# Using Land Data Assimilation Systems for Drought Monitoring, Water Resources, and Hydrologic Indicators

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SAIC at NASA/GSFC, Hydrological Sciences Laboratory

The **North American Land Data Assimilation System (NLDAS)** is a collaborative project between NOAA/NCEP and NASA/GSFC, and is supported by the NOAA Climate Program Office's Modeling Analysis, Predictions, and Projections (MAPP) Program.

PIs and Co-Is: Christa D. Peters-Lidard (NASA), David M. Mocko (SAIC at NASA), Sujay V. Kumar (NASA)
Youlong Xia and Michael B. Ek (NOAA)

The **National Climate Assessment – Land Data Assimilation System (NCA-LDAS)** is led by the Hydrological Sciences Laboratory at NASA/GSFC, and is supported by NASA HQ.

PI: Michael Jasinski (NASA)  PI of initial proposal: Christa D. Peters-Lidard (NASA)

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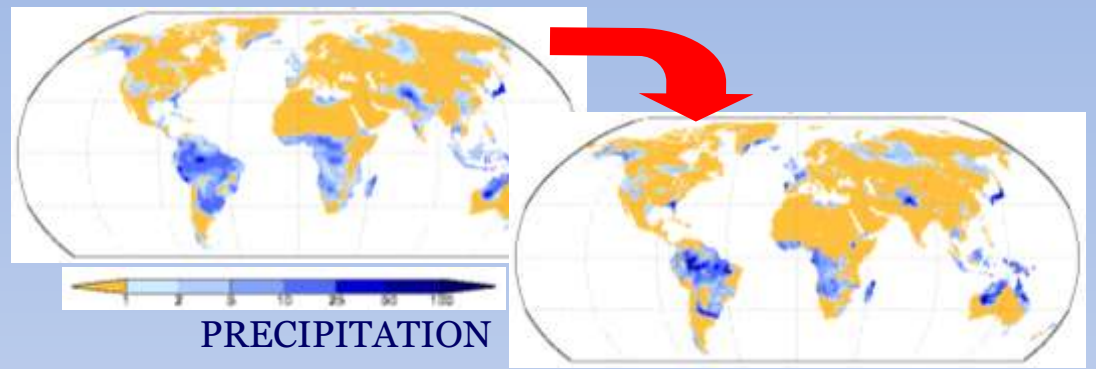
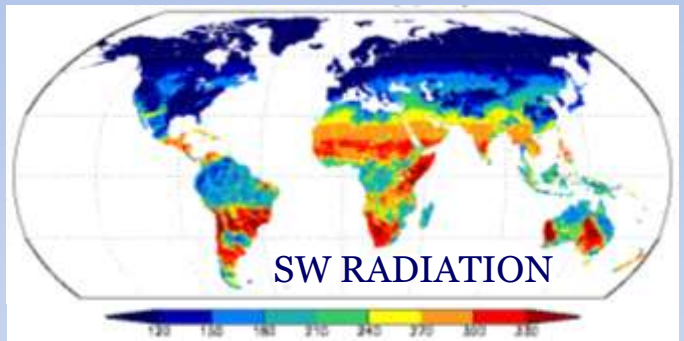
# What is a Land Data Assimilation System?

A Land Data Assimilation System – or LDAS – is a dataset from land-surface models (LSMs) forced with the best-available observations to support water resources applications.

Remotely-sensed land satellite observations are assimilated into the LSMs to improve the depiction of water/energy cycles.

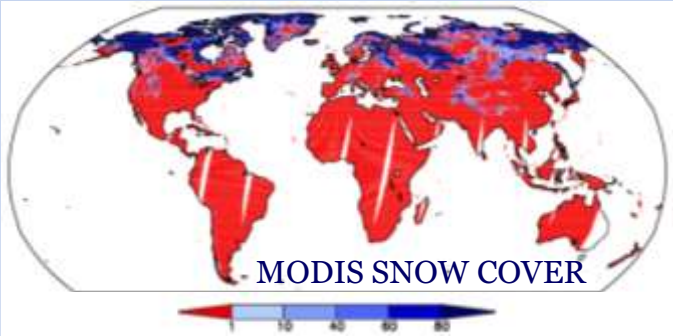
INTERCOMPARISON and OPTIMAL MERGING of land-surface data fields

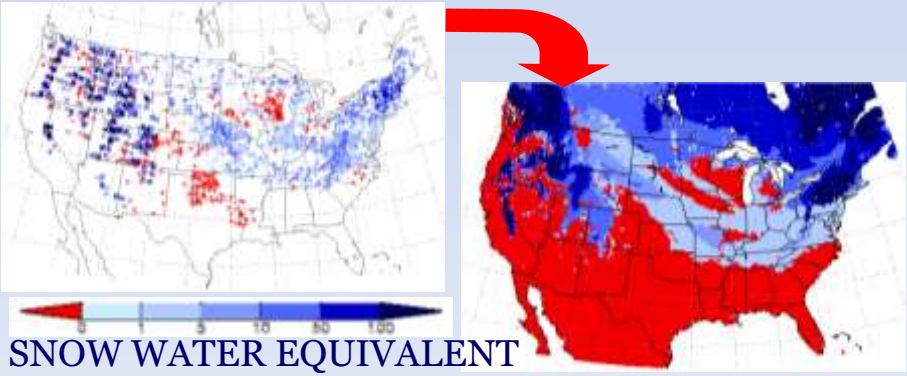



Reanalysis and/or radar/satellite-observed surface meteorological data combined and used as land-surface model FORCING

ASSIMILATION of satellite-based land surface state fields (snow, soil moisture, terrestrial water storage, irrigation, etc.)




Ground-based observations used to VALIDATE model output

**Examples from NASA's GLDAS**
**http://ldas.gsfc.nasa.gov/**

Slide by Matt Rodell

# Four LDAS systems are available from NASA/GSFC/HSL

**GLDAS** – Global LDAS

**NLDAS** – North American LDAS

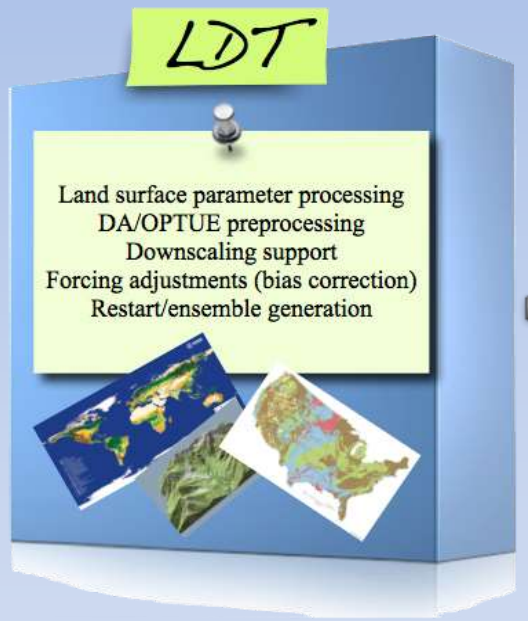
**NCA-LDAS** – National Climate Assessment LDAS

**FLDAS** – Famine Early Warning System Network (FEWS NET LDAS)

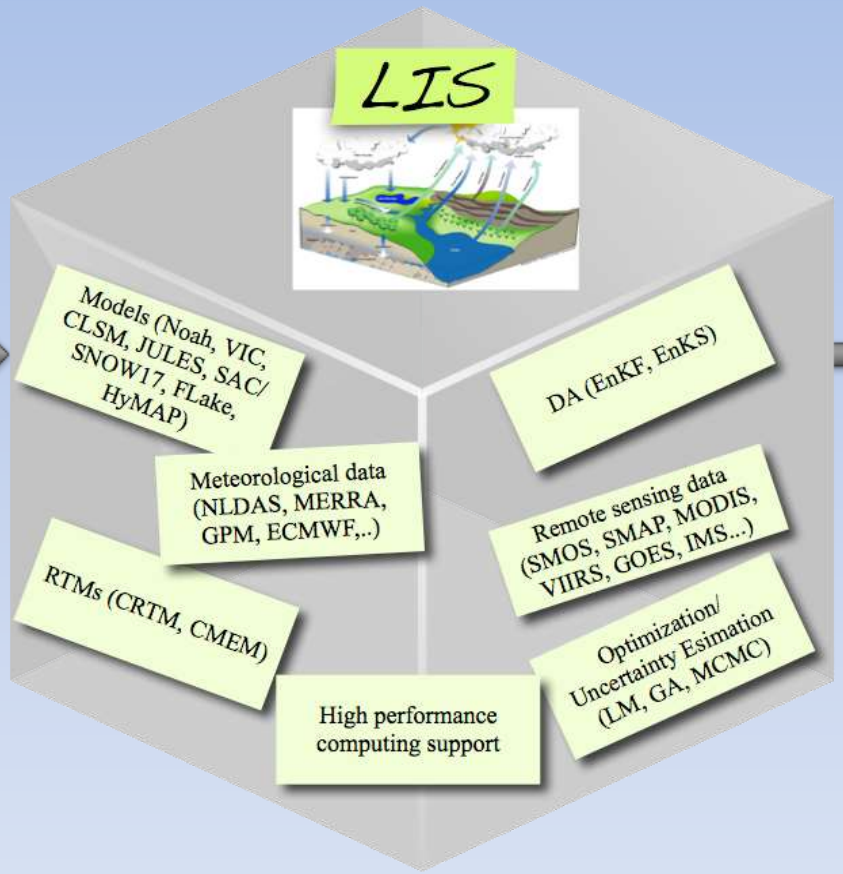

**NLDAS & NCA-LDAS** **FLDAS** **GLDAS**

http://ldas.gsfc.nasa.gov/

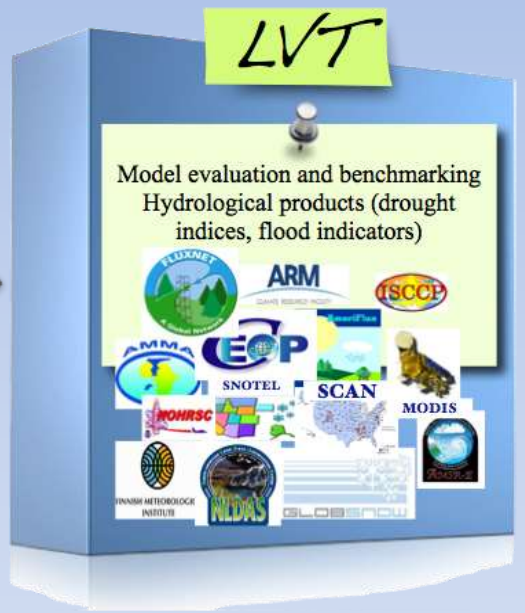
# NASA's Land Information System (LIS) software framework is used to drive the models and perform data assimilation




