The NLDAS Drought Monitor

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Youlong Xia[3,4], Michael B. Ek[3], Jiarui Dong[3,4]

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

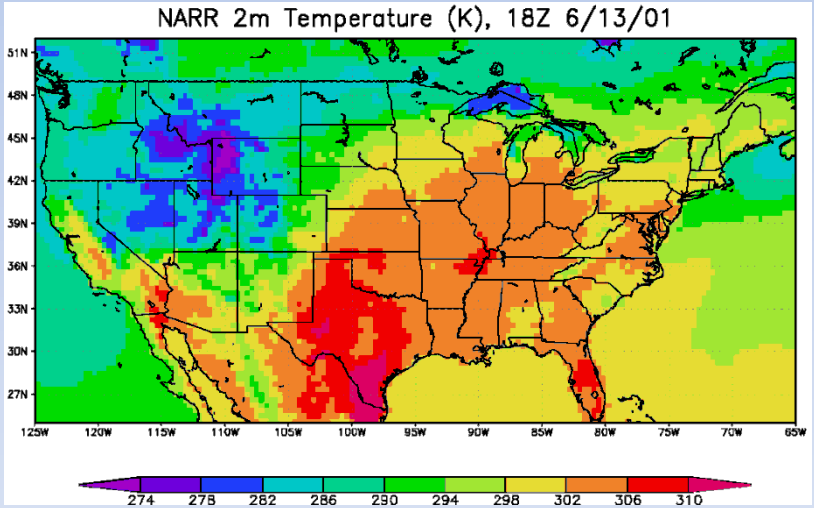
Acknowledgements: Brian Cosgrove[5], Shugong Wang[1,2], Kristi Arsenault[1,2], Yuqiong Liu[1,5], Grey Nearing[1,2], Augusto Getirana[1,6], Sarith Mahanama[1,7], Benjamin Zaitchik[8], Jim Geiger[1], Michael Jasinski[1] , Bailing Li[1,6], Hualan Rui[1,9], Bill Teng[1,9], Bruce Vollmer[1], and numerous members of both the NLDAS and LIS teams over the last 15+ years

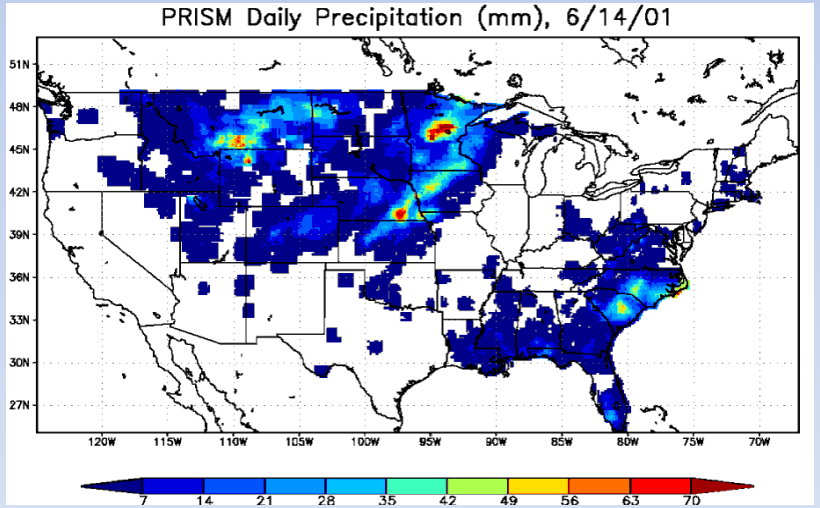
1 – NASA/GSFC; 2 – SAIC; 3 – NOAA/NCEP/EMC; 4 – IMSG; 5 – OHD; 6 – Univ. MD; 7 – SSAI; 8 – Johns Hopkins Univ.; 9 - ADNET

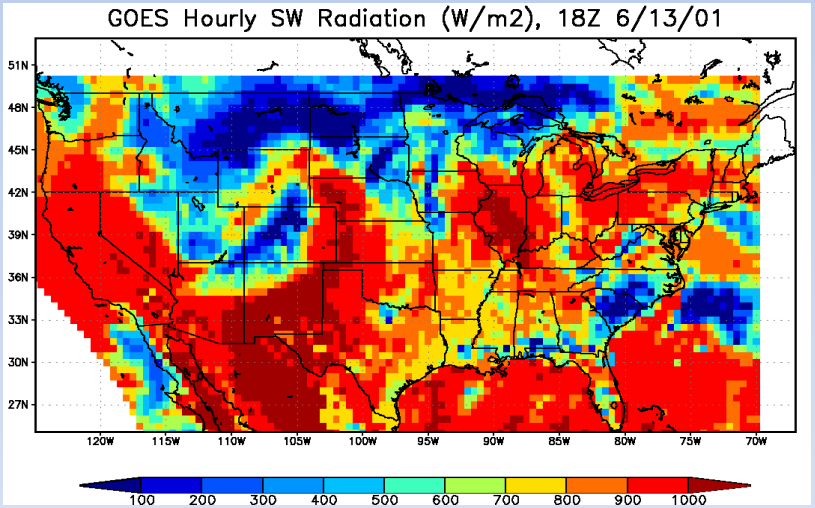
NLDAS combines a high-quality surface forcing dataset and land-surface modeling to produce consistent products

