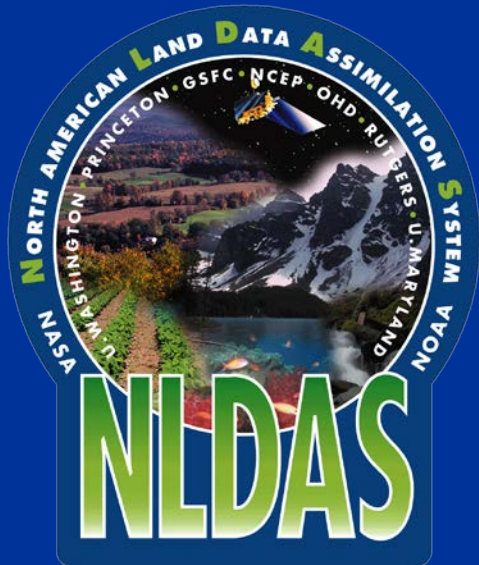# The North American Land Data Assimilation System (NLDAS):
30+ Years of Meteorological and Land Surface Fluxes and States

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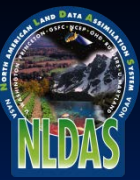
David M. Mocko[1,3], Christa D. Peters-Lidard[1],
Sujay V. Kumar[1,3], Youlong Xia[2,4], Michael Ek[2],
Jiarui Dong[2,4], Hualan Rui[5,6]

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)
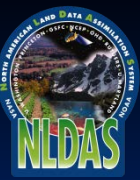
Focus question to be addressed …

- **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).
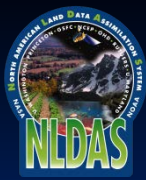
NLDAS-2 Land Surface Forcing Background

- Hourly and on an 1/8th 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.
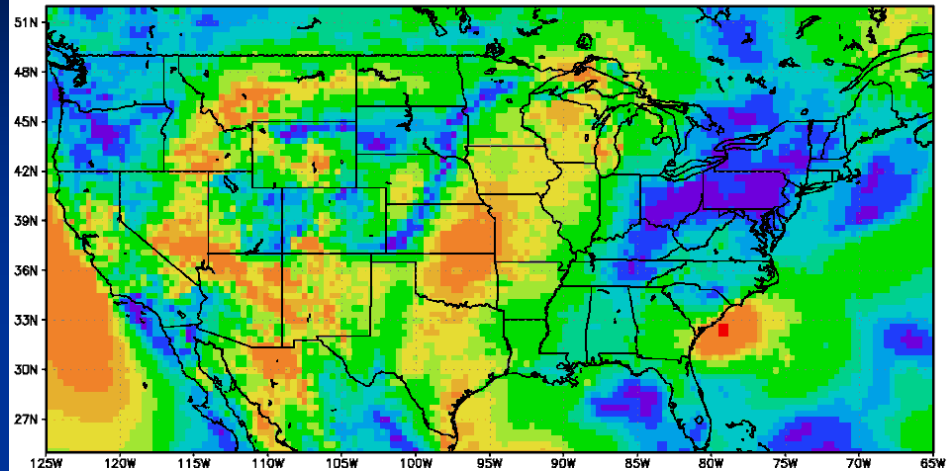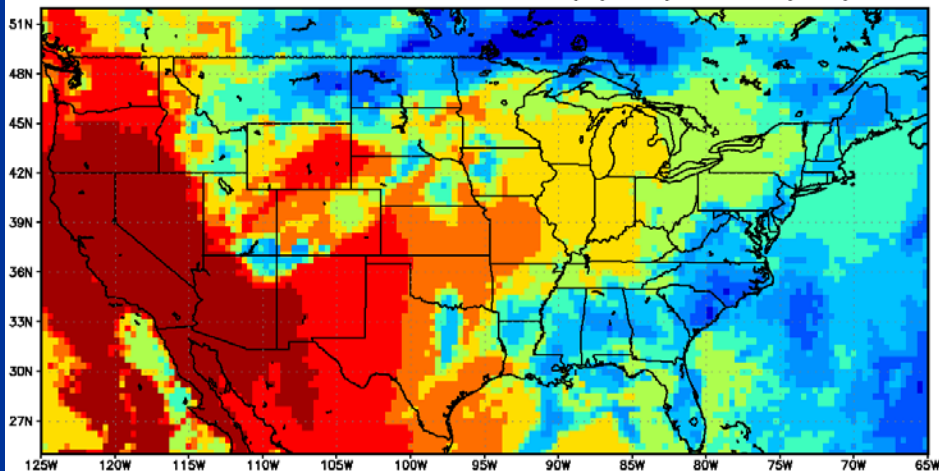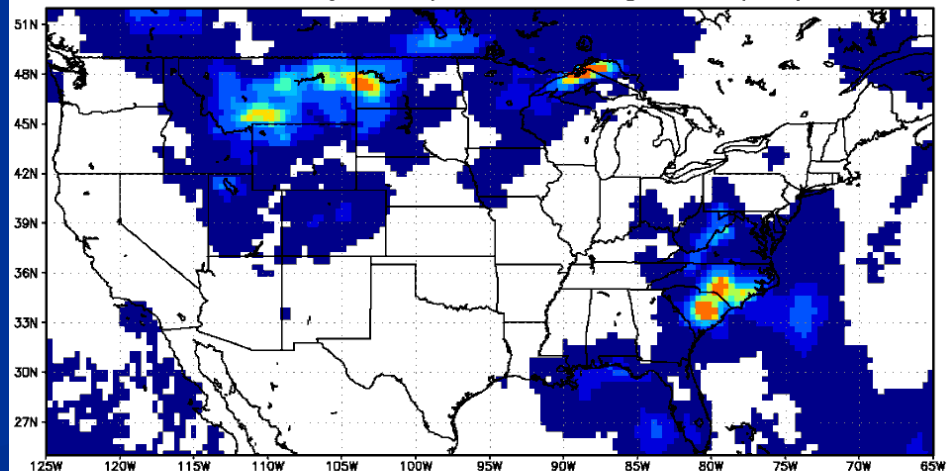
NARR sample plots over NLDAS
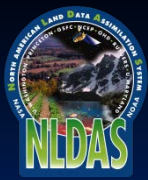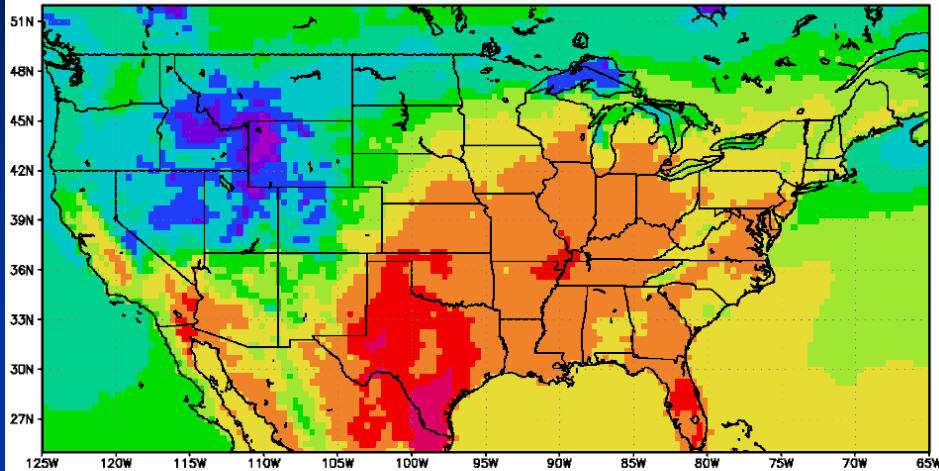
Earth Observations in NLDAS-2