Land surface Data Toolkit (LDT)




Land Information System (LIS)




Land surface Verification Toolkit (LVT)

http://lis.gsfc.nasa.gov/

@NASA_LIS

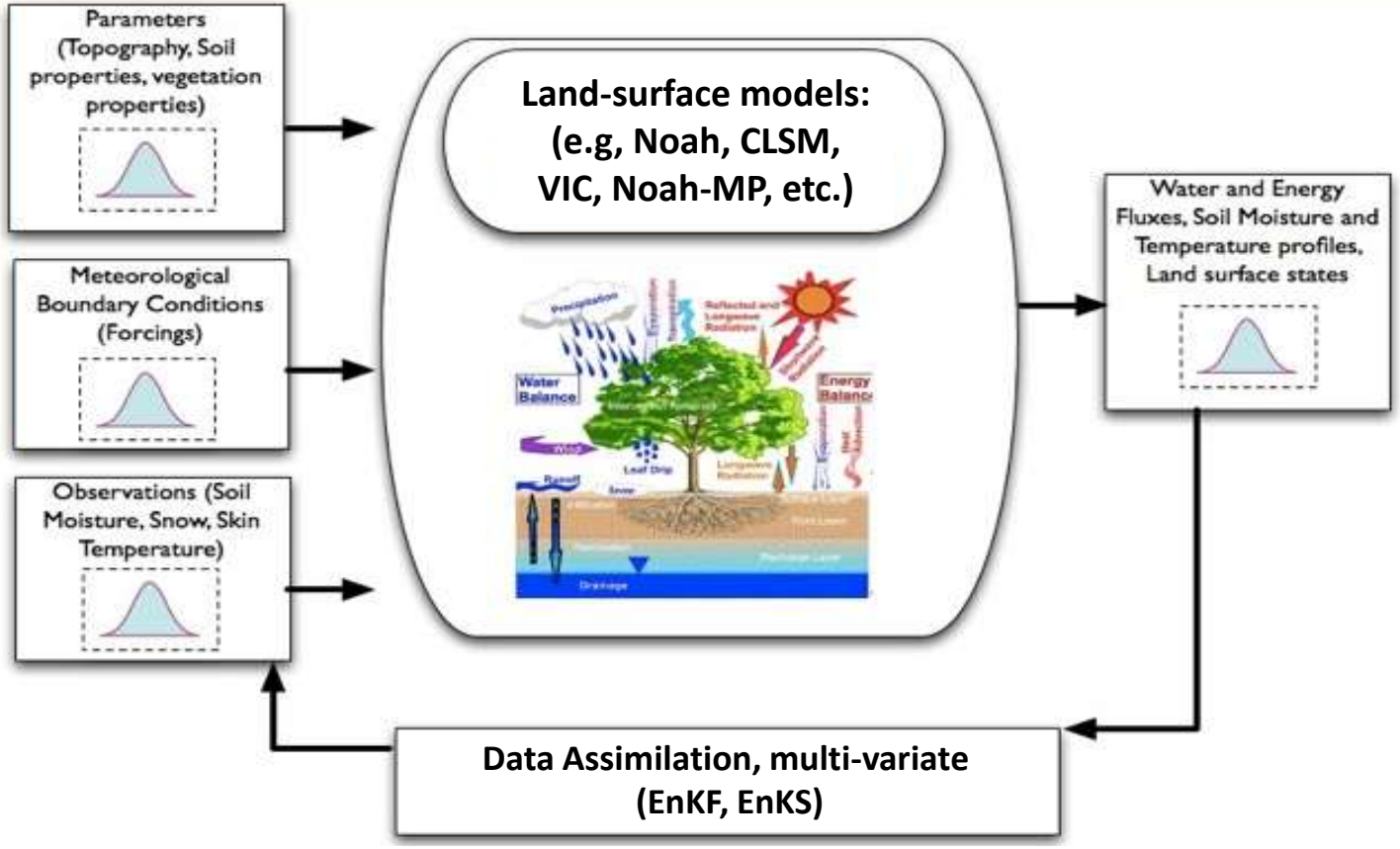
# LIS software uses parameters, meteorological forcings, and remotely-sensed environmental data records

## Using the Land Information System for an LDAS

**Best-available input datasets depending on the region of interest and application**

**Satellite EDRs***

**SM, SCA, SWE, TWS, and II**



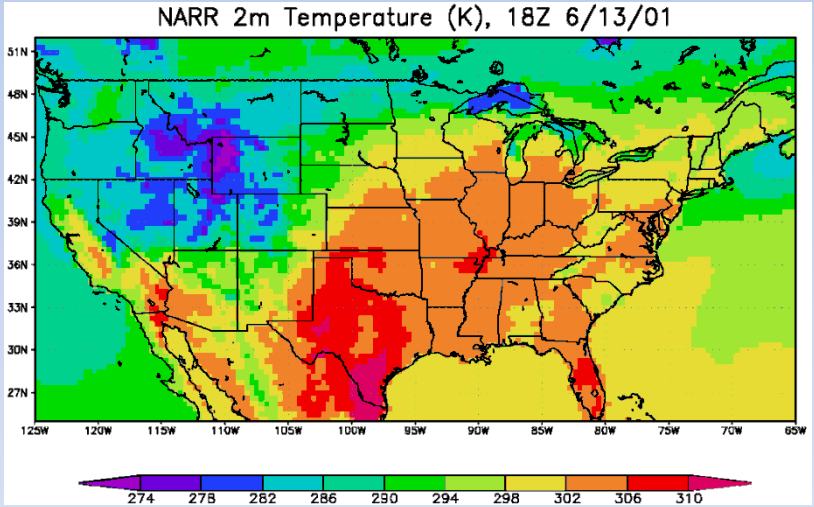

* Satellite-based Environmental Data Records (EDRs): soil moisture (SM), snow-covered area (SCA), snow water equivalent (SWE), terrestrial water storage (TWS), & irrigation intensity (II)

The **Land Information System (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.

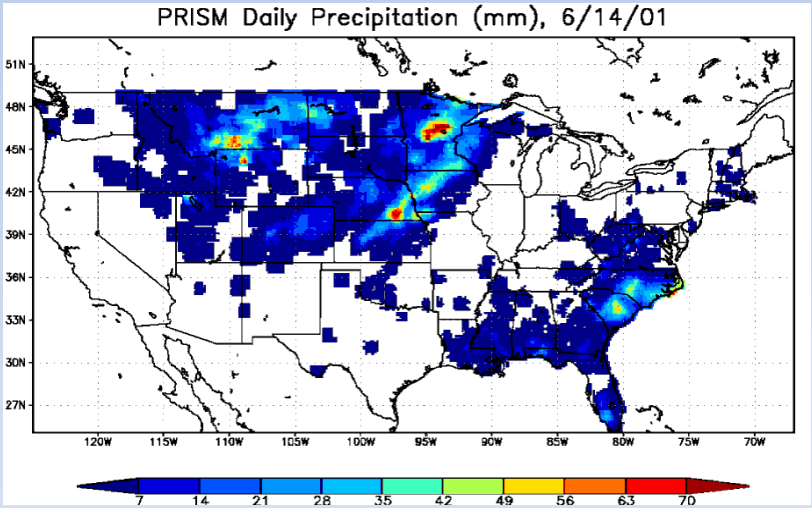
# NLDAS combines a high-quality surface forcing dataset and land-surface modeling to produce consistent products

- Jan 1979 to present (operationally w/ ~3.5-day latency); hourly/monthly
- 1/8$^{th}$-degree (~12.5km) over CONUS-centered domain (25-53°N; 125-67°W)

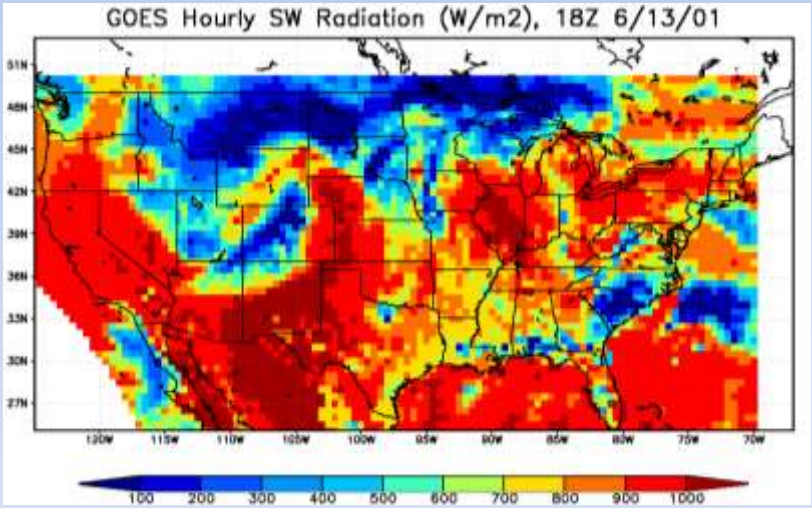
NARR near-surface meteorology




CPC Daily Precipitation Analysis




Bias-corrected SW radiation (SRB)