- January 1979 to near real-time (~3.5-day lag); hourly and monthly available
- 1/8th-degree (~12.5km) over CONUS domain (25-53°N; 125-67°W)

NARR near-surface meteorology	CPC Daily Precipitation Analysis	Bias-corrected SW radiation (SRB)

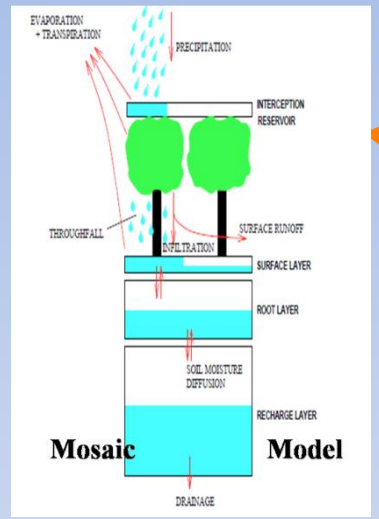




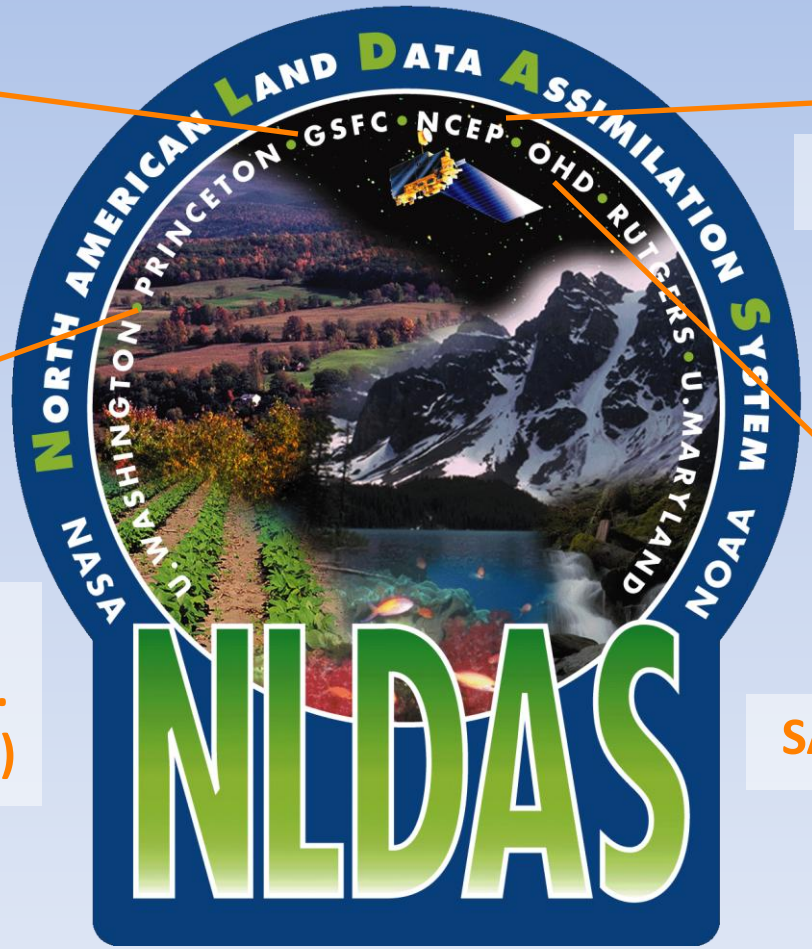


- Stage II radar, CMORPH, other precipitation datasets, or NARR used to temporally disaggregate the CPC Daily Analysis into hourly precipitation

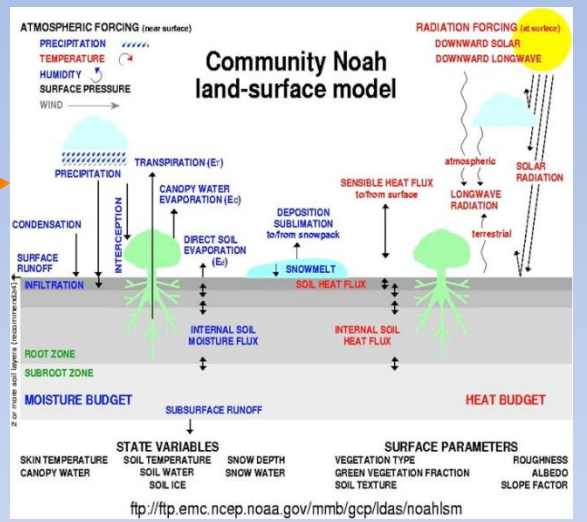
NLDAS forcings drive four separate land-surface models to produce surface/ground states and fluxes

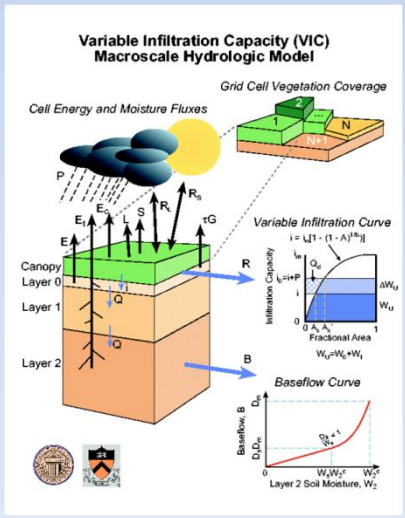


Mosaic (GSFC)