- The <u>observation fields</u> 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:

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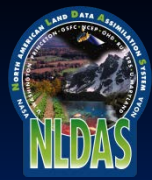
Generation of NLDAS-2 precipitation

| Dataset	Years	CONUS	Mexico	Canada
CPC daily gauge analysis	1979 – present	$1/8^{th}$-degree PRISM-adjusted analysis	$1/4^{th}$-degree (before 2001, 1-degree) analysis	Not used
Stage II Doppler hourly 4-km radar data	1996 – present	1st choice to temporally disaggregate	Not used	Not used
CMORPH satellite-retrieved half-hourly 8-km analysis	2002 – present	2nd choice to temporally disaggregate	1st choice to temporally disaggregate	Not used
CPC HPD 2x2.5-degree hourly analysis	1979 – present	3rd choice to temporally disaggregate	2nd choice to temporally disaggregate	Not used
NARR/R-CDAS 3-hourly 32km model-simulated precipitation	1979 – present	4th choice to temporally disaggregate	3rd choice to temporally disaggregate	Used for all precip over Canada areas; a 1-degree blend near U.S.-Canada border is done.

NLDAS-2 precipitation diurnal cycle
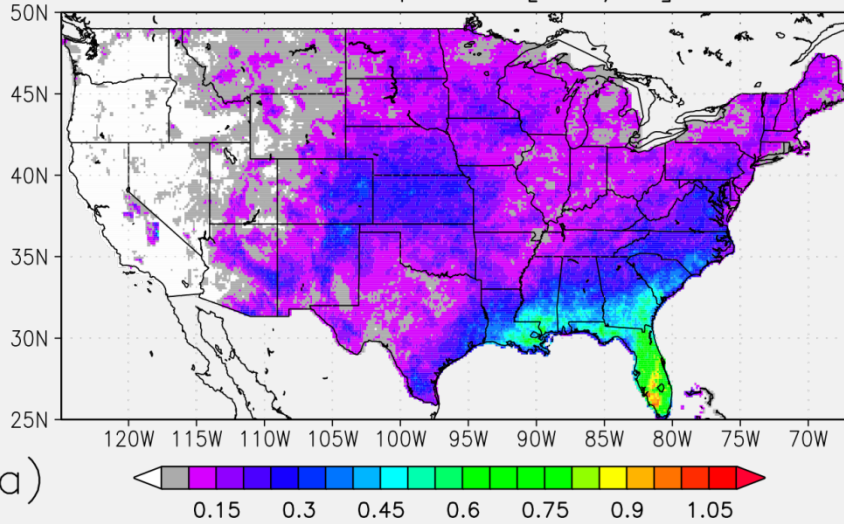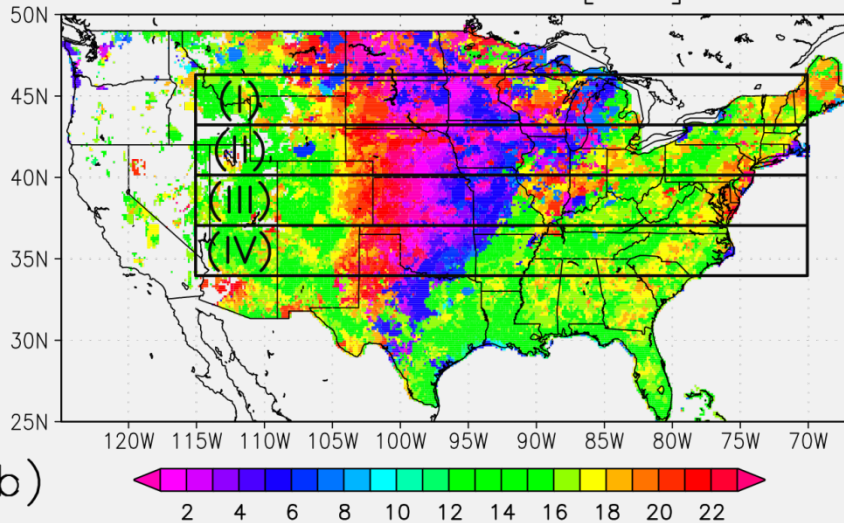
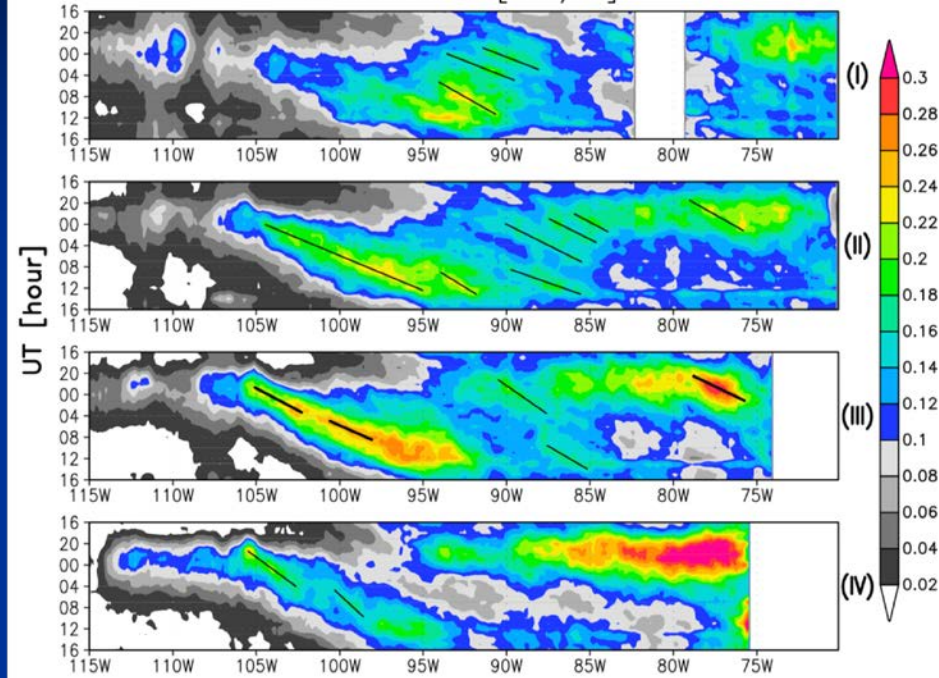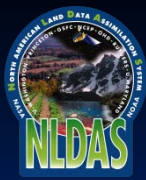Matsui et al. (2010; GRL) examined the diurnal cycle of summertime precipitation in NLDAS over CONUS. Zonal phase speeds of the precipitation were estimated and compared to background zonal wind speeds from the MERRA reanalysis.

