The North American Land Data Assimilation System (NLDAS): 30+ Years of Meteorological and Land Surface Fluxes and States

Kristi R. Arsenault[1,3],
David M. Mocko[1,3], Christa D. Peters-Lidard[1], Sujay V. Kumar[1,3], Youlong Xia[2,4], Michael Ek[2], Jiarui Dong[2,4], Hualan Rui[5,6]

1 – Hydrological Sciences Laboratory, NASA/GSFC, Greenbelt, MD
2 – NOAA/NCEP/EMC, College Park, MD
3 – SAIC, Beltsville, MD; 4 – IMSG, Rockville, MD;
5 -- GES DISC, NASA/GSFC, Greenbelt, MD; 6 – ADNET, Lanham, MD
Presentation Outline

- Introduction of the North American Land Data Assimilation System-Phase 2 (NLDAS-2) datasets
  - An example of meeting hydrological and meteorological information needs in a mutually consistent way.

- Assimilation of Hydrological and Meteorological Observations for NLDAS-2 (via LIS)
  - Improving model states and fluxes by blending best of both model and observations (aka, the “analysis” data)

- Serving the information needs of the hydrologic and meteorological communities
  - Providing the NLDAS-2 datasets to the meteorological and hydrologic communities via the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)
Focus question to be addressed …

- How do we serve the information needs of the hydrologic and meteorological communities in a mutually consistent way?

- How can the NLDAS-2 datasets address this question and need … :
  - Combines the best knowledge of long-term model- and observation-based hydro-meteorological datasets,
  - Provides these hydrological and meteorological based fields on a common grid with a relatively high resolution, of the same format (e.g., grib-1) and timestep (1-hour).
NLDAS-2 Land Surface Forcing Background

- Hourly and on an 1/8\(^{th}\) deg. resolution CONUS domain, including parts of Canada/Mexico (25-53 °N; 125-67 °W)

- The NLDAS-2 land surface forcing dataset is a combination of both model and observations

- The model-based fields are derived from the NCEP North American Regional Reanalysis (NARR) analysis fields:
  - NARR surface data used as base (3 hourly, 32km, Jan 1979 – present)
  - Elevation correction for temperature, pressure, humidity, and longwave
  - Includes 21 standard surface/2m/10m and lowest model layer forcing fields

- NARR also has a real-time continuation product known as the Regional Climate Data Assimilation System (R-CDAS), which contributes the base fields from 2003-present.
The observation fields used as part of NLDAS-2 include:

- NARR’s surface-based downward shortwave radiation (SWdown) is bias-corrected using GOES UMD SRB SW data
- Hourly NLDAS precipitation based on CPC daily PRISM-corrected gauge data, hourly Stage II Doppler radar data, half-hourly CMORPH, hourly HPD data, and 3-hourly NARR model data (depending on location and availability)

List of Earth Observations in the NLDAS-2 forcing along with coverage dates and temporal and spatial resolutions of the data:

<table>
<thead>
<tr>
<th>Forcing</th>
<th>Coverage</th>
<th>Temporal Resolution</th>
<th>Spatial Resolution</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARR Model</td>
<td>1979-2003</td>
<td>3 Hourly</td>
<td>32km</td>
<td></td>
</tr>
<tr>
<td>R-CDAS Model</td>
<td>2003-Present</td>
<td>3 Hourly</td>
<td>32km</td>
<td>Realtime version of NARR</td>
</tr>
<tr>
<td>GOES Radiation</td>
<td>1996-2000</td>
<td>Hourly</td>
<td>1/8th degree</td>
<td>Used to bias correct NARR</td>
</tr>
<tr>
<td>CPC PRISM Gauge</td>
<td>1979-Present</td>
<td>Daily</td>
<td>1/8th degree</td>
<td>Used over CONUS, Mexico</td>
</tr>
<tr>
<td>CPC Gauge</td>
<td>1979-Present</td>
<td>Hourly</td>
<td>2 X 2.5 degree</td>
<td>Used over CONUS</td>
</tr>
<tr>
<td>CMORPH Precip</td>
<td>2002-Present</td>
<td>1/2 Hourly</td>
<td>8km</td>
<td>Used over CONUS, Mexico</td>
</tr>
<tr>
<td>Stage II Precip</td>
<td>1996-Present</td>
<td>Hourly</td>
<td>4km</td>
<td>Used over CONUS</td>
</tr>
</tbody>
</table>
## Generation of NLDAS-2 precipitation