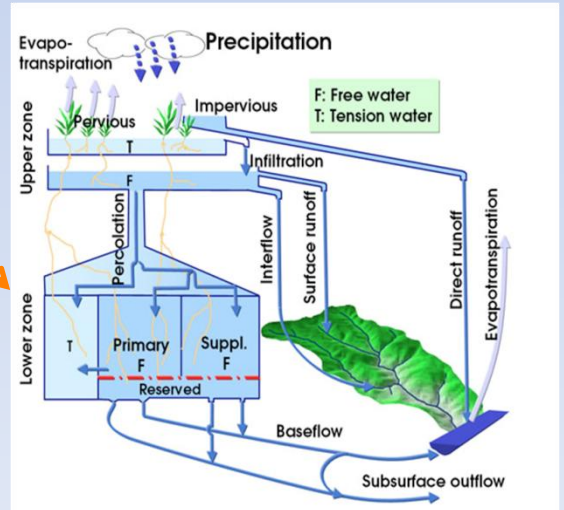
Noah (NCEP)





VIC (Princeton Univ. and Univ. of Washington)

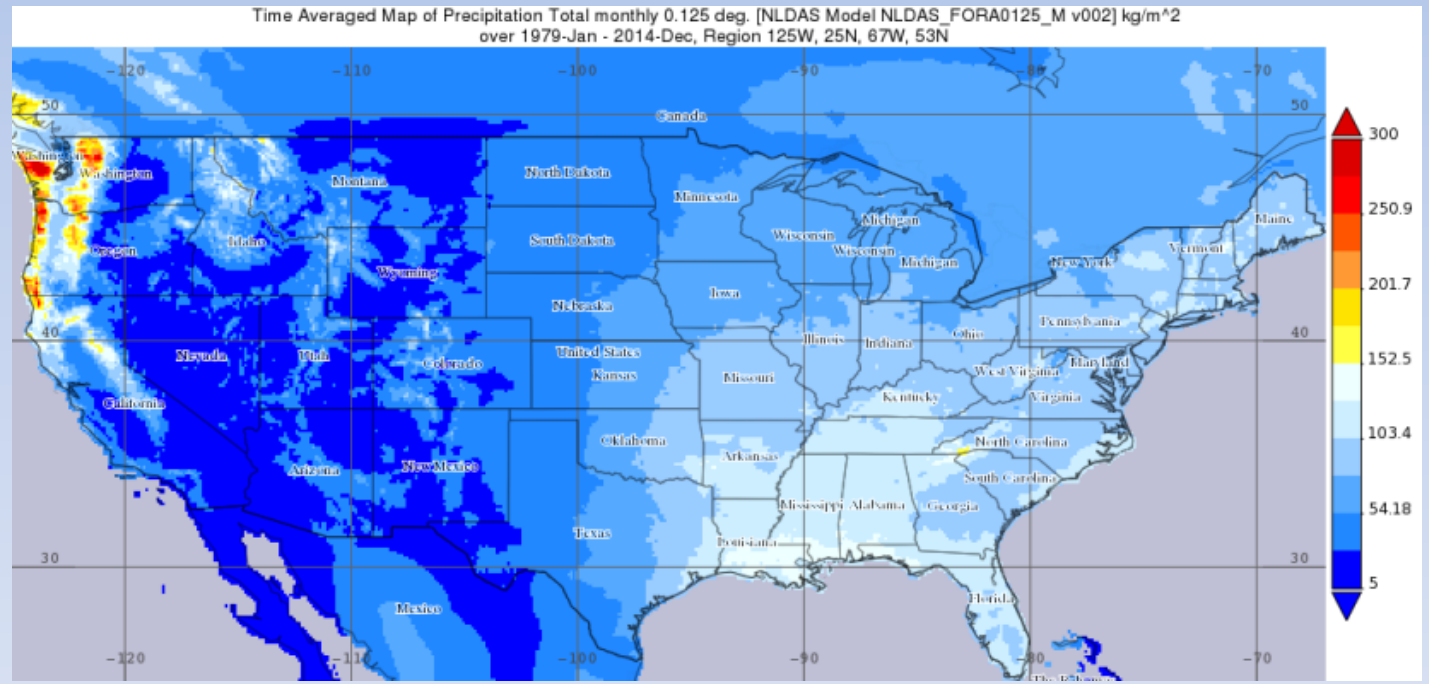
SAC (OHD)



The NASA Goddard Earth Sciences Data and Information Services Center provides NLDAS datasets and services

- Hourly/Monthly datasets available in GRIB-1 (or netCDF conversion service)
- Available via FTP, GDS, Mirador, Giovanni with variable/domain subsetting