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
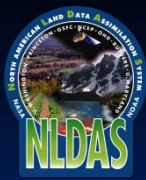

Xia et al. (2012): Part 1, JGR-Atmos.
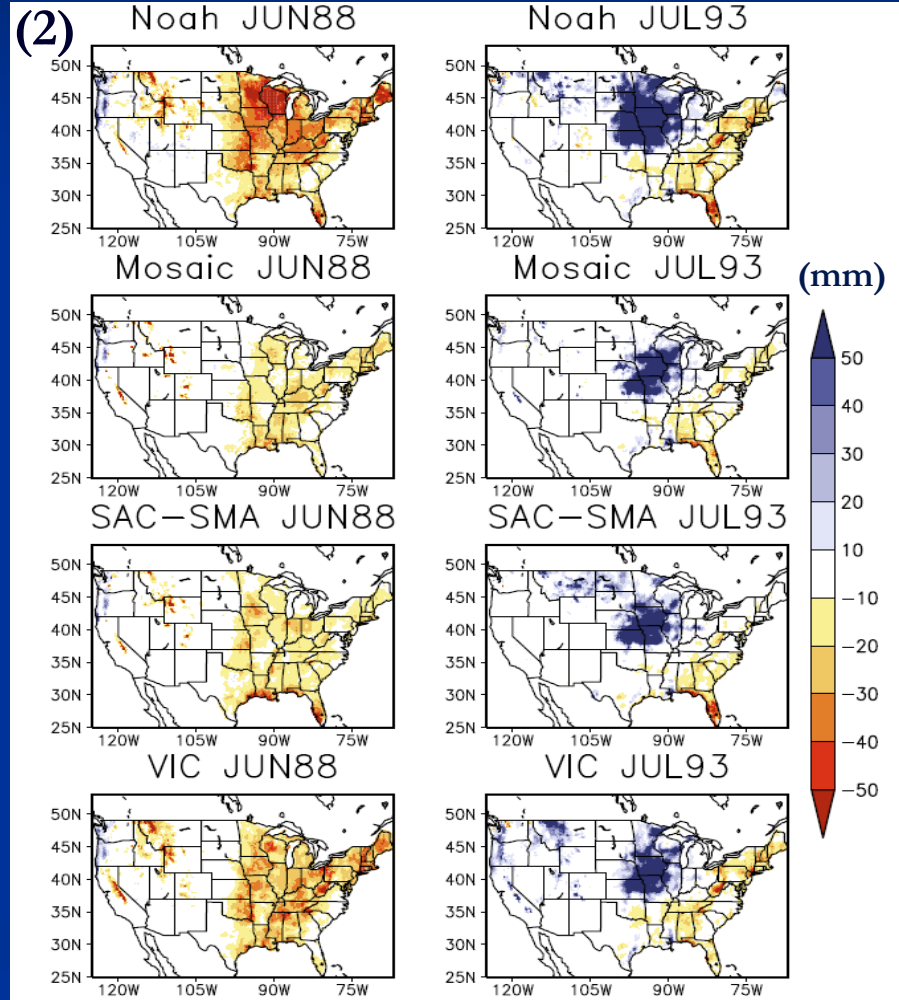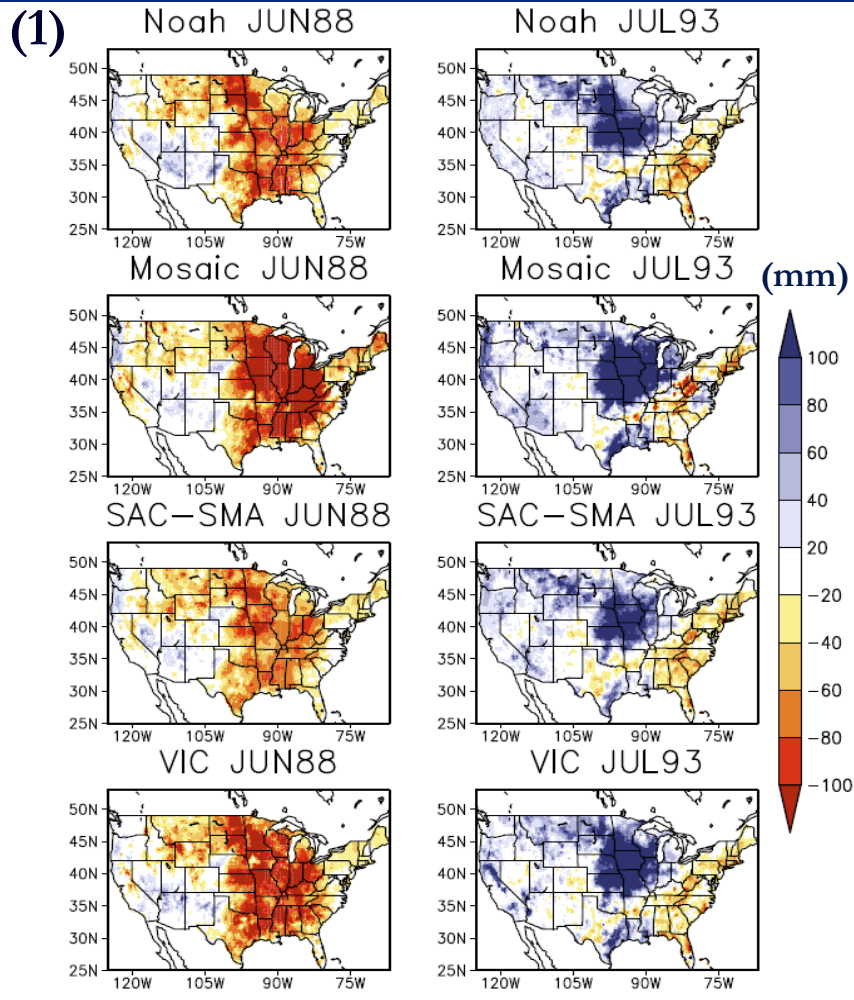
Streamflow Comparisons