- Stage II radar, CMORPH, other precipitation datasets, or NARR used to temporally disaggregate the CPC Daily Analysis into hourly precipitation

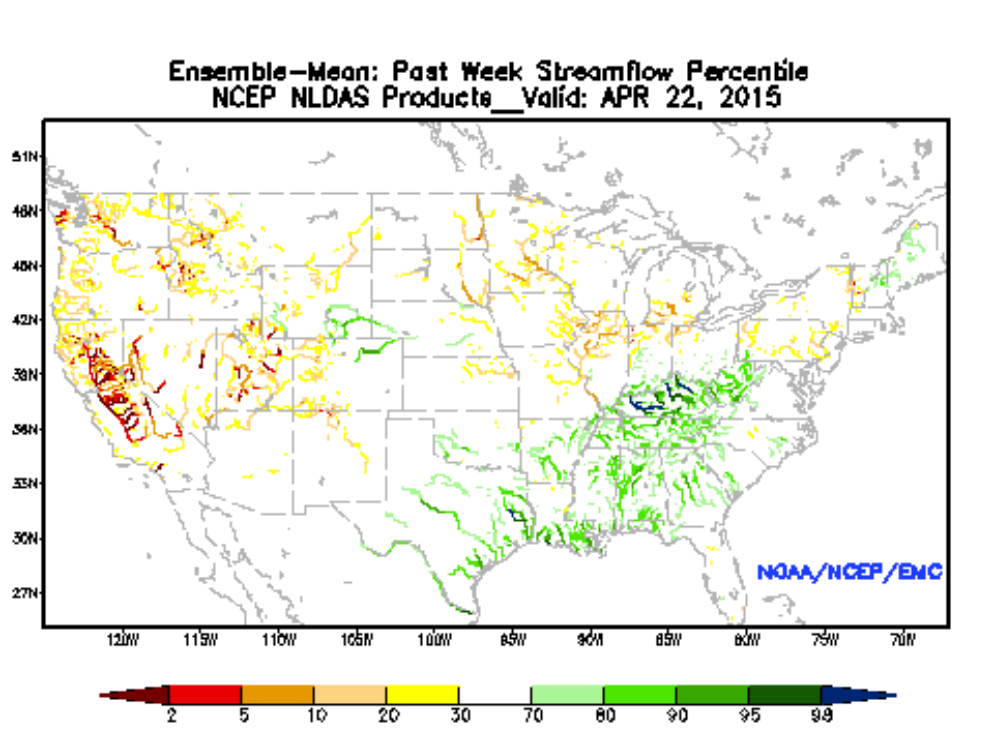
# The NLDAS Drought Monitor is updated daily, and is one of the datasets used for the weekly U.S. Drought Monitor

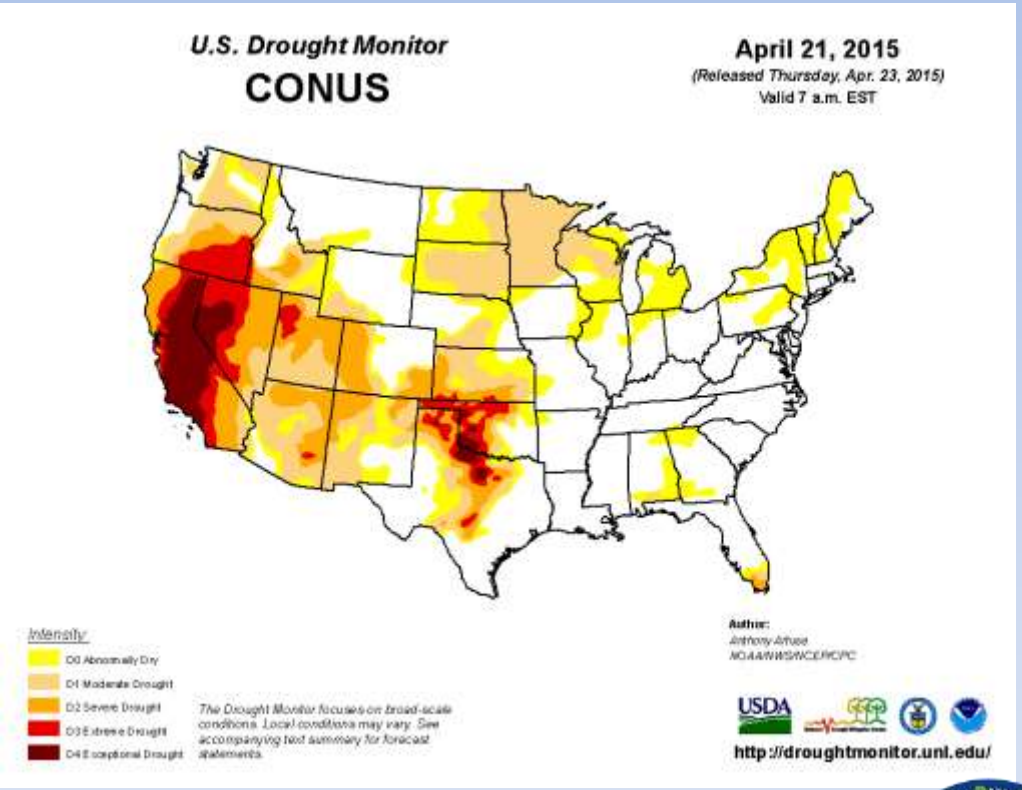
Percentiles and anomalies of: precipitation, soil moisture, snow, evaporation, runoff, and streamflow (from river routing)

Streamflow Percentile

Snow Anomaly (mm)

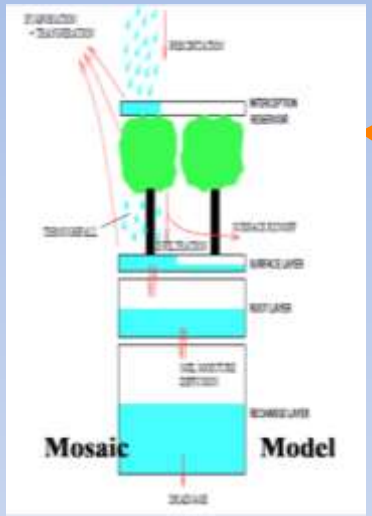
Soil Moisture Anomaly (mm)



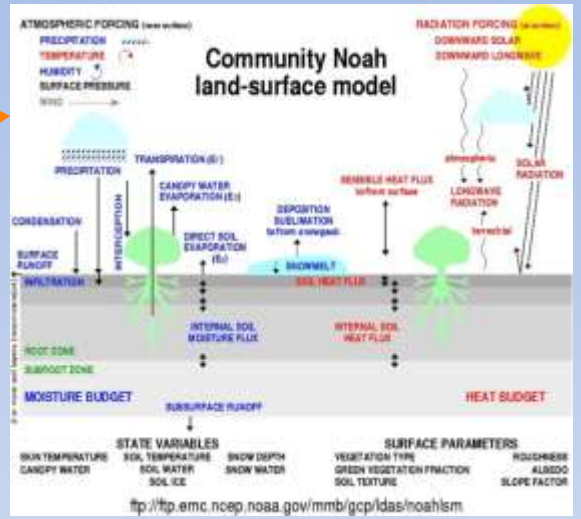

http://www.emc.ncep.noaa.gov/mmb/nldas/drought/

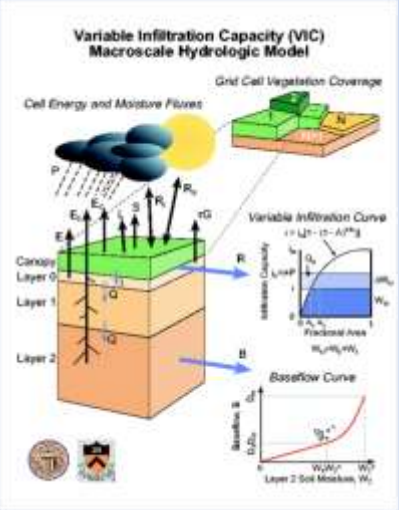
# Collaboration between NOAA/NCEP/EMC and NASA/GSFC w/ other groups; it runs 4 LSMs (Noah, Mosaic, VIC, & SAC)




Mosaic (GSFC)

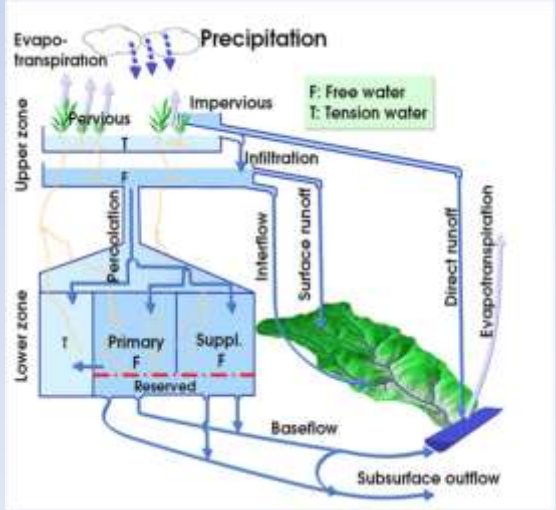
Noah (NCEP)