	Data Type (Short Name)	Description	FTP	GDS	Mirador		Giovanni*	SSW**
					Navigation	Search		
NLDAS-1, 0.125 degree, North America (NLDAS-1 README)								
Hourly	NLDAS_FOR0125_H.001	Forcing	✓	✓	✓	✓	✓	✓
Monthly	NLDAS_FOR0125_M.001	Forcing	✓	✓	✓	✓	✓	
Monthly Climatology	NLDAS_FOR0125_MC.001	Forcing	✓	✓	✓	✓	✓	
NLDAS-2, 0.125 degree, North America (NLDAS-2 README)								
Hourly	NLDAS_FORA0125_H.002	Primary forcing	✓	✓	✓	✓	✓	✓
	NLDAS_FORB0125_H.002	Secondary forcing	✓	✓	✓	✓	✓	✓
	NLDAS_MOS0125_H.002	Mosaic Model	✓	✓	✓	✓	✓	✓
	NLDAS_NOAH0125_H.002	Noah Model	✓	✓	✓	✓	✓	✓
	NLDAS_VIC0125_H.002	VIC Model	✓	✓	✓	✓	✓	
Monthly	NLDAS_FORA0125_M.002	Primary forcing	✓	✓	✓	✓	✓	
	NLDAS_FORB0125_M.002	Secondary forcing	✓	✓	✓	✓	✓	
	NLDAS_MOS0125_M.002	Mosaic Model	✓	✓	✓	✓	✓	
	NLDAS_NOAH0125_M.002	Noah Model	✓	✓	✓	✓	✓	
	NLDAS_VIC0125_M.002	VIC Model	✓	✓	✓	✓	✓	
Monthly Climatology	NLDAS_FORA0125_MC.002	Primary forcing	✓	✓	✓	✓	✓	
	NLDAS_FORB0125_MC.002	Secondary forcing	✓	✓	✓	✓	✓	
	NLDAS_MOS0125_MC.002	Mosaic Model	✓	✓	✓	✓	✓	
	NLDAS_NOAH0125_MC.002	Noah Model	✓	✓	✓	✓	✓	
	NLDAS_VIC0125_MC.002	VIC Model	✓	✓	✓	✓	✓	



http://disc.sci.gsfc.nasa.gov/hydrology

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- Available via FTP, GDS, Mirador, Giovanni with variable/domain subsetting

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					Navigation	Search		
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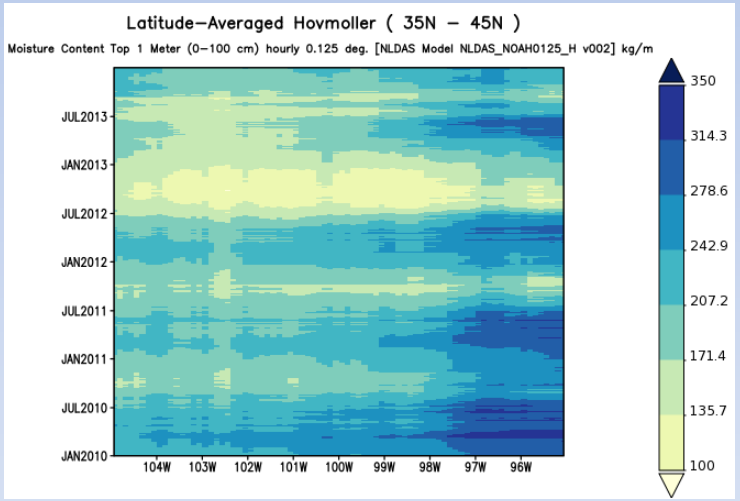
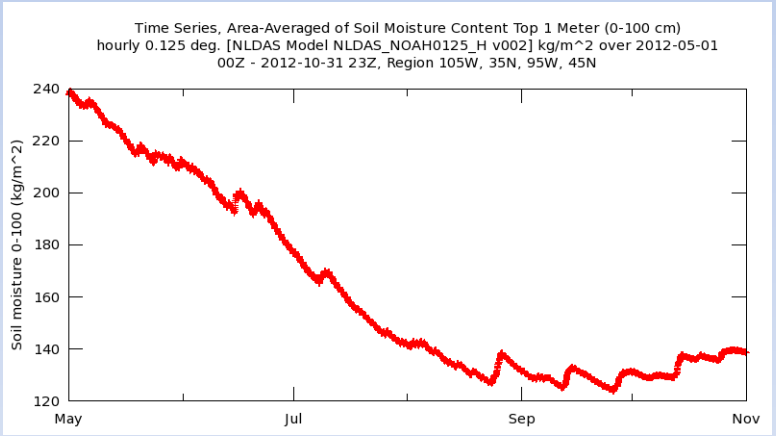
Hourly	NLDAS_FOR0125_H.001	Forcing	✓	✓	✓	✓	✓	✓
Monthly	NLDAS_FOR0125_M.001	Forcing	✓	✓	✓	✓	✓	
Monthly Climatology	NLDAS_FOR0125_MC.001	Forcing	✓	✓	✓	✓	✓	
NLDAS-2, 0.125 degree, North America (NLDAS-2 README)								
Hourly	NLDAS_FORA0125_H.002	Primary forcing	✓	✓	✓	✓	✓	✓
	NLDAS_FORB0125_H.002	Secondary forcing	✓	✓	✓	✓	✓	✓
	NLDAS_MOS0125_H.002	Mosaic Model	✓	✓	✓	✓	✓	✓
	NLDAS_NOAH0125_H.002	Noah Model	✓	✓	✓	✓	✓	✓
	NLDAS_VIC0125_H.002	VIC Model	✓	✓	✓	✓	✓	
Monthly	NLDAS_FORA0125_M.002	Primary forcing	✓	✓	✓	✓	✓	
	NLDAS_FORB0125_M.002	Secondary forcing	✓	✓	✓	✓	✓	
	NLDAS_MOS0125_M.002	Mosaic Model	✓	✓	✓	✓	✓	
	NLDAS_NOAH0125_M.002	Noah Model	✓	✓	✓	✓	✓	
	NLDAS_VIC0125_M.002	VIC Model	✓	✓	✓	✓	✓	
Monthly Climatology	NLDAS_FORA0125_MC.002	Primary forcing	✓	✓	✓	✓	✓	
	NLDAS_FORB0125_MC.002	Secondary forcing	✓	✓	✓	✓	✓	
	NLDAS_MOS0125_MC.002	Mosaic Model	✓	✓	✓	✓	✓	
	NLDAS_NOAH0125_MC.002	Noah Model	✓	✓	✓	✓	✓	
	NLDAS_VIC0125_MC.002	VIC Model	✓	✓	✓	✓	✓	