- **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 <u>monthly</u> means (961 basins)

- Bottom figure: For <u>daily</u> means for 8 major U.S. river bains

13

NLDAS-2 Drought Monitor

-- http://www.emc.ncep.noaa.gov/mmb/nldas/drought/
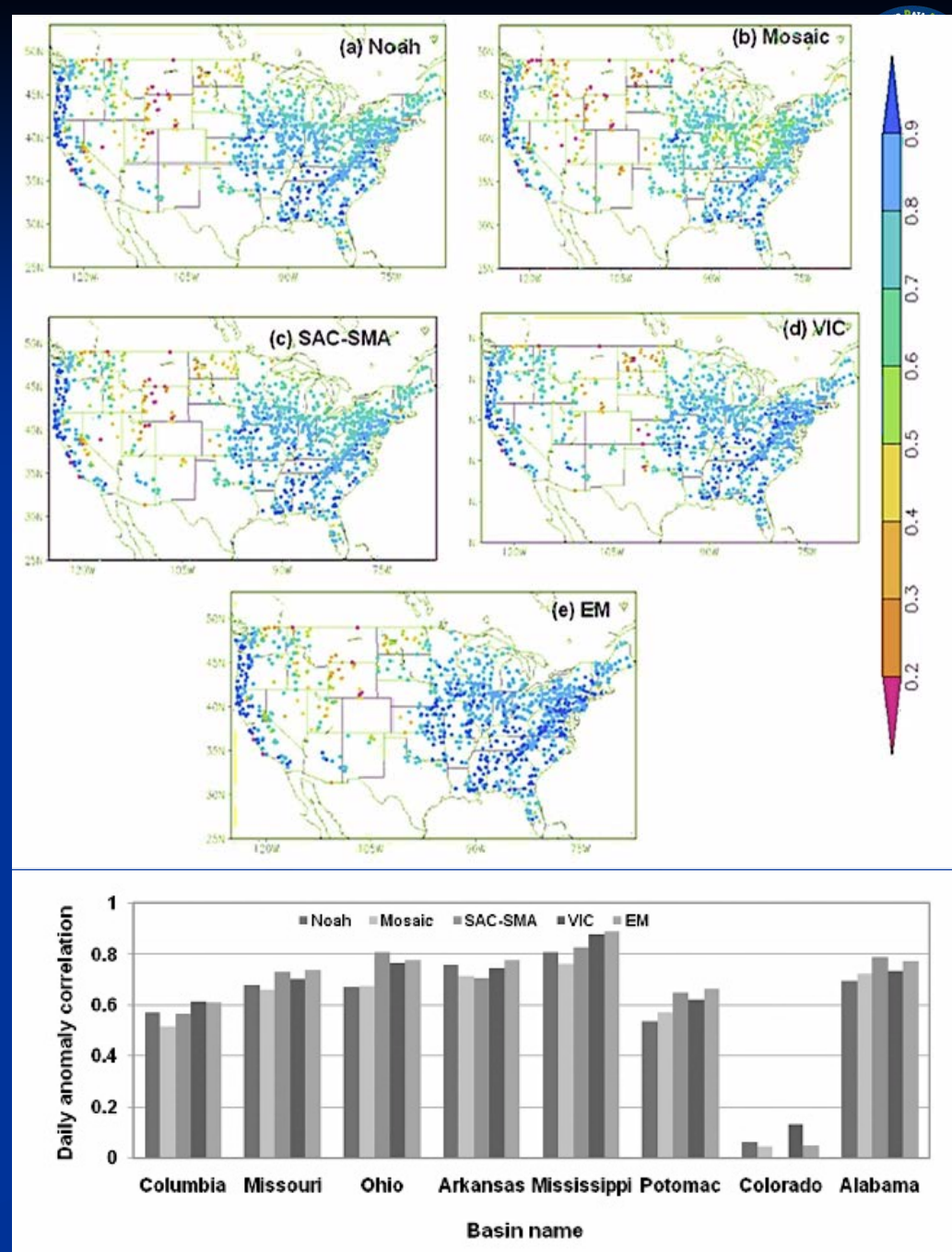
➢ NLDAS-2 model data are also used in a near-real-time **drought monitor** (with anomalies/percentiles against the entire NLDAS data archive).