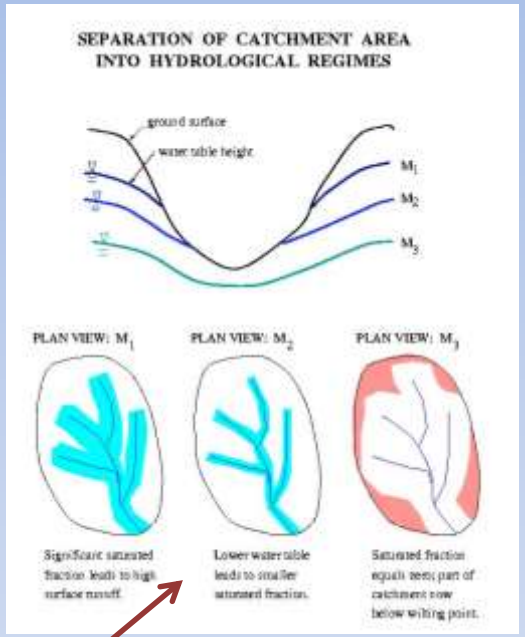

VIC (Princeton Univ. and Univ. of Washington)

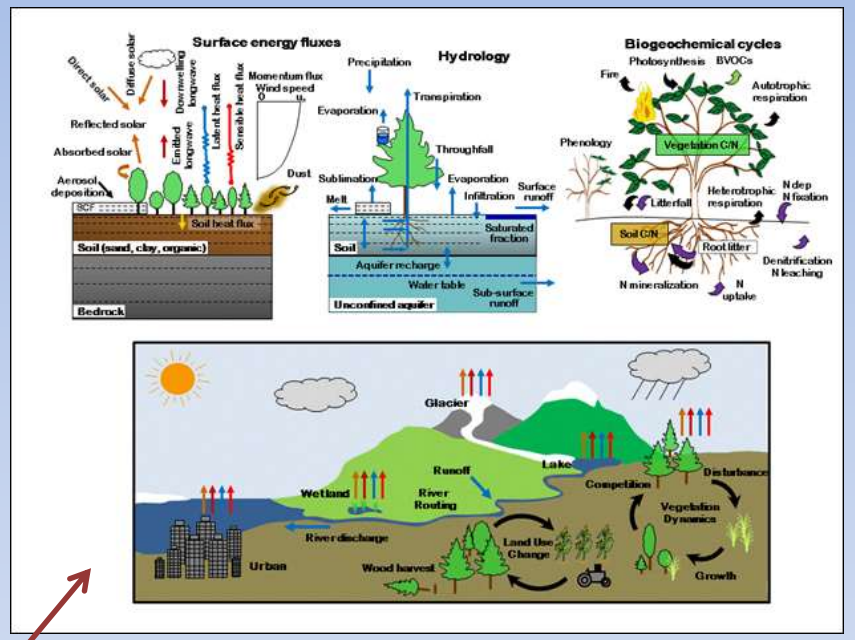
SAC (OHD)

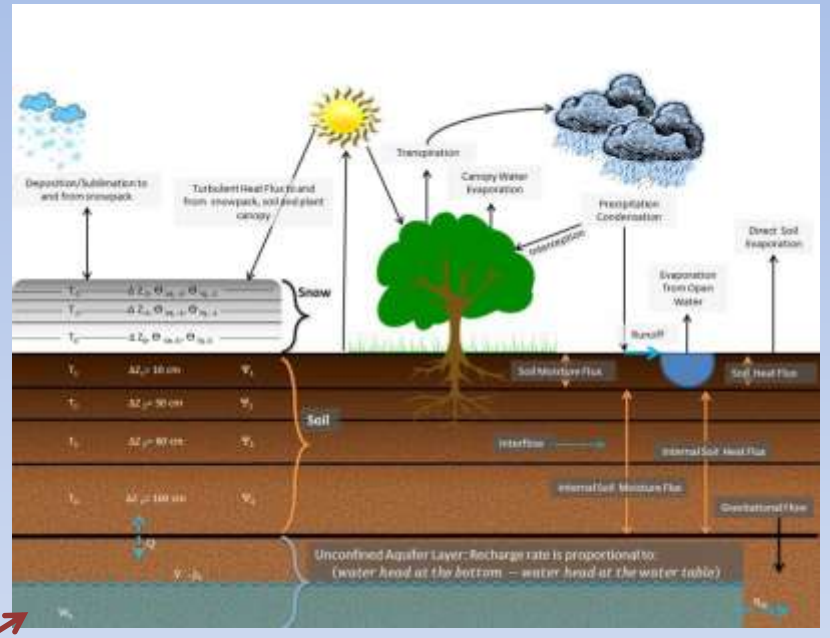



http://ldas.gsfc.nasa.gov/nldas/

# NASA's Catchment LSM as well as CLM are being added, with the other LSMs being upgraded to their latest versions




**Catchment LSM (CLSM)** is developed by NASA/GMAO, and is the land-surface component of the NASA GEOS-5 GCM.

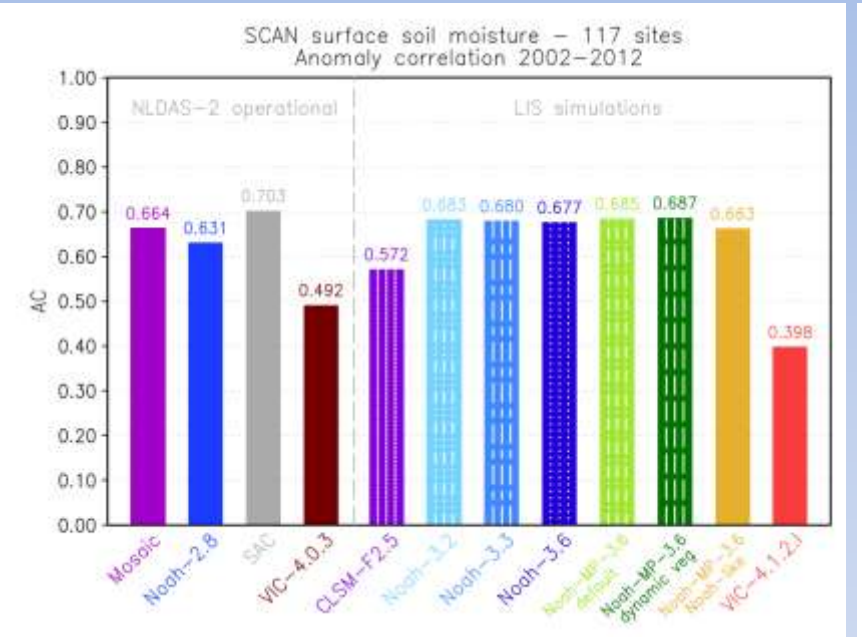
**Community Land Model (CLM-4.5)** is maintained by NCAR, and is the land-surface model for the Community Earth System Model (CESM).

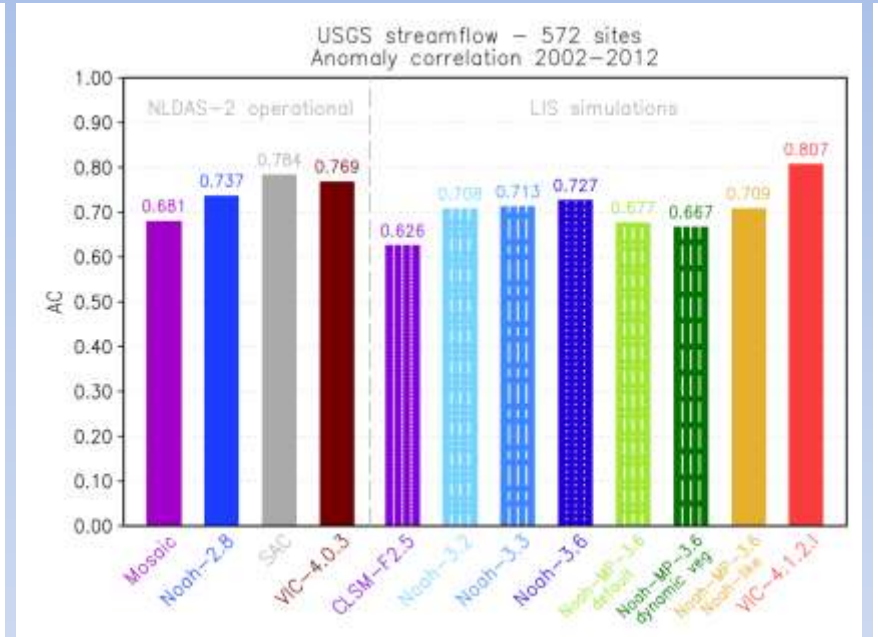
**Noah-MP-3.6** is a LSM option within WRF, with Multiple Physics options, including dynamic vegetation & groundwater modules.

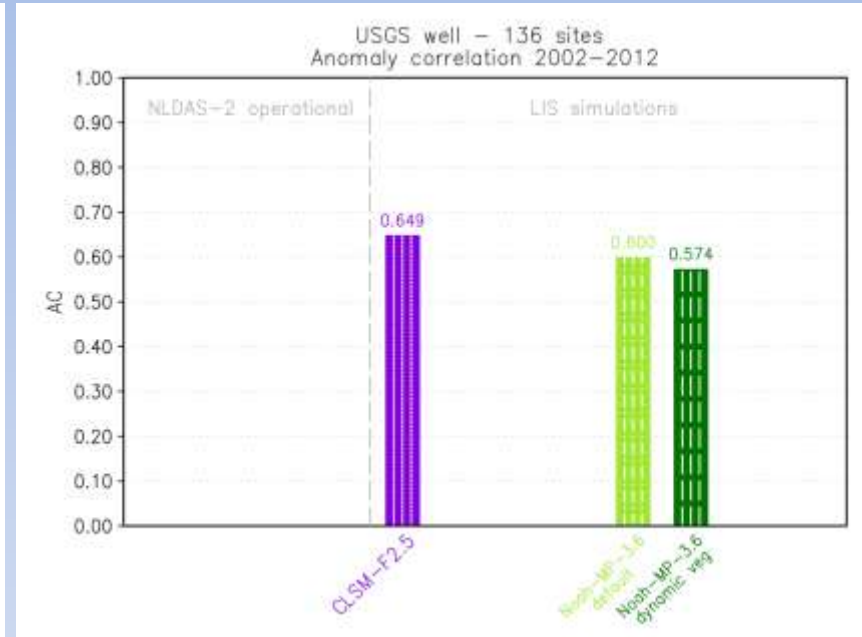
**VIC-4.1.2.l, SAC-HTET-3.5.6, and Noah-3.6** are also in LIS and contain numerous upgrades.

