upper/bottom middle), particularly over the Ohio Basin. The annual cycle of streamflow for NWS RFCs (upper right) is shown in the bottom right. CLSM-F2.5 has low streamflow in many eastern basins, while VIC-4.1.2.l tends to have higher streamflow in these areas.

Evaluation against ground water well measurements (USGS)



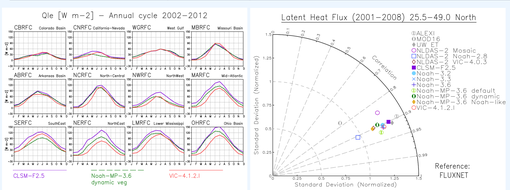
The new LSMs in LIS of CLSM-F2.5 and Noah-MP also now simulate ground water. The LSMs compare favorably to USGS well depth measurements. CLSM-F2.5 does well in the Southeast and Midwest regions, while Noah-MP does better in the Northeast region.

Evaluation against gridded snow depth (CMC and GHCN)



Evaluations were made against gridded snow depth products from CMC, an analysis/model product (top row), and SNODAS, based on in situ measurements (bottom row). The (left) panels show monthly-averaged RMSEs of the seasonal cycle from NLDAS-2 LSMs; (middle) CLSM-F2.5 and the Noah LSMs; (right) VIC-4.1.2.l and the Noah-MP-3.6 versions. Some small improvements in RMSE is found in the Noah LSMs, and VIC-4.1.2.l is improved only when compared to CMC. Biases (not shown) show some moderate improvements in the new LSMs over the NLDAS-2 LSMs. Regionally, the CLSM-F2.5 has low spring snow depth/SWE in some locations, contributing to lower runoff/streamflow.

Evaluation against gridded surface fluxes (FLUXNET and others)



(Far left) annual cycle of Qle for the new LSMs for NWS RFCs; (Left) Taylor diagram for a common observation period (2001-2008) using FLUXNET as a reference product. ALEXI, MOD16, & UWET also included.

Evaluations were made against latent (Qle) and sensible (Qh) heat fluxes from a gridded product based on FLUXNET towers, and also of Qle from ALEXI retrievals based on thermal remote sensing, and of Qle from the MOD16 and the Univ. Washington products based on MODIS. The Qle in CLSM-F2.5 is on the higher end, particularly in the east. Some minor improvements in Qle in the newer LSMs can be seen in the Taylor diagram.

Summary and Future Work

New/upgraded LSMs in the NASA Land Information System (LIS) were simulated with NLDAS-2 forcing and evaluated against NLDAS-2 LSM outputs and observations using the Land surface Verification Toolkit (LVT). Overall, the new LSMs perform as well as, or show some improvements over, the NLDAS-2 LSMs, although additional model tuning/refinement will also be needed. Several model performance deficiencies were noted in the evaluations. Data assimilation of remotely-sensed soil moisture, snow cover/area, and TWS products using LIS will also be evaluated in the new LSMs. The benchmarking capability in LVT will be used to train a regression model in LIS using NLDAS-2 forcing, to evaluate against the advanced physics of the LSMs, both with and w/o data assimilation.

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