“Flash” Drought in the central U.S. during summer 2012





http://disc.sci.gsfc.nasa.gov/hydrology

NLDAS datasets are widely-used for different applications and scientific studies – including drought monitoring

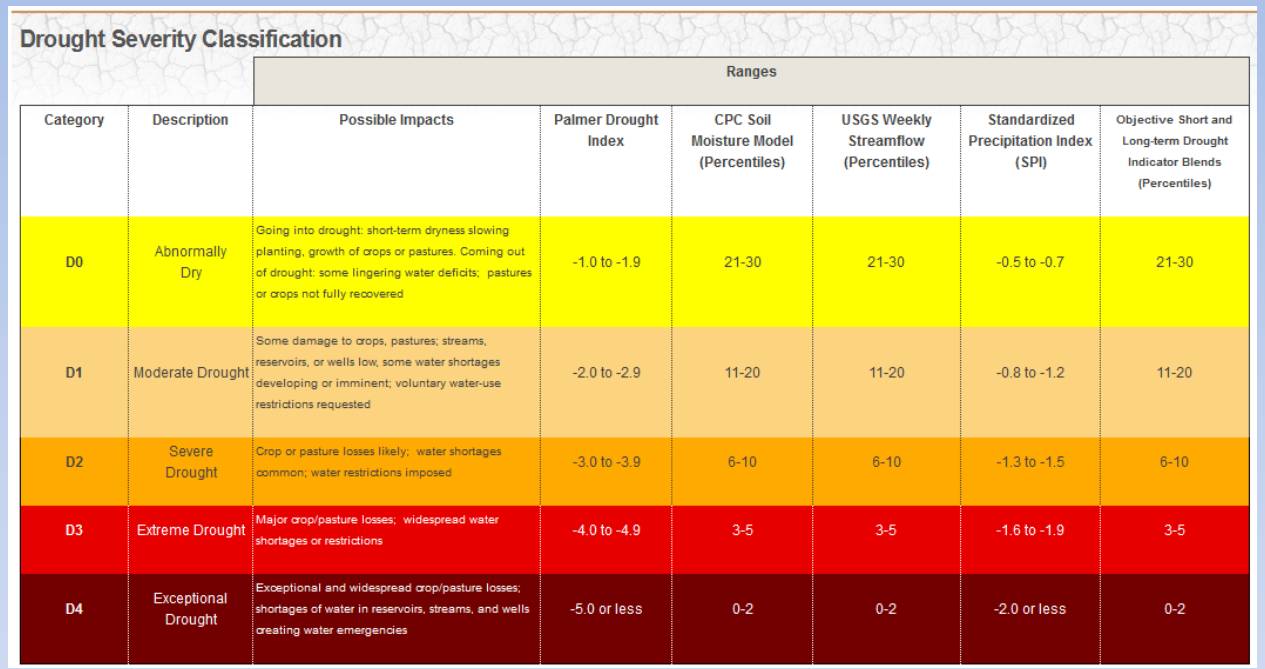
Other uses: initial conditions for numerical weather/climate simulations, watershed and water quality studies/monitoring, CUAHSI hydrologic studies, crop failure insurance estimates, West Nile virus spread and mosquito monitoring, water management, etc.

Distribution of all NLDAS products from the NASA GES DISC alone for calendar year 2014:

- Number of Distinct Users: 5,437
- Number of Files: Over 44 million
- Total Volume: Over 93 Tb

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

The NLDAS Drought Monitor produces anomalies and percentiles relative to a 28-year climatology (1980-2007)



Drought Severity Classification

		Ranges					
Category	Description	Possible Impacts	Palmer Drought Index	CPC Soil Moisture Model (Percentiles)	USGS Weekly Streamflow (Percentiles)	Standardized Precipitation Index (SPI)	Objective Short and Long-term Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	-1.0 to -1.9	21-30	21-30	-0.5 to -0.7	21-30
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested	-2.0 to -2.9	11-20	11-20	-0.8 to -1.2	11-20
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed	-3.0 to -3.9	6-10	6-10	-1.3 to -1.5	6-10
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions	-4.0 to -4.9	3-5	3-5	-1.6 to -1.9	3-5
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0-2	0-2	-2.0 or less	0-2