# NLDAS Science Testbed evaluation

The new and upgraded LSMs for the next phase of NLDAS have been run using the LIS software framework, and the new results and the NLDAS-2 operational LSMs have been evaluated against observations using the LVT software.



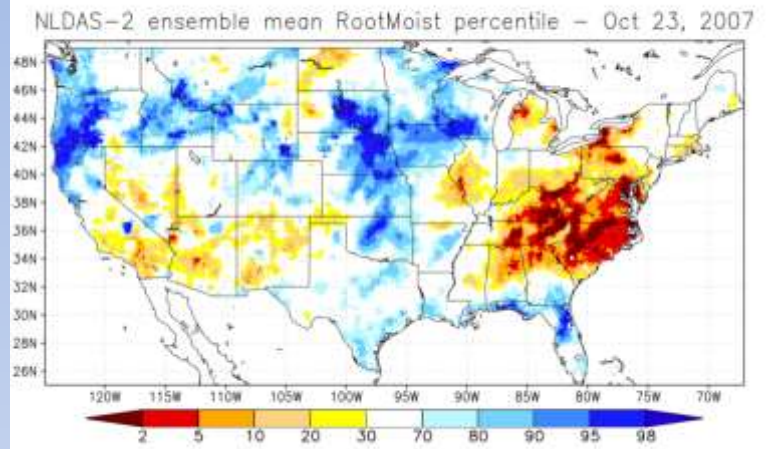



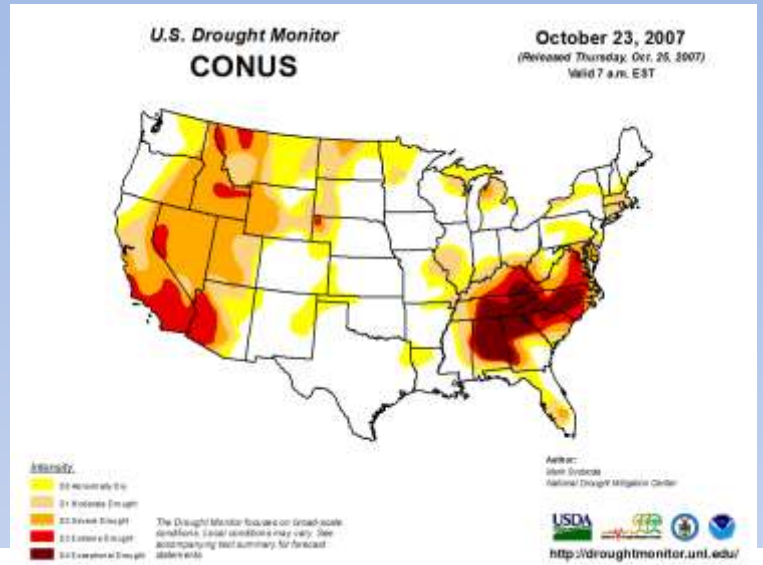

**Surface soil moisture** **Streamflow** **Groundwater**

Anomaly correlations are shown for the 4 NLDAS-2 LSMs (left of the dashed line) and various instances/options of the LIS LSMs (right of the dashed line). Against 117 quality-controlled SCAN soil moisture sites (left panel), the new versions of Noah and Noah-MP are improved over NLDAS-2's Noah. For routed streamflow (middle) against USGS observations at 572 small, unregulated basins, the LSMs do well, particularly the new version of VIC. Groundwater anomaly correlation is shown (right) against 136 USGS well observations. Groundwater is not available in any of the NLDAS-2 LSMs, while two of the new LSMs in LIS calculate groundwater. Fluxes, snow, TWS are also in evaluation.