Examples of (1) soil moisture percentiles and (2) streamfow 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.

(1) Ensemble-Mean – Past Week Top 1M Soil Moisture Percentile
NCEP NLDAS Products___ Valid: AUG 02, 2012
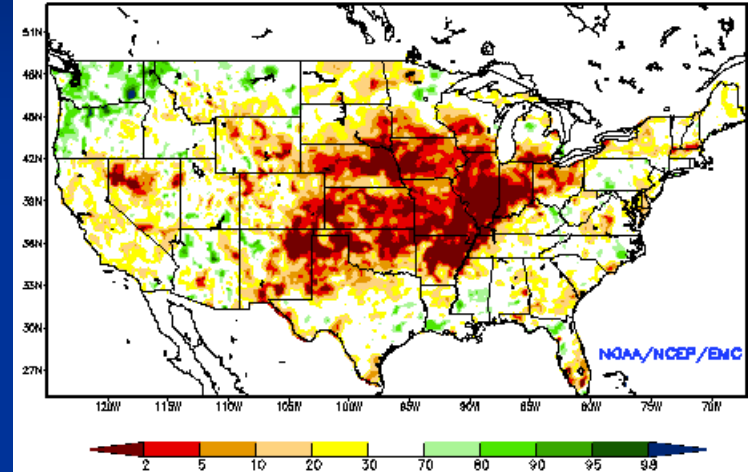
(2) Ensemble-Mean: Current Streamflow Anomaly (m³/s)
NCEP NLDAS Products__Valid: AUG 02, 2012
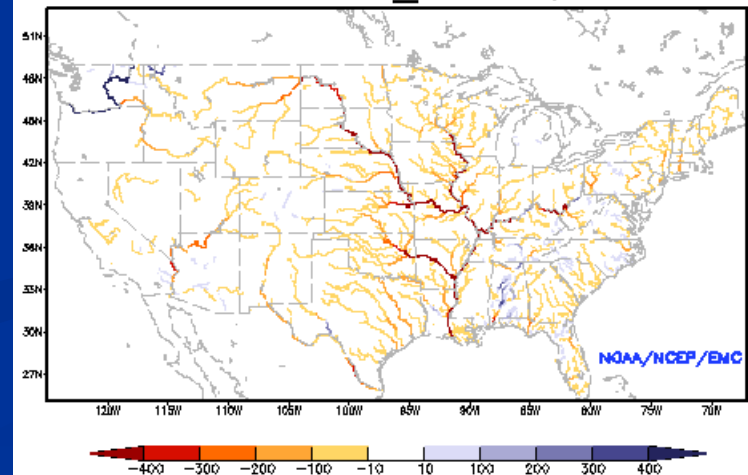
Next NLDAS-Phase (III):

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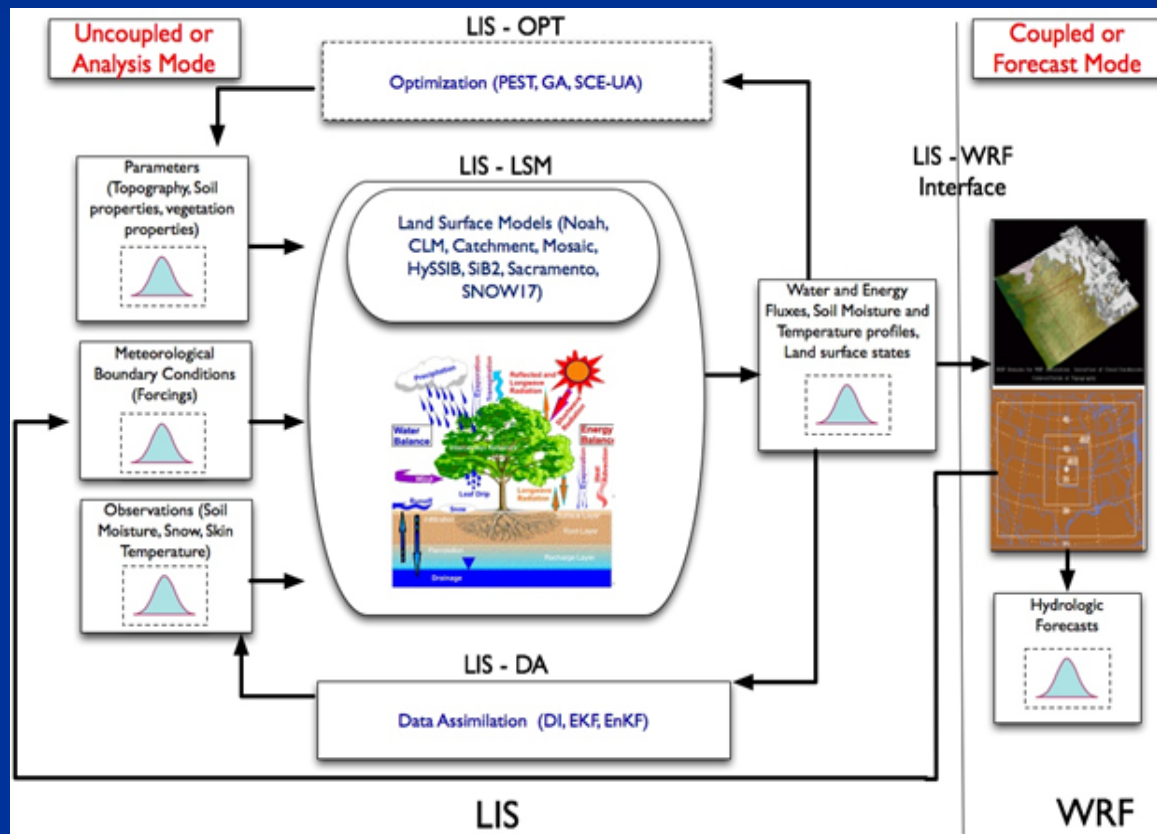
- LIS can use different LSMs, forcings, parameter datasets, observations, and includes modules for data assimilation and parameter optimization techniques.

