NASA LIS-based NLDAS status and future plans

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Current LIS (version 7) configuration

- **Land Data Toolkit (LDT)**: handles all the LSM (e.g., parameters) and data assimilation pre-processing needs of LIS.
- **Land Information System (LIS)**: provides a comprehensive modeling and data assimilation environment.
- **Land Verification Toolkit (LVT)**: provides a comprehensive environment for model evaluation and data analysis.

* NOTE: LIS version 7 requires LDT processed inputs before its run-time execution ...

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

LIS-based next phase of NLDAS

1979 – Present
NLDAS-2
Forcings and Parameters

Satellite EDRs*
SM, SCA, SWE, TWS, LST, and II

Noah-3.3, CLSM-F2.5,
VIC-4.1.2.1, SAC-HTET-
3.5.6/SNOW-17

Data Assimilation, multi-variate
(EnKF, EnKS)

Water and Energy
Fluxes, Soil Moisture and
Temperature profiles, Land
surface states

Parameters
(Topography, Soil
properties, vegetation
properties)

Meteorological
Boundary Conditions
(Forcings)

Observations
(Soil Moisture, Snow, Skin
Temperature)

* Satellite-based Environmental Data Records (EDRs): soil moisture (SM), snow-covered area (SCA), snow water equivalent (SWE), terrestrial water storage (TWS), land surface temperature (LST), and irrigation intensity (II)
Land surface models

**Noah-3.3** (including warm season updates as well as snow-physics upgrades), **Noah-3.6** (Univ. Arizona’s snow-physics option), and **Noah-MP**

Soil moisture, snow DA tested for Noah-3.3 and Noah-3.6

**CLSM-F2.5** (Fortuna-2.5) version (same version used in MERRA-Land)

Soil moisture, snow, and TWS DA tested for CLSM-F2.5

**VIC-4.1.2.1** (numerous fixes and upgrades, including to soil temperatures)

VIC is computationally more intensive compared to Noah/CLSM. No DA implementation yet.

**SAC-HTET-3.5.6** (RDHM-3.5.6) includes updates to the treatment of heat and to vegetation effects. Coupled to SNOW-17.

Still working on the full implementation and support of NLDAS parameters. No DA implementation yet.

Reference(s): Chen et al. (1996, JGR); Ek et al. (2003, JGR); Wei et al. (2012, HP); Livneh et al. (2010, JHM)
## Next phase of LIS-NLDAS status

<table>
<thead>
<tr>
<th>LSM</th>
<th>In LIS-7</th>
<th>Parameters in LDT</th>
<th>Configured for DA</th>
<th>Time to run 1 year in the NLDAS domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noah-3.3/3.6</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>1 hr, 20 mins</td>
</tr>
<tr>
<td>CLSM-F2.5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>1 hr, 18 mins</td>
</tr>
<tr>
<td>VIC-4.1.2.l</td>
<td>Yes</td>
<td>No Read NLDAS-VIC pars</td>
<td>No</td>
<td>7 hrs, 45 mins</td>
</tr>
<tr>
<td>SAC-HTET-3.5.6</td>
<td>Yes</td>
<td>No Need to implement Victor Koren’s code for parameters based on soil textures in LDT</td>
<td>No</td>
<td>TBD</td>
</tr>
<tr>
<td>Noah-MP-3.6.1</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>TBD, although should be similar to Noah-3.3/3.6</td>
</tr>
</tbody>
</table>

“Time to Run” is average time to run one calendar year of simulation on the NASA/GSFC NCCS’s Discover platform, using 240 processors. Noah and CLSM were run with a 15-minute timestep, and VIC was run with a 1-hour timestep. VIC is slower in winter due to frozen soil calculations.
LIS-NLDAS routing status

- LIS is configured (in the NLDAS domain) to be able to run either the NLDAS router or the HyMAP router (Getirana et al., 2012, 2013)

The Hydrological Modeling and Analysis Platform (HyMAP):

- Global scale;
- Adjustable spatial and temporal resolutions;
- Composed of four modules accounting for:
  1. surface runoff and baseflow time delays;
  2. a river-floodplain interface;
  3. flow routing in river channels and floodplains; and
  4. evaporation from open water surfaces.

Model outputs:
- Water volume stored in rivers and floodplains;
- Water depth of rivers and floodplains;
- Streamflows in rivers and floodplains;
- Flow velocity in rivers and floodplains;
- Flooded area;
- Evaporation from open water surfaces.
Noah-3.3 + NLDAS

HyMAP router compared against NLDAS router

<table>
<thead>
<tr>
<th>Location</th>
<th>HYMAP</th>
<th>NLDAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>NS = 0.77, r = 0.92, RE = -0.20, DI = 0</td>
<td>NS = 0.83, r = 0.94, RE = -0.15, DI = 0</td>
</tr>
<tr>
<td>Potomac</td>
<td>NS = 0.21, r = 0.78, RE = -0.55, DI = 0</td>
<td>NS = 0.24, r = 0.76, RE = -0.52, DI = 1</td>
</tr>
<tr>
<td>Apalachicola</td>
<td>NS = 0.65, r = 0.93, RE = -0.16, DI = 0</td>
<td>NS = 0.65, r = 0.94, RE = -0.16, DI = 0</td>
</tr>
<tr>
<td>Ohio</td>
<td>NS = 0.32, r = 0.82, RE = -0.39, DI = 0</td>
<td>NS = 0.35, r = 0.87, RE = -0.41, DI = 0</td>
</tr>
</tbody>
</table>
Vision for data assimilation within NLDAS

NLDAS to-date, has not included the assimilation of remote sensing datasets. The focus of the new phase of NLDAS is to enable the “DA” in NLDAS.