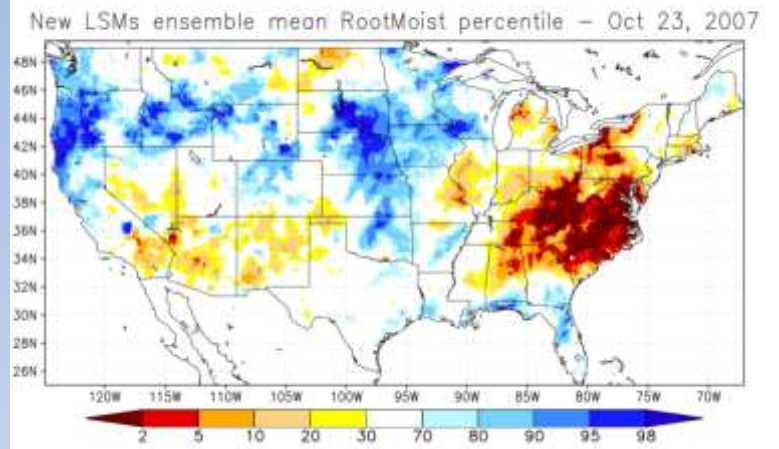
# Oct 23, 2007 – Southeast Drought

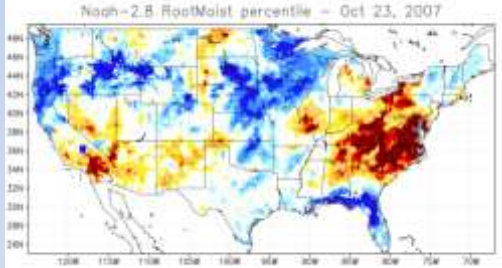
NLDAS-2 operational LSMs

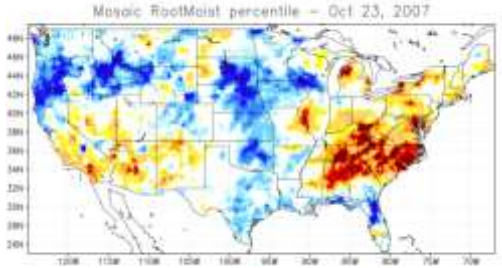


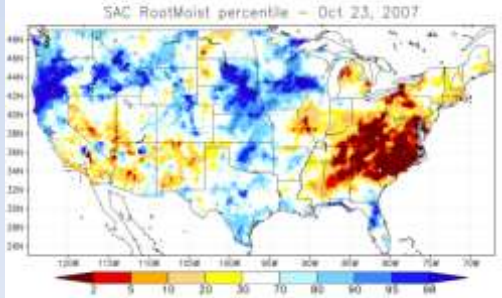



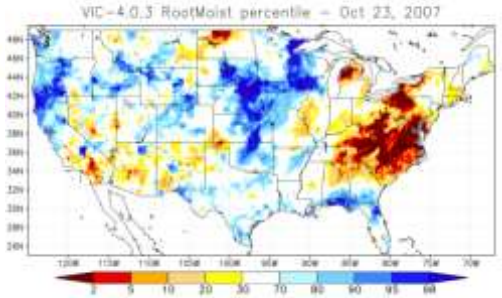

LIS LSMs for next phase



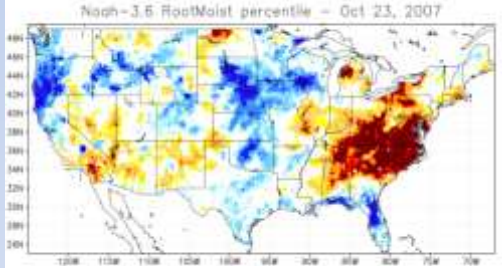



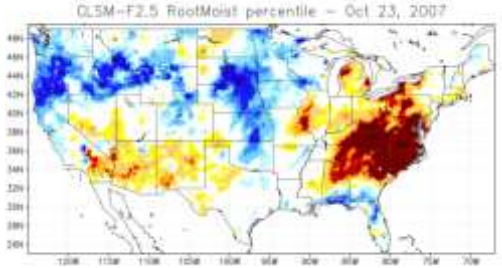



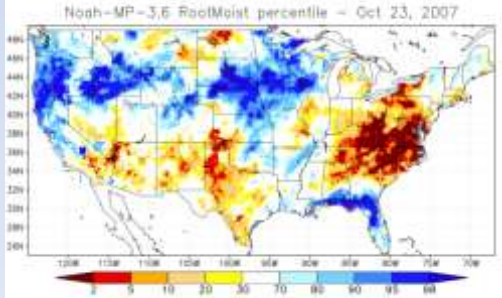



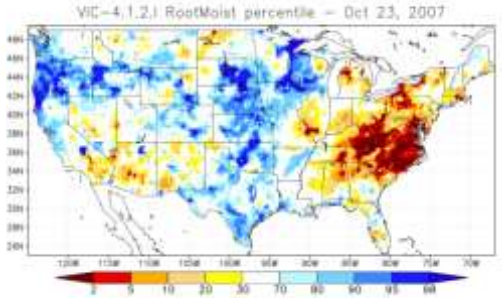




**Top 1-meter soil moisture**



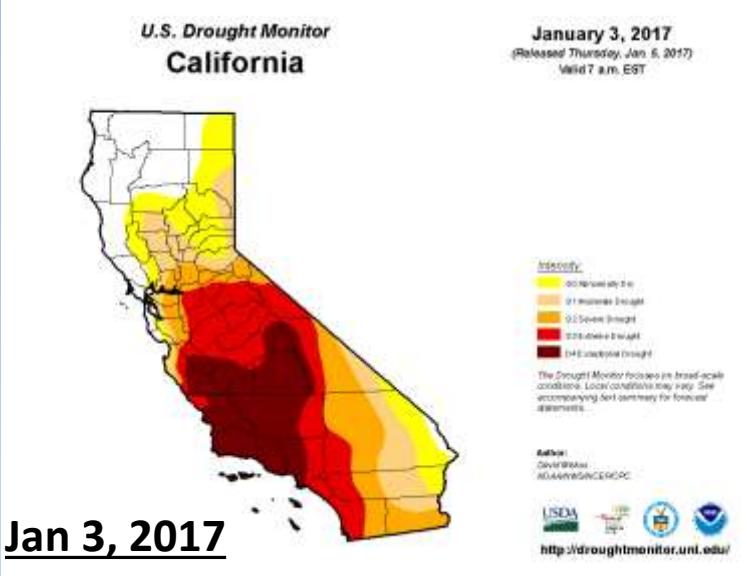



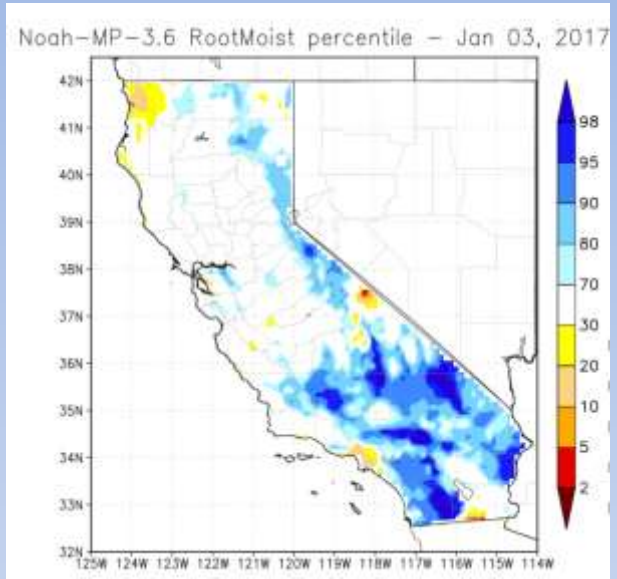



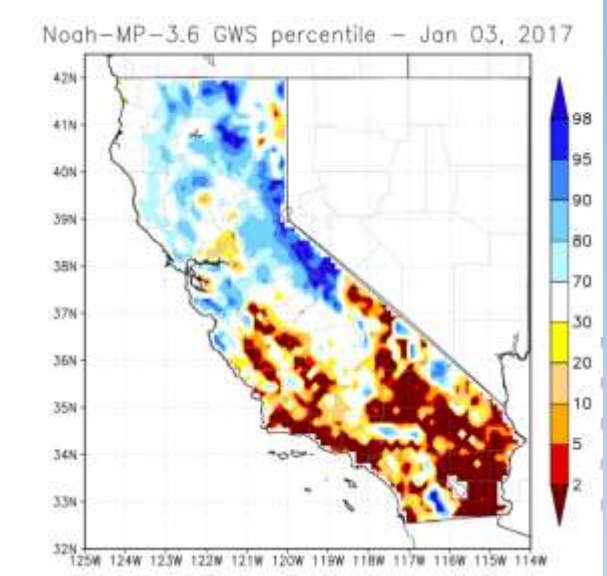
# California winter drought reduction 2016-2017

Comparisons to the U.S. Drought Monitor on Jan 3 and Jan 24, 2017 are shown. The percentiles of groundwater from Noah-MP in LIS show dryness despite many winter storms. The USDM noted the dry groundwater well observations in many areas of Southern California in issuing the USDM maps for these dates. The root zone soil moisture percentiles do not tell the entire story.