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Years</th>
<th>CONUS</th>
<th>Mexico</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPC daily gauge analysis</td>
<td>1979 – present</td>
<td>1/8&lt;sup&gt;th&lt;/sup&gt;-degree PRISM-adjusted analysis</td>
<td>1/4&lt;sup&gt;th&lt;/sup&gt;-degree (before 2001, 1-degree) analysis</td>
<td>Not used</td>
</tr>
<tr>
<td>Stage II Doppler hourly 4-km radar data</td>
<td>1996 – present</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; choice to temporally disaggregate</td>
<td>Not used</td>
<td>Not used</td>
</tr>
<tr>
<td>CMORPH satellite-retrieved half-hourly 8-km analysis</td>
<td>2002 – present</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; choice to temporally disaggregate</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; choice to temporally disaggregate</td>
<td>Not used</td>
</tr>
<tr>
<td>CPC HPD 2x2.5-degree hourly analysis</td>
<td>1979 – present</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; choice to temporally disaggregate</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; choice to temporally disaggregate</td>
<td>Not used</td>
</tr>
<tr>
<td>NARR/R-CDAS 3-hourly 32km model-simulated precipitation</td>
<td>1979 – present</td>
<td>4&lt;sup&gt;th&lt;/sup&gt; choice to temporally disaggregate</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; choice to temporally disaggregate</td>
<td>Used for all precip over Canada areas; a 1-degree blend near U.S.-Canada border is done.</td>
</tr>
</tbody>
</table>
Matsui et al. (2010; GRL) examined the diurnal cycle of summertime precipitation in NLDAS over CONUS. Zonal phase speeds of the precipitation were estimated and compared to background zonal wind speeds from the MERRA reanalysis.
NLDAS-2 Land Surface Model (LSM) Reanalysis Datasets

- NLDAS-2 forcing is used to drive a suite of LSMs from the meteorological (Noah and Mosaic) and hydrology (Sacramento and VIC) communities.

- These models utilize selected common parameters, like:
  - Land mask/cover datasets from AVHRR and MODIS
  - Monthly albedo, greenness, and LAI/SAI climatologies
  - STATSGO (for CONUS) and FAO (outside CONUS) soil info
  - GTOPO-30 ~1-km elevation dataset

- 30-year output from these NLDAS-based models have been and will be provided to the hydrologic and meteorological communities
Evaluating NLDAS-2 LSM Results

- (1) Top 2m soil moisture and (2) runoff anomalies for both the 1988 drought (left panels) and 1993 wet (right panels) years for the four NLDAS LSMs

Xia et al. (2012): Part 1, JGR-Atmos.
Streamflow Comparisons

- Correlation coefficients between mean observed and simulated streamflow anomalies for the four models and their multi-model ensemble mean (EM) for years, 1979-2008

- Top figure: For monthly means (961 basins)

- Bottom figure: For daily means for 8 major U.S. river basins

Xia et al. (2012): Part 2, JGR-Atmos.
NLDAS-2 model data are also used in a near-real-time drought monitor (with anomalies/percentiles against the entire NLDAS data archive). Examples of (1) soil moisture percentiles and (2) streamflow anomalies from the NLDAS Drought Monitor is shown to the right.

Anomaly climatology maps contain 1 value per day (daily average over 28 years) for each gridbox. The percentile climatology maps contain 140 soil moisture values per day (5 for each year) for each gridbox.
Next NLDAS-Phase (III):
Benchmarking latest LSM versions and improving NLDAS reanalysis data with assimilating land surface observations

Observation examples include:
-- SWE, SCA, and soil moisture from MODIS/AMSR-e;
-- GRACE-based terrestrial water storage;
-- MODIS irrigation

→ Using NASA’s Land Information System (LIS)
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 observational data products with land-surface models.

- LIS can use different LSMs, forcings, parameter datasets, observations, and includes modules for data assimilation and parameter optimization techniques.

- In addition to being run in an offline/uncoupled mode, LIS can also run coupled to the WRF forecast model.
The LIS framework will allow data assimilation (DA) of soil moisture and snow products to help improve drought diagnosis using NLDAS.

Parameters and satellite sensor data being used:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Spatial Resolution</th>
<th>Satellite Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow covered area (SCA)</td>
<td>500 m</td>
<td>Terra/Aqua MODIS</td>
</tr>
<tr>
<td>Snow water equivalent</td>
<td>25-km</td>
<td>Aqua AMSR-E</td>
</tr>
<tr>
<td>SCA &amp; SWE</td>
<td>25-km</td>
<td>ANSA</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>25-km</td>
<td>Aqua AMSR-E</td>
</tr>
</tbody>
</table>

Shown next: Some benefits of assimilating these observations into the LSMs using LIS.
Soil moisture data assimilation to improve ET

How does soil moisture (SM) data assimilation improve evapotranspiration (ET) estimation?