- In addition to being run in an offline/uncoupled mode, LIS can also run coupled to the WRF forecast model.
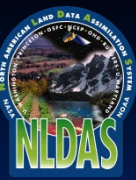
# NLDAS and Data Assimilation in LIS

- 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:

Parameters	Spatial Resolution	Satellite Sensors
Snow covered area (SCA)	500 m	Terra/Aqua MODIS
Snow water equivalent	25-km	Aqua AMSR-E
SCA & SWE	25-km	ANSA
Soil moisture	25-km	Aqua AMSR-E

- 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,

➜ (RMSE(**no DA**) – RMSE (**SM DA**))
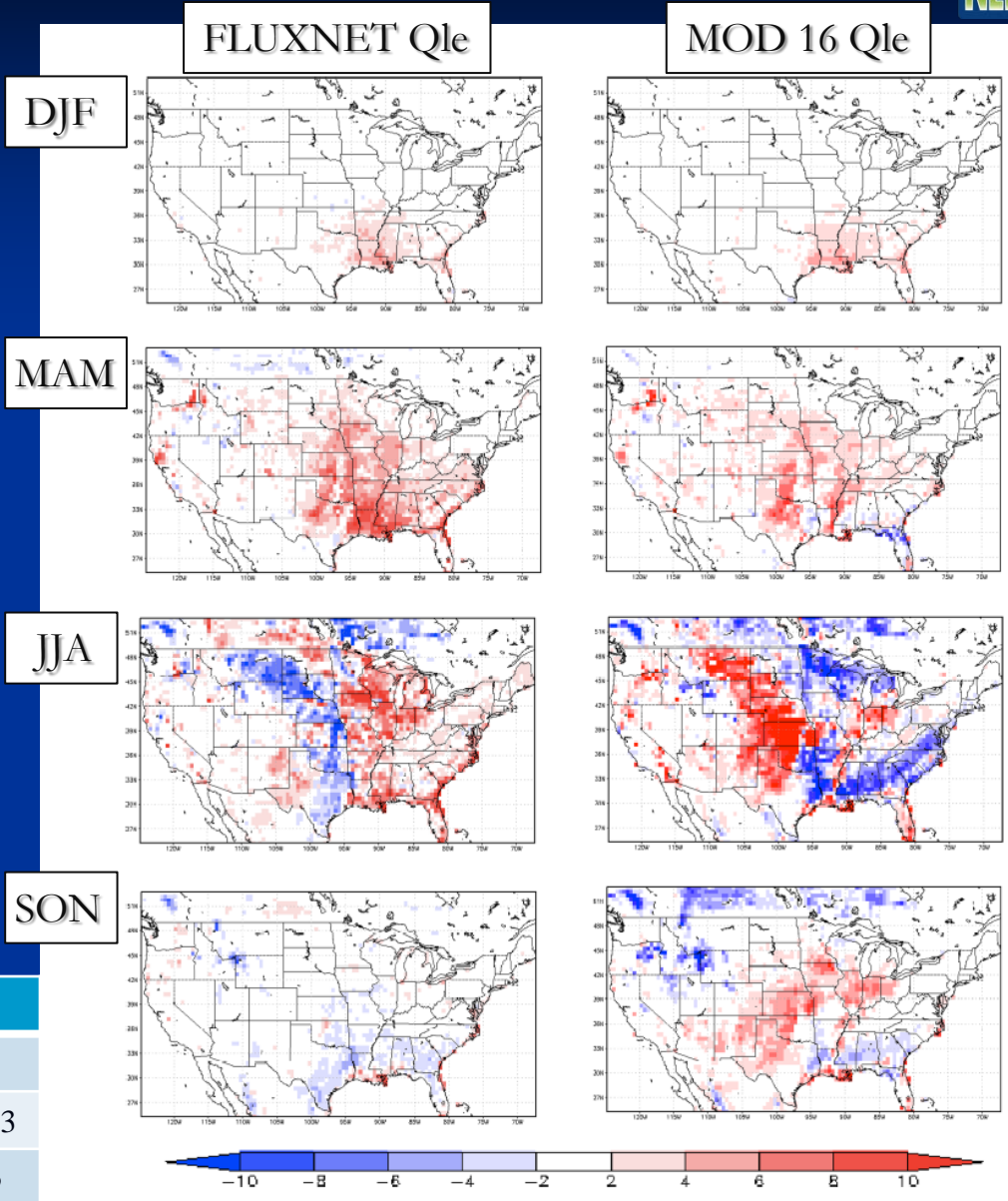
Noah v3.2 Qle	FLUXNET (W m^{-2})		MOD16 (W m^{-2})	
	RMSE	Bias	RMSE	Bias
Open-loop	27.6 ± 0.3	12.9 ± 0.4	22.7 ± 0.2	11.2 ± 0.3
LPRM DA	**25.6 ± 0.3**	**10.9 ± 0.3**	**21.9 ± 0.3**	**9.2 ± 0.3**

FLUXNET Qle   MOD 16 Qle

DJF   MAM   JJA   SON
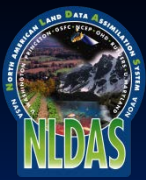
Evaluating Snow Assimilation Results