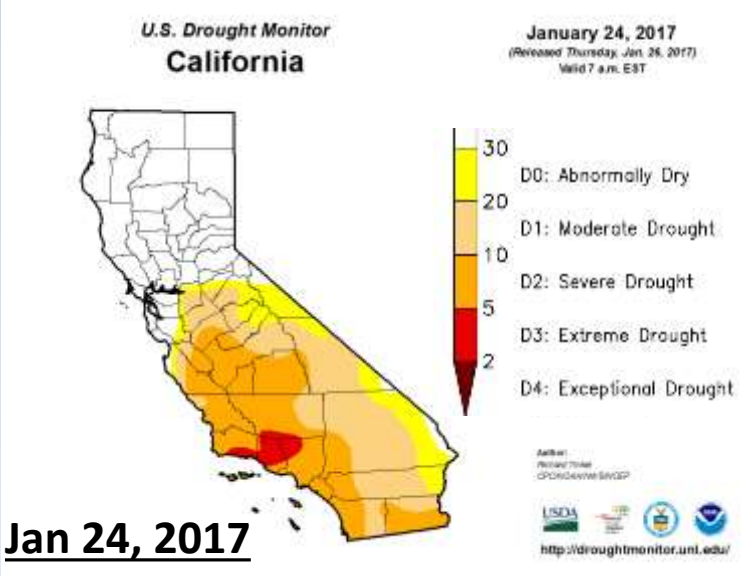



Jan 3, 2017

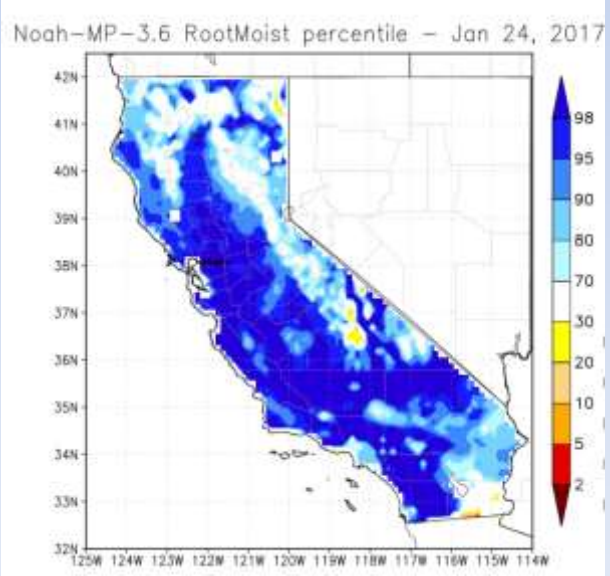


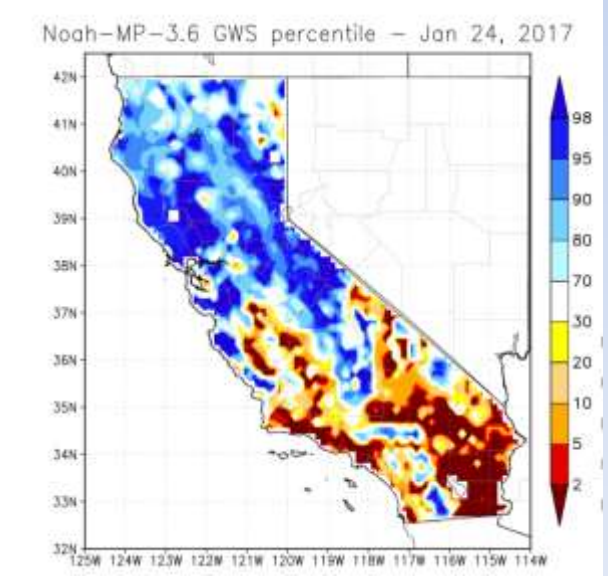




**U.S. Drought Monitor** **LIS Noah-MP Top 1-m soil moisture**



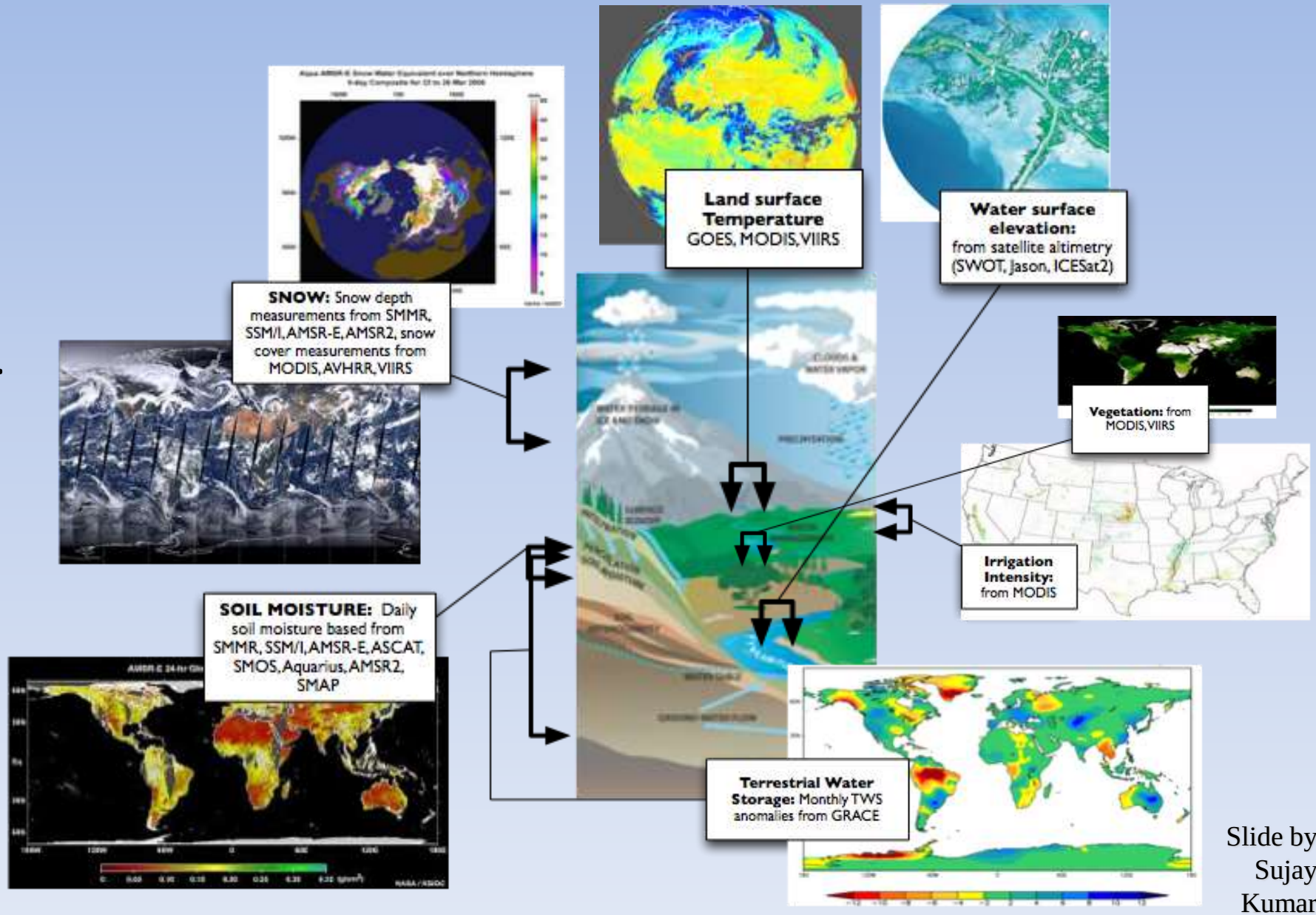

Jan 24, 2017



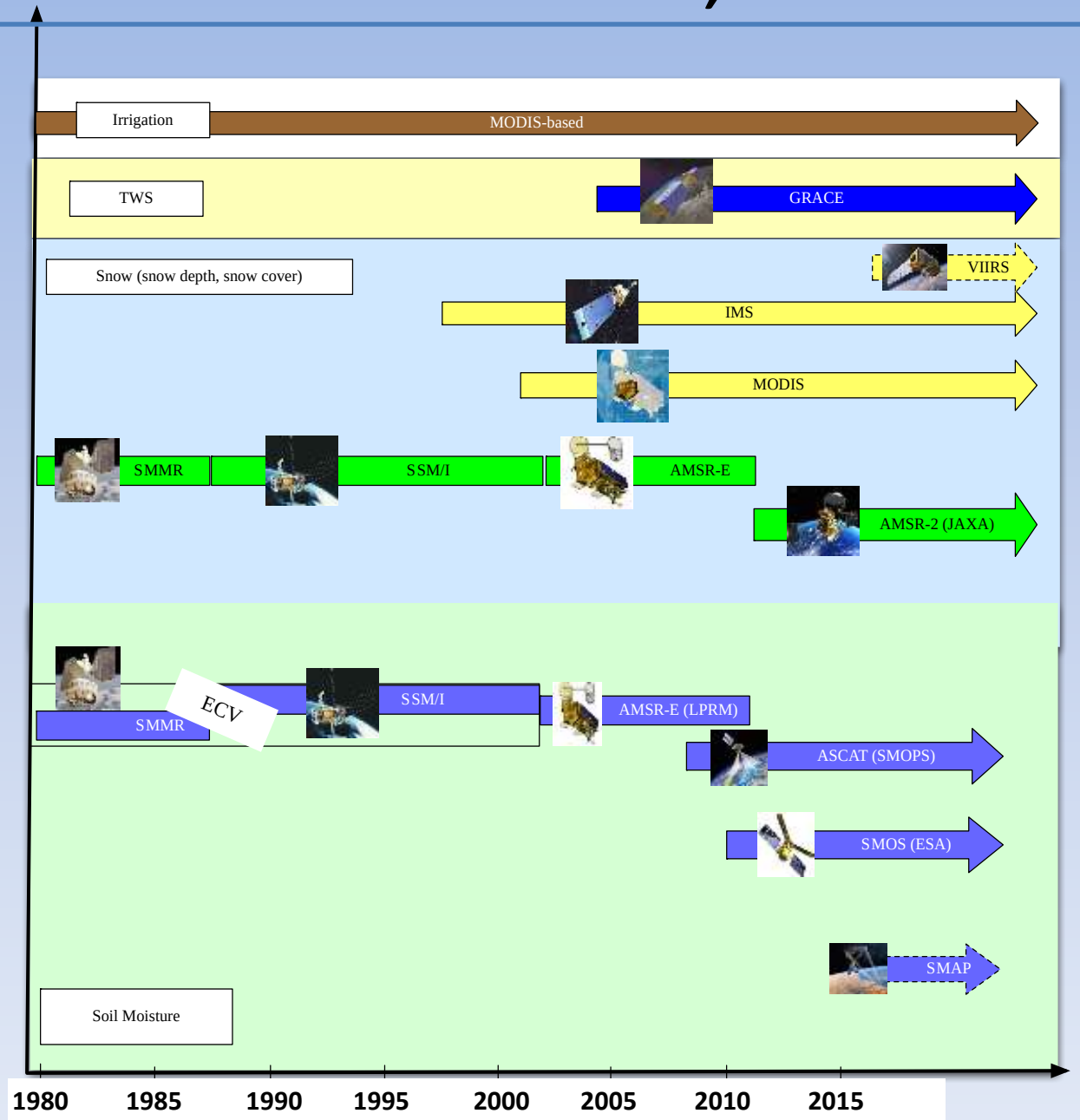
# NCA-LDAS Vision

- Create an enabling tool for development, evaluation, and dissemination of hydrological indicators to support the National Climate Assessment (NCA).
- Generate indicators through multivariate assimilation of satellite-era data products (1979-present) using the NASA Land Information System (LIS) software framework.

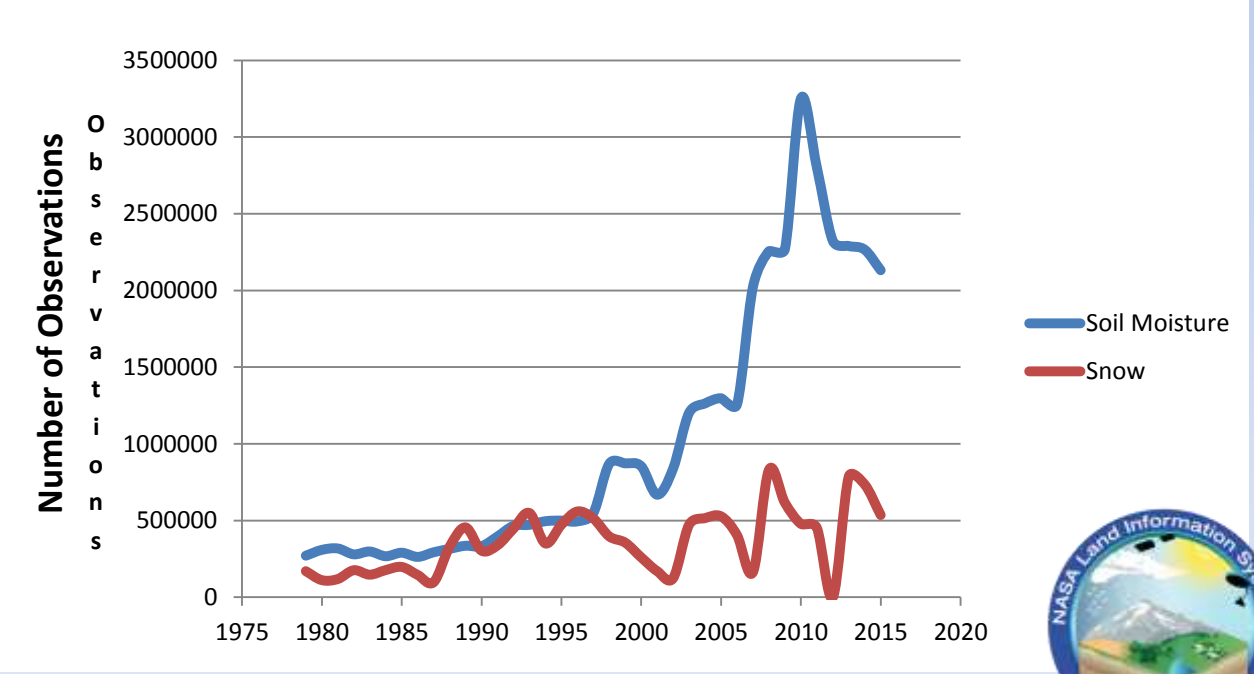



Slide by Sujay Kumar

# Multivariate, Multisensor Data Assimilation




**Model domain**: Same as NLDAS (1/8th-degree centered over CONUS)
**Forcing data**: NLDAS Phase 2 (w/ daily CPC gauge-based precipitation)
**Models**: Noah LSM ver 3.3, and CLSM Fortuna-2.5: a 60-year spin-up, followed by 36-year simulation; streamflow simulations using HyMAP (Getirana et al. 2012)
**Data assimilation method**: 1-d Ensemble Kalman Filter (EnKF) and 3-d Ensemble Kalman Smoother (EnKS)
**Time period**: Jan 1, 1979 to Dec 31, 2015




Slide by Sujay Kumar

# Univariate Assimilation Experiments/Papers


2446 JOURNAL OF HYDROMETEOROLOGY VOLUME 15

SPECIAL Advances in Drought Monitoring COLLECTION

**Assimilation of Remotely Sensed Soil Moisture and Snow Depth Retrievals for Drought Estimation**

SUJAY V. KUMAR,* CHRISTA D. PETERS-LIDARD,+ DAVID MOCKO,* ROLF REICHLE,# YUQIONG LIU,& KRISTI R. ARSENAULT,* YOULONG XIA,** MICHAEL EK,++ GEORGE RIOGS,** BEN LIVNEH,@@ AND MICHAEL COSH&&

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\# Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland
& Earth System Science Interdisciplinary Center, University of Maryland, College Park, College Park, and


1736 JOURNAL OF HYDROMETEOROLOGY VOLUME 16

**Quantifying the Added Value of Snow Cover Area Observations in Passive Microwave Snow Depth Data Assimilation**

SUJAY V. KUMAR,*+ CHRISTA D. PETERS-LIDARD,+ KRISTI R. ARSENAULT,*+ AUGUSTO GETIRANA,*# DAVID MOCKO,*+@ AND YUQIONG LIU*&