U.S. Drought Monitor Classification

D0 = Abnormally Dry (21-30%)
D1 = Moderate Drought (11-20%)
D2 = Severe Drought (6-10%)
D3 = Extreme Drought (3-5%)
D4 = Exceptional Drought (0-2%)

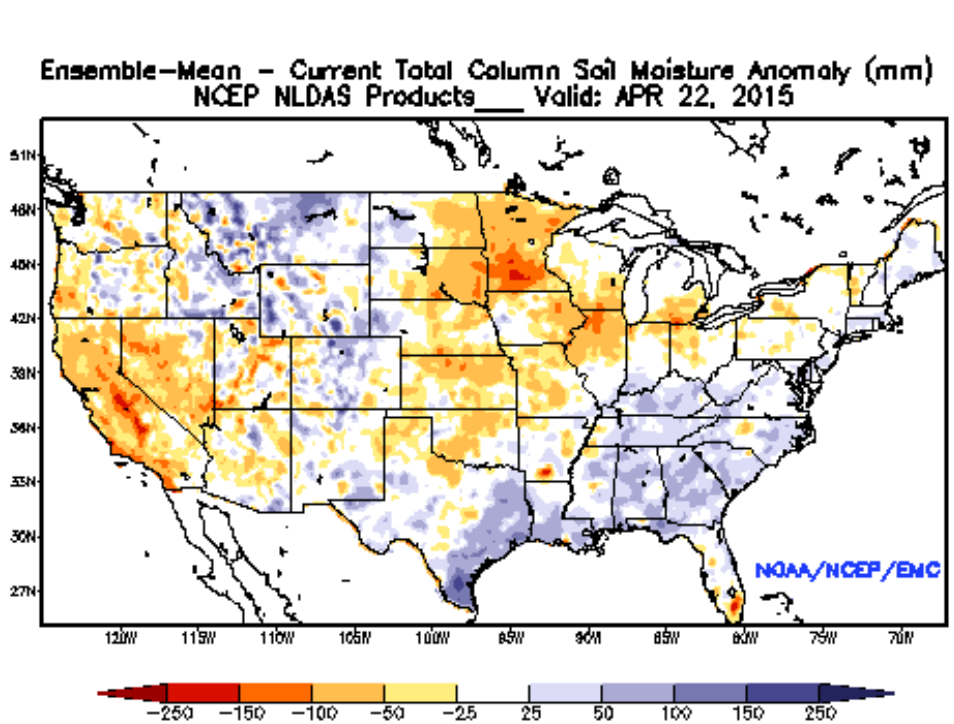
Anomalies are calculated relative to the climatology on that day of the year.
Percentiles are calculated using a 5-day moving window about that day of the year in the climatology, to smooth the records and prevent spurious changes.

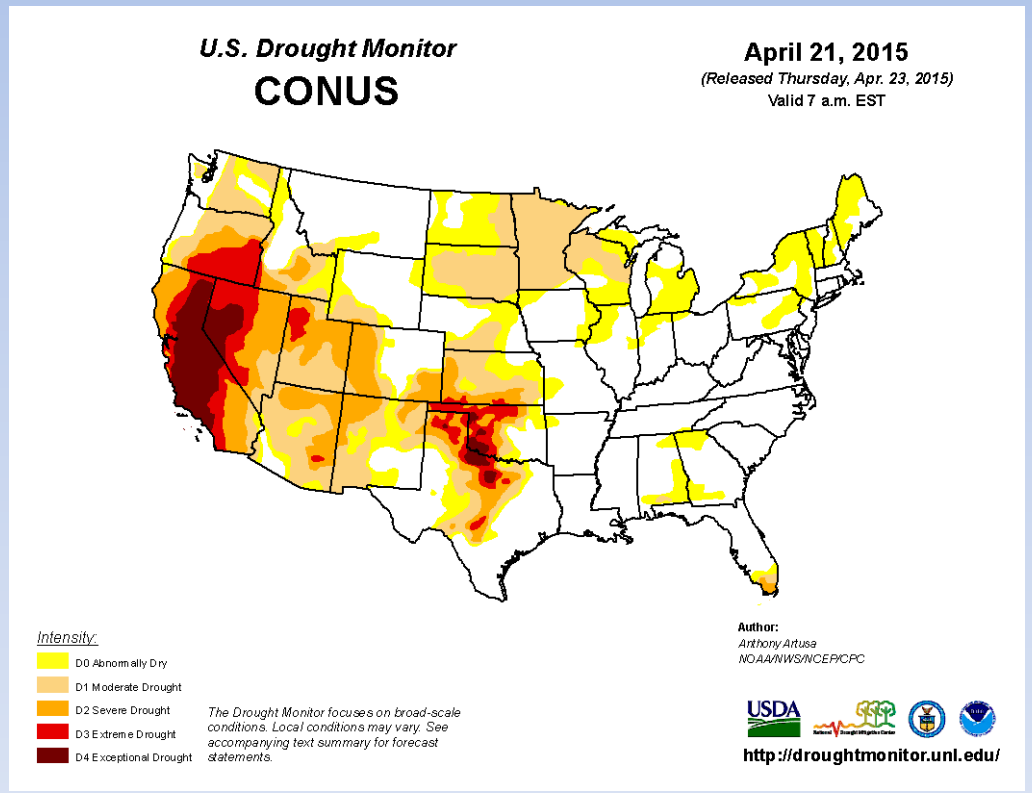
http://www.drought.gov/ http://droughtmonitor.unl.edu/