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

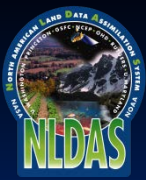- Validation performed with the U. S. NOAA/NWS COOP stations
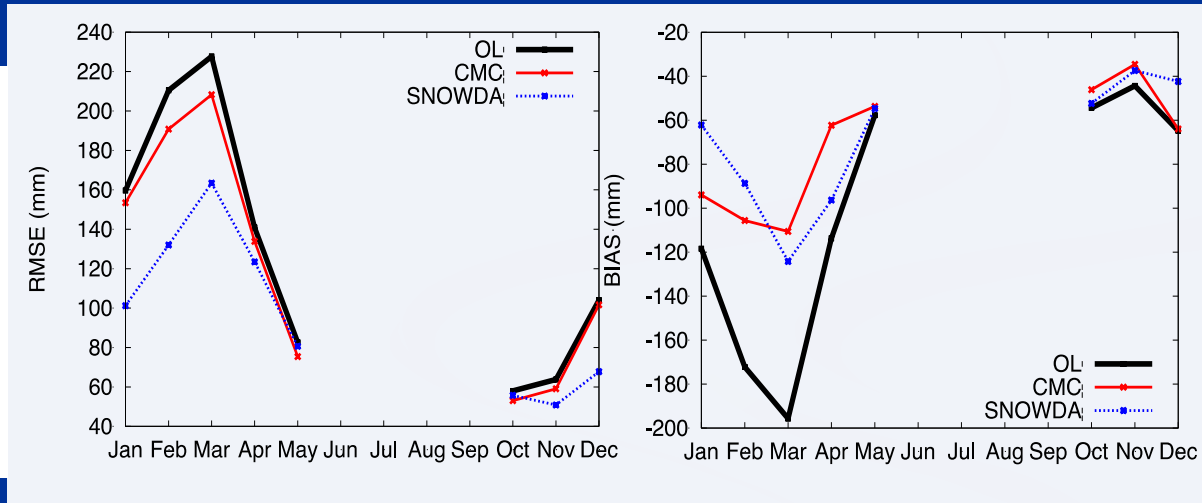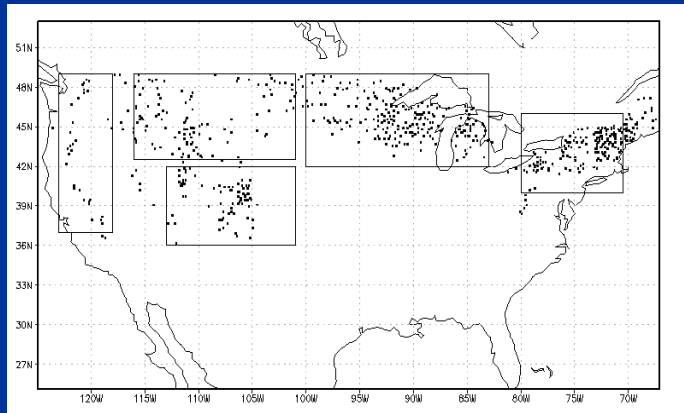
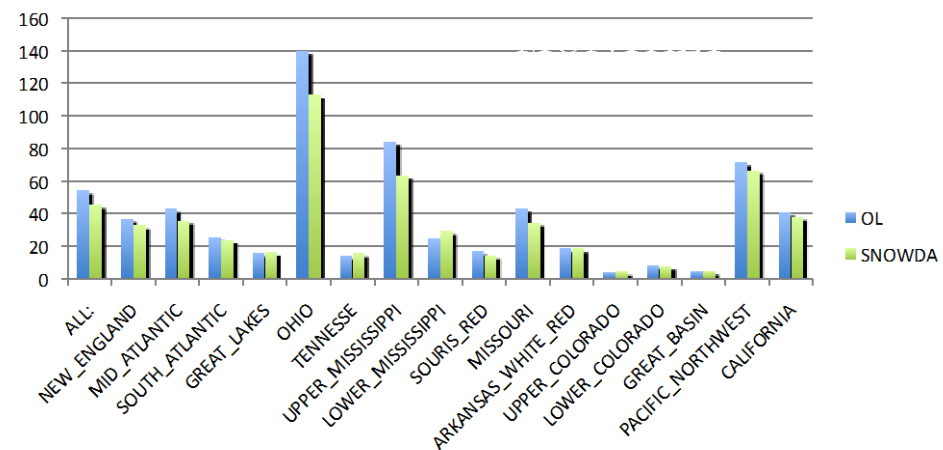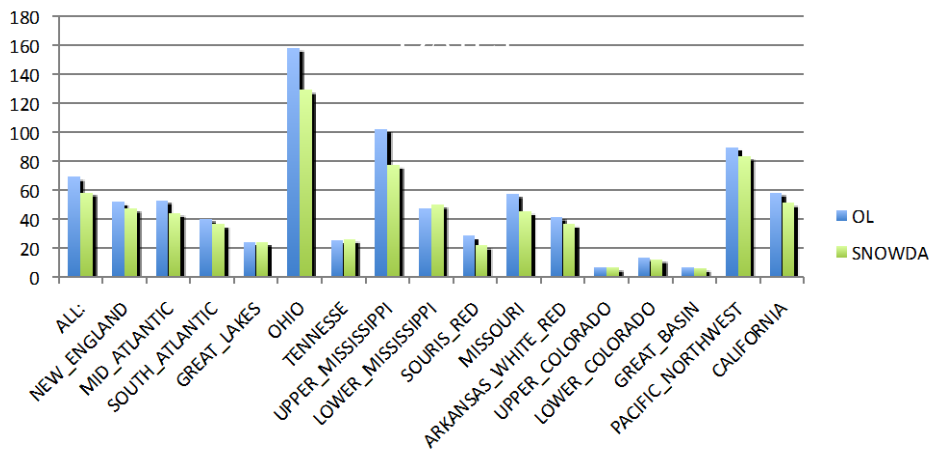|	RMSE(mm)	Bias (mm)	R
OL	212 ± 10.7	-130.0 ± 11	0.63 ± 0.01
CMC	197 ± 8.0	-85.9 ± 8.0	0.70 ± 0.01
SNOWDA	**152 ± 8.5**	**-77.6 ± 8.19**	**0.77 ± 0.01**