Assimilation of LPRM retrievals of AMSR-E soil moisture into the Noah LSM

The ET estimates are compared against FLUXNET and MODIS-based reference datasets

Panels (right) show seasonally averaged improvement metrics,

$$\text{(RMSE(no DA) – RMSE (SM DA))}$$

<table>
<thead>
<tr>
<th></th>
<th>FLUXNET (W m⁻²)</th>
<th>MOD16 (W m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE</td>
<td>Bias</td>
</tr>
<tr>
<td>Open-loop</td>
<td>27.6 ± 0.3</td>
<td>12.9 ± 0.4</td>
</tr>
<tr>
<td>LPRM DA</td>
<td>25.6 ± 0.3</td>
<td>10.9 ± 0.3</td>
</tr>
</tbody>
</table>

Evaluating Snow Assimilation Results

- Non-assimilated open-loop (“OL”) simulations compared with assimilated (“SNOWDA”) and observations (“CMC”), which are included for an independent evaluation of the simulations.

- Validation performed with the U. S. NOAA/NWS COOP stations

<table>
<thead>
<tr>
<th></th>
<th>RMSE(mm)</th>
<th>Bias (mm)</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>OL</td>
<td>212 ± 10.7</td>
<td>-130.0 ± 11</td>
<td>0.63 ± 0.01</td>
</tr>
<tr>
<td>CMC</td>
<td>197 ± 8.0</td>
<td>-85.9 ± 8.0</td>
<td>0.70 ± 0.01</td>
</tr>
<tr>
<td>SNOWDA</td>
<td>152 ± 8.5</td>
<td>-77.6 ± 8.19</td>
<td>0.77 ± 0.01</td>
</tr>
</tbody>
</table>
NLDAS Snow DA ~ Streamflow evaluation
(Using Xia et al. (2011) stations)

RMSE (m³/s)

BIAS (m³/s)

RMSE and bias errors are reduced systematically with data assimilation
Providing NLDAS-2 Datasets and Evaluations to the Hydrological and Meteorological

Main data web services:

-- NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)
-- NOAA/EMC/NLDAS Web pages
-- CUAHSI Hydrologic Information Services
NLDAS data/services at the GES DISC

- Hydrology DISC (HDISC)
  http://disc.gsfc.nasa.gov/hydrology/
- GrADS Data Server (GDS)
  http://hydro1.sci.gsfc.nasa.gov/dods/

32+ years of hourly NLDAS datasets available at the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)

Data is available via 4 methods: 1) Mirador searching, subsetting, and downloading; 2) Giovanni online visualization and analysis; 3) anonymous ftp, and 4) a GDS. Currently, NLDAS-1 forcing as well as NLDAS-2 forcing and Mosaic and Noah model output datasets are available.
LDAS Datasets Added to CUAHSI

The GES DISC has integrated NLDAS & GLDAS data into the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS):

- A Web Service that provides the data as a time series along with corresponding metadata in WaterML
- Schematic on left shows data access using the CUAHSI HIS client HydroDesktop; the data can be searched, retrieved, and analyzed along with hydrological data from other sources available via HIS.

1 Courtesy NASA Goddard Earth Sciences Data and Information Services Center and Hydrological Sciences Branch
2 NLDAS (North American Land Data Assimilation System) is a collaboration among NOAA, NASA, Princeton Univ., Univ. of Washington, and others.
Summary

- NLDAS is a successful collaboration project that has produced over 32 years of hourly 1/8th-degree surface forcing and land-surface model output over CONUS and parts of Canada/Mexico.

- NLDAS integrates many different Earth Observations in the creation of the surface forcing as well as in the LSMs to produce model output of soil moisture, evaporation, snow pack, runoff, and surface fluxes.

- The next NLDAS phase includes upgraded LSMs as well as data assimilation of soil moisture and snow products towards improved diagnosis of drought and initial conditions for forecasts.

- The NASA GES DISC provides many NLDAS datasets/services; NLDAS/GLDAS datasets now available at CUAHSI HIS.
Acknowledgements

- The hourly NLDAS-2 land surface forcing dataset
  - Brian Cosgrove, Charles Alonge, Youlong Xia, Michael Ek, Kenneth Mitchell, Kingtse Mo, Yun Fan, and the NLDAS team

- Assimilation of Hydrological and Meteorological Observations in NLDAS (via LIS)
  - David Mocko, Christa Peters-Lidard, Sujay Kumar, Youlong Xia, Michael Ek, and Jiarui Dong

- NLDAS dataset availability and services provided by the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC)
  - Hualan Rui, Bill Teng, Guang-Dih Lei, Bruce Vollmer, and David Mocko
  - Collaborations with AquaTerra and CUAHSI
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/