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)

Soil Moisture Anomaly (mm)





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

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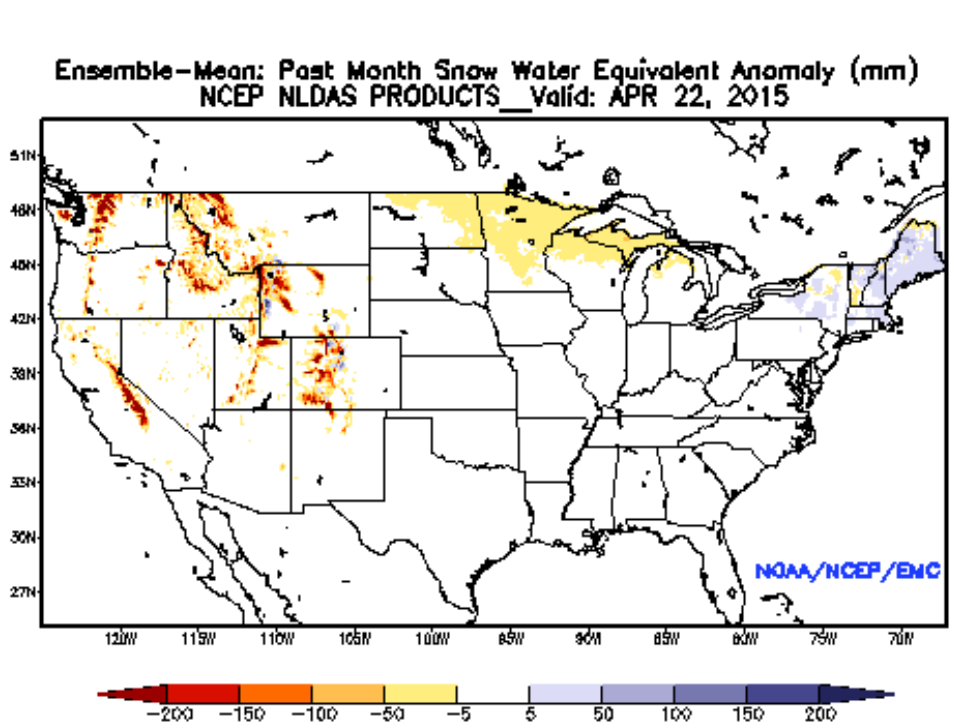
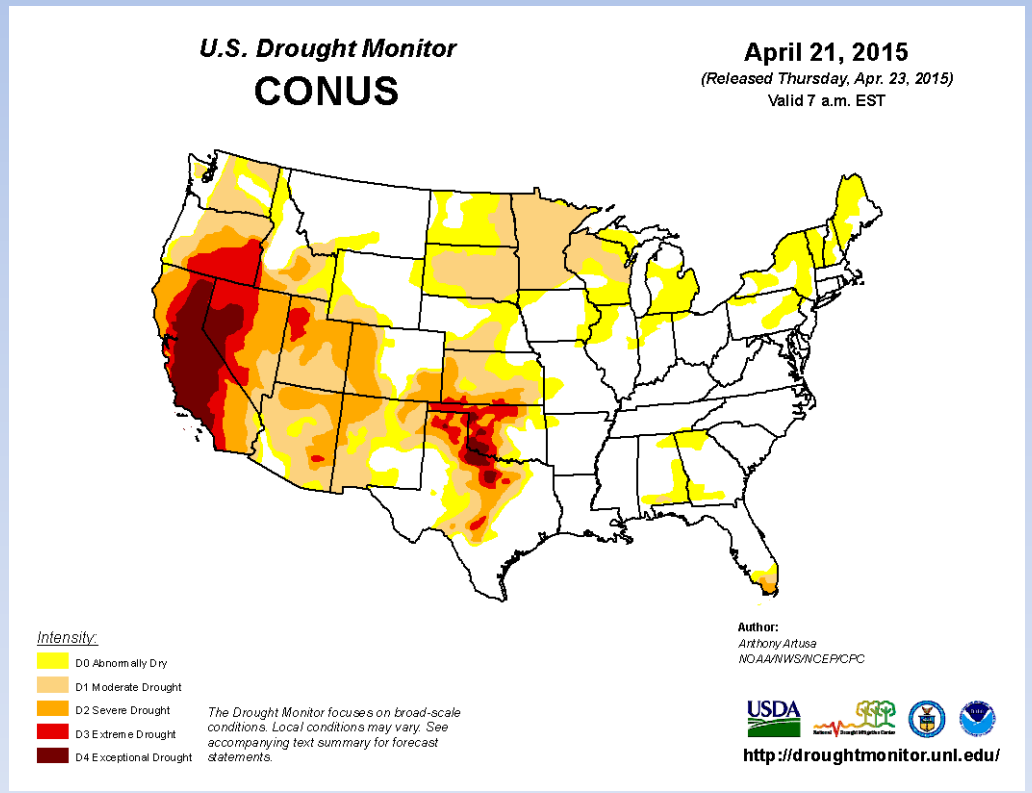
Percentiles and anomalies of: precipitation, soil moisture, snow, evaporation, runoff, and streamflow (from river routing)