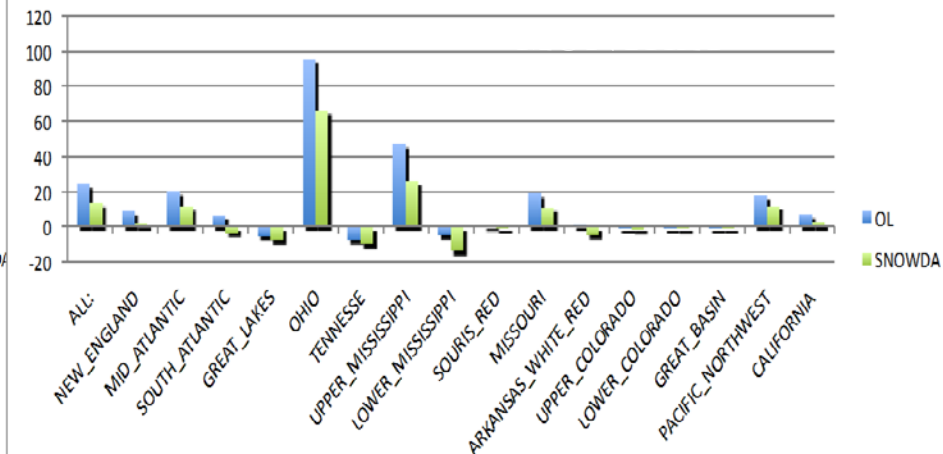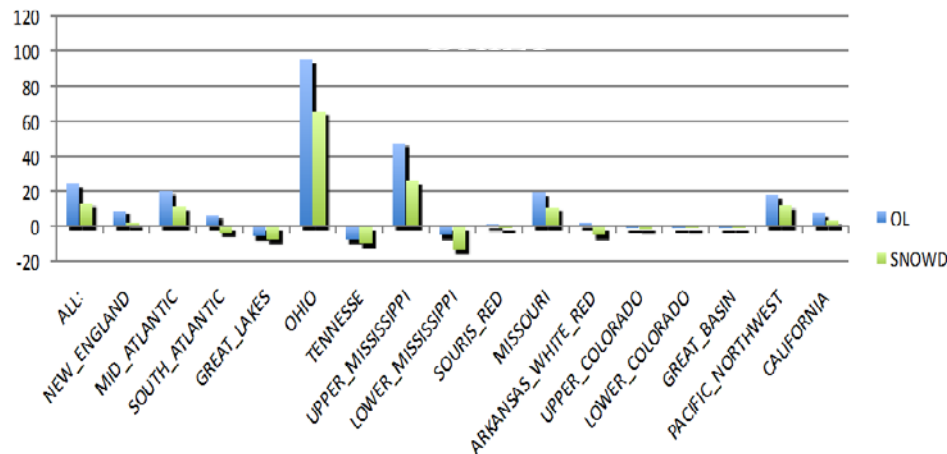# NLDAS Snow DA ~ Streamflow evaluation
(Using Xia et al. (2011) stations)

RMSE (m3/s)

BIAS (m3/s)

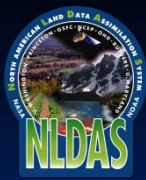**RMSE and bias errors are reduced systematically with data assimilation**

20

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)
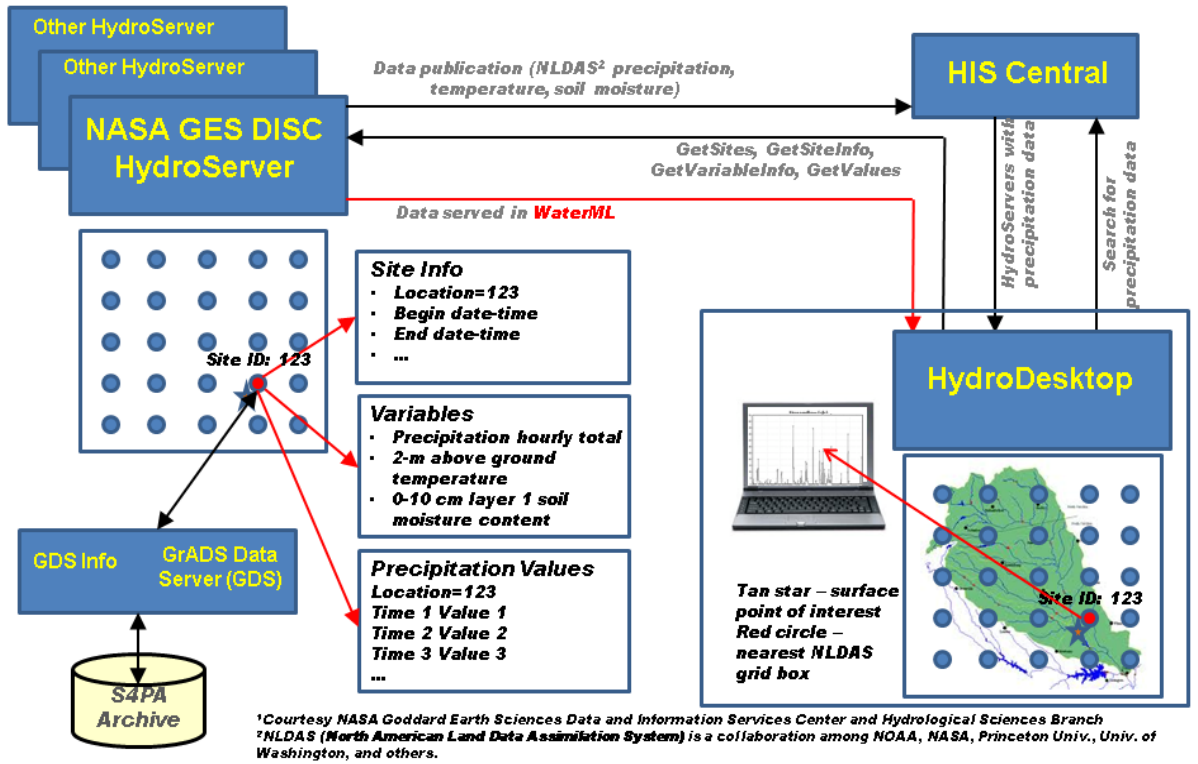

Data is available via 4 methods: 1) Mirador searching, subsetting, and downloading; 2) Giovanni online visualization and analysis; 3) anonymous ftp, and 4) a GDS. Currently, NLDAS-1 forcing as well as NLDAS-2 forcing and Mosaic and Noah model output datasets are available.
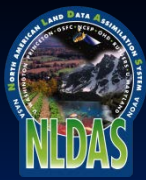
22

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):

NASA Hydrologic Data Access from HydroDesktop (an example)[1]

[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.

- 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.

23

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
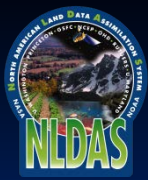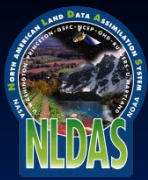
Acknowledgements

- 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/