As part of this new phase of NLDAS, we examine the assimilation of various terrestrial hydrological datasets, from 1979 onwards.
**Chronology of land remote sensing datasets**

**Data assimilation method:**
1-d Ensemble Kalman Filter (EnKF) and 3-d Ensemble Kalman Smoother (EnKS)

**Time period:** Jan 1, 1979 to 1 Jan 2013.

All simulations performed using the NASA Land Information System (LIS; http://lis.gsfc.nasa.gov)
Univariate assimilation: soil moisture and snow depth

A recent study examined the individual assimilation of soil moisture (ECV, LPRM) and snow (SMMR, SSMI, AMSR-E) data sets, into the Noah LSM (Kumar et al., JHM 2014).

The open loop soil moisture skills are high and assimilation improvements in soil moisture were small and barely at the statistically significant levels.

The assimilation of snow depth datasets were found to generally improve the snow fields.

Evaluation of streamflow

The improvements are expressed using an Normalized Information Contribution (NIC) metric that measures the skill improvement from DA as a fraction of the maximum possible skill improvement

\[ NIC_{NSE} = \frac{NSE_a - NSE_o}{1 - NSE_o} \]

Minor improvements are observed in streamflow estimates with soil moisture data assimilation. Snow DA indicates a slight overall degradation.

Skill improvements from soil moisture assimilation are mostly over parts of the Mississippi, Missouri, and Arkansas-Red basins and parts of Southeastern U.S. Notable degradations due to snow DA are observed over Colorado headwater region and over Northwest U.S.
Snow DA approach was updated to use visible snow cover data (IMS/MODIS) as an added constraint. SCA observations are used as the default for identifying the presence or absence of snow. If SCA indicates no-snow, zero snow depth is assimilated. If SCA indicates non-zero snow and passive microwave data indicates no-snow, then snow depth data is not assimilated. Non-zero snow depth from passive microwave data is assimilated only if SCA data also indicates non-zero snow.

The use of SCA data is helpful in providing added improvements to the passive microwave snow data assimilation.

Assimilation (univariate) of GRACE data

Maps show Anomaly R differences – Anomaly R(DA) – Anomaly R (OL); Warm colors indicate improvements and cool colors indicate degradations.

<table>
<thead>
<tr>
<th>Anomaly R</th>
<th>OL</th>
<th>DA-TWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground water</td>
<td>0.64 +/- 0.02</td>
<td>0.69 +/- 0.02</td>
</tr>
<tr>
<td>Surface soil moisture</td>
<td>0.44 +/- 0.02</td>
<td>0.58 +/- 0.02</td>
</tr>
<tr>
<td>Root zone soil moisture</td>
<td>0.48 +/- 0.02</td>
<td>0.54 +/- 0.02</td>
</tr>
</tbody>
</table>

Statistically significant improvements in ground water and soil moisture fields from GRACE data assimilation

Multivariate assimilation

Noah (soil moisture, snow depth, snow cover, irrigation)
CLSM (soil moisture, snow depth, snow cover, irrigation, terrestrial water storage)

Maps show Anomaly R differences – Anomaly R(DA) – Anomaly R (OL) (using SCAN data as reference); Warm colors indicate improvements and cool colors indicate degradations.

<table>
<thead>
<tr>
<th>Anomaly R</th>
<th>Surface soil moisture</th>
<th>Root zone soil moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noah OL</td>
<td>0.60</td>
<td>0.55</td>
</tr>
<tr>
<td>Noah DA</td>
<td>0.65</td>
<td>0.55</td>
</tr>
<tr>
<td>CLSM OL</td>
<td>0.43</td>
<td>0.48</td>
</tr>
<tr>
<td>CLSM DA</td>
<td>0.61</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Noah – improvements in soil moisture fields are small, some degradation in the western locations observed

CLSM – more significant improvements in both surface and root zone fields
LIS-NLDAS plans

• Transfer LIS7 to Youlong and others at EMC

• Complete SAC-HTET parameters and Noah-MP (configuration TBD)

• NLDAS Benchmarking system using LVT

• Perform probabilistic drought analysis with LIS7-UE

• Add NCAR’S latest CLM model

• Test new satellite products/radiances for data assimilation (SMAP, IMS, AMSR-2, etc.)