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(Manuscript received 30 January 2015, in final form 2 April 2015)

ABSTRACT


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**Assimilation of Gridded GRACE Terrestrial Water Storage Estimates in the North American Land Data Assimilation System**

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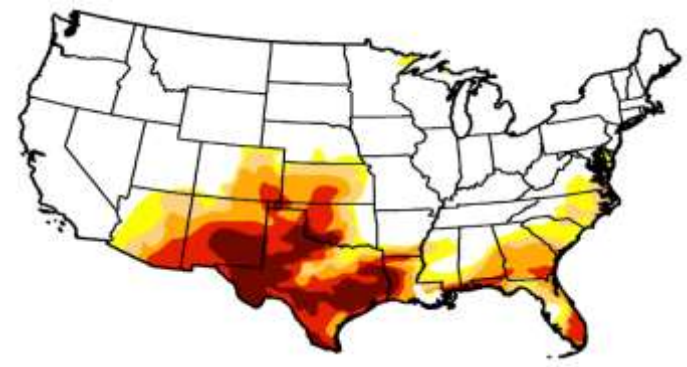
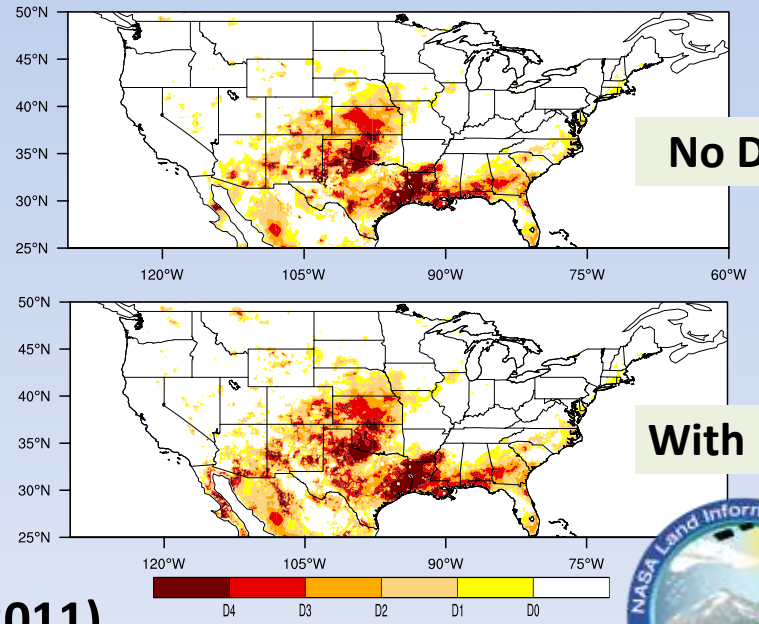
Univariate data assimilation experiments demonstrated that:

- Assimilation of satellite soil moisture, snow, and terrestrial water storage observations improved water cycle components of soil moisture, snow, terrestrial water storage, and evapotranspiration.
- Joint use of snow cover and passive microwave based snow depth data reduced RMSEs.
- Use of gridded GRACE TWS anomalies for DA are beneficial.
- These improvements also translated to short-term improvements for applications such as drought monitoring.



**U.S. Drought Monitor**




**Impact of soil moisture DA on drought estimates (May 10-17, 2011)**

Slide by Sujay Kumar

# LDAS Data Availability at NASA/GSFC

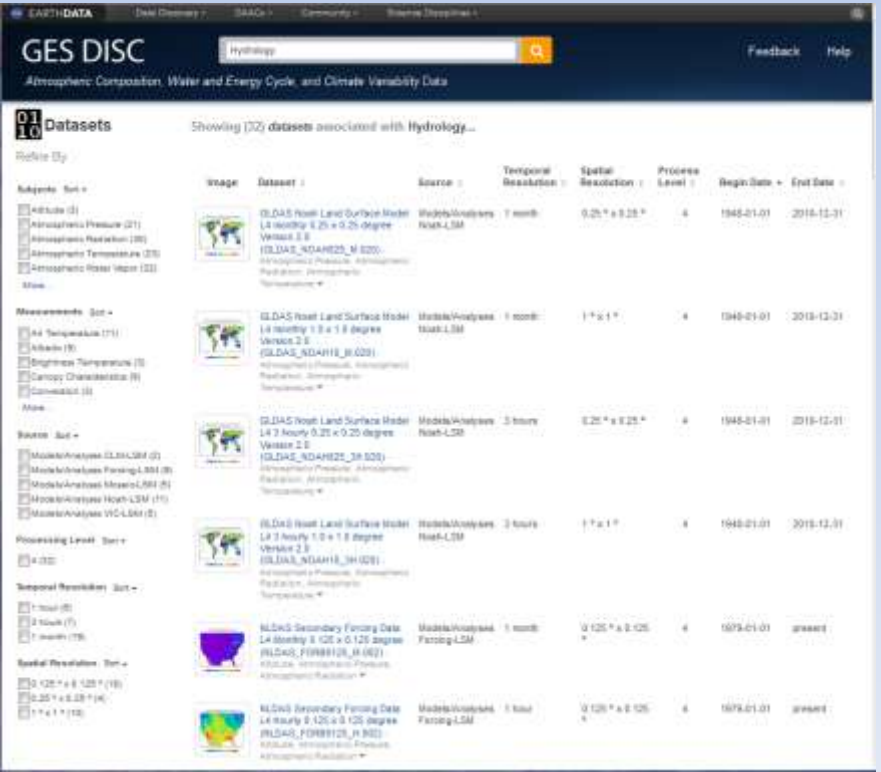
## https://disc.gsfc.nasa.gov/hydrology

**NLDAS**: (Phase 1 and Phase 2)
0.125°, 1979-present (~3.5-day latency): Noah, Mosaic, VIC

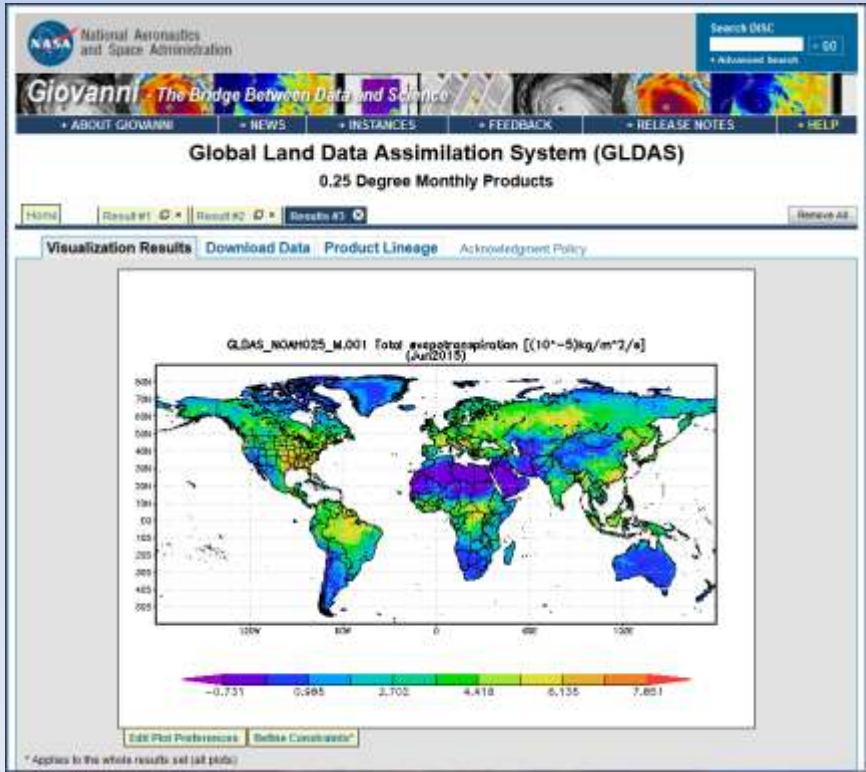
**NCA-LDAS**:
0.125°, 1979-2015 (annual updates expected): Noah
(CLSM to come)

**GLDAS**: (v1.0, v2.0, v2.1)
1.0° or 0.25°, 1979-present (1-2 month latency) or 1948-2010: Noah, Mosaic, VIC, CLM-2

**FLDAS**:
0.25° or 0.1°, 1982 or 2001-present (~1-day latency): Noah, VIC




- Access via HTTP, GDS, or quick-look visualization in Giovanni (right)
- GRIB-1 and NetCDF formats
- On-the-fly subsetting
- Full documentation, including README files and a FAQ
- LDAS projects support a growing number of national/international hydrometeorological investigations and water resources applications



# Next steps

- Next phase of NLDAS will include new/updated LSMs with data assimilation of operational remotely-sensed products – and close the 3.5-day latency gap
- NLDAS will also expand the domain and to go finer resolution (details in a forthcoming white paper written in coordination with NOAA/NCEP)
- NCA-LDAS is expected to have annual updates to extend the record as well as include the assimilation of additional remotely-sensed products
- Studies with all LDAS systems are updated on the websites, including a LIS blog
- Datasets and documentation are being updated and a mailing list is available

**@NASA_LIS**

https://disc.gsfc.nasa.gov/hydrology

http://ldas.gsfc.nasa.gov/ http://lis.gsfc.nasa.gov/

# Take-away Messages

- A Land Data Assimilation System – or LDAS – is a dataset from land-surface models (LSMs) forced with the best-available observations to support water resources applications, including drought monitoring
- Remotely-sensed land satellite observations are assimilated into the LSMs to improve the depiction of water/energy cycles
- The NASA Land Information System (LIS) software framework is used for several different LDASs and datasets/documentation are available from NASA/GSFC
- Data assimilation has been shown to improve LDAS depiction of soil moisture, snow, evaporation, and streamflow compared to in situ & gridded observations

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