Snow Water Equiv. Anomaly (mm)





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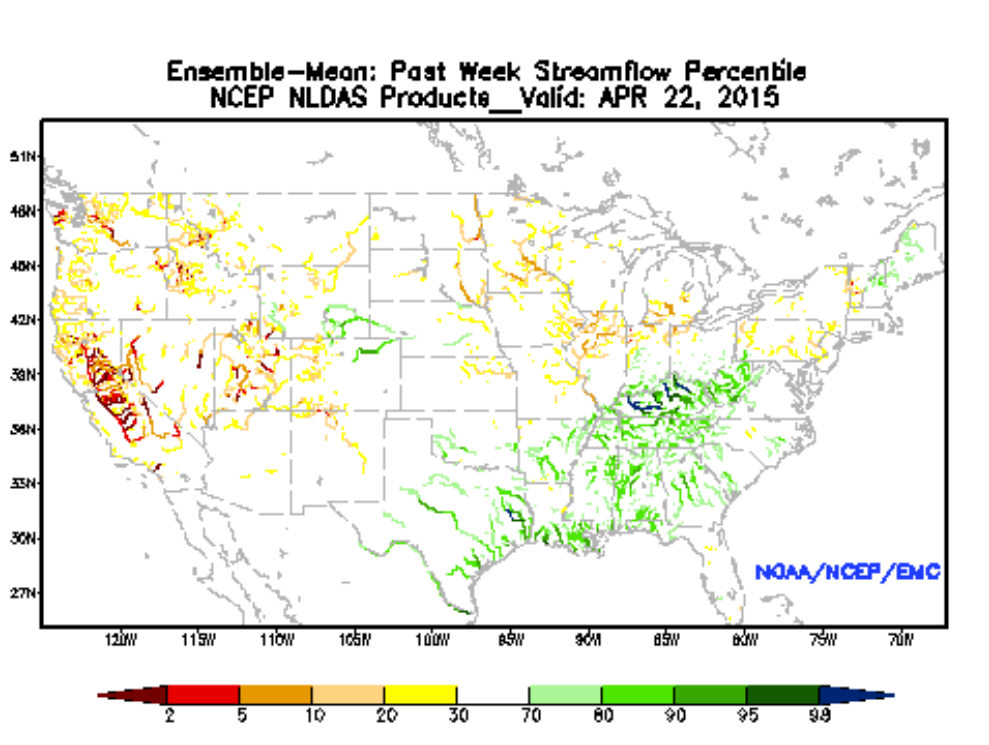
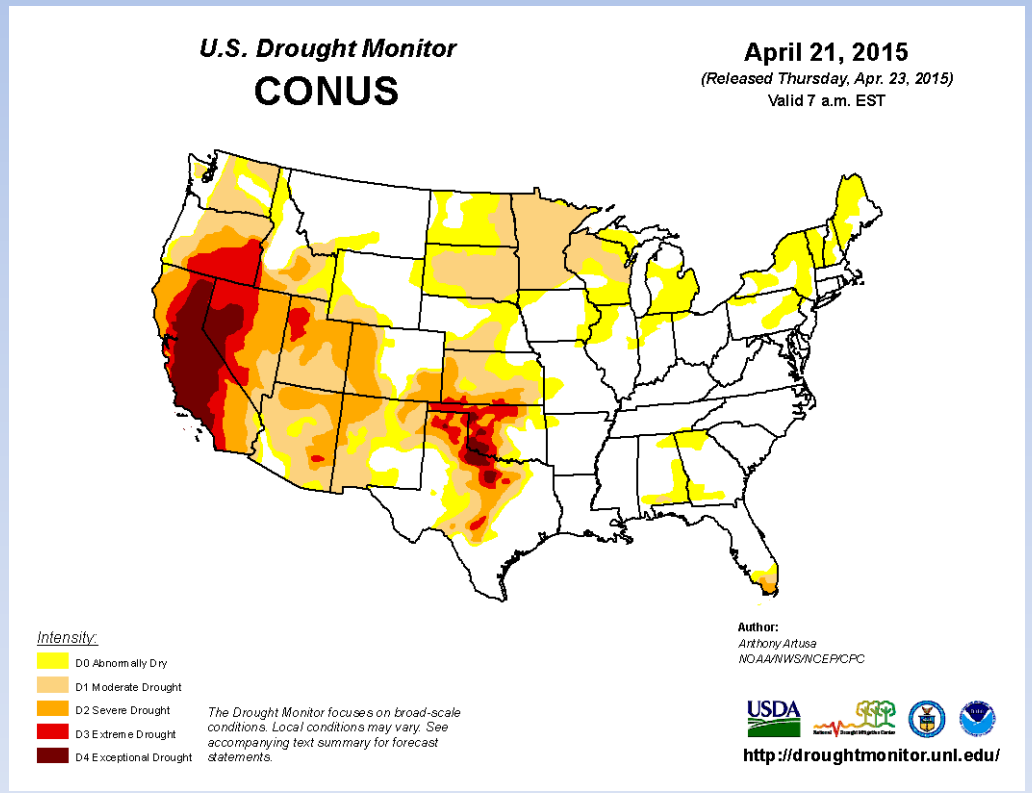
Streamflow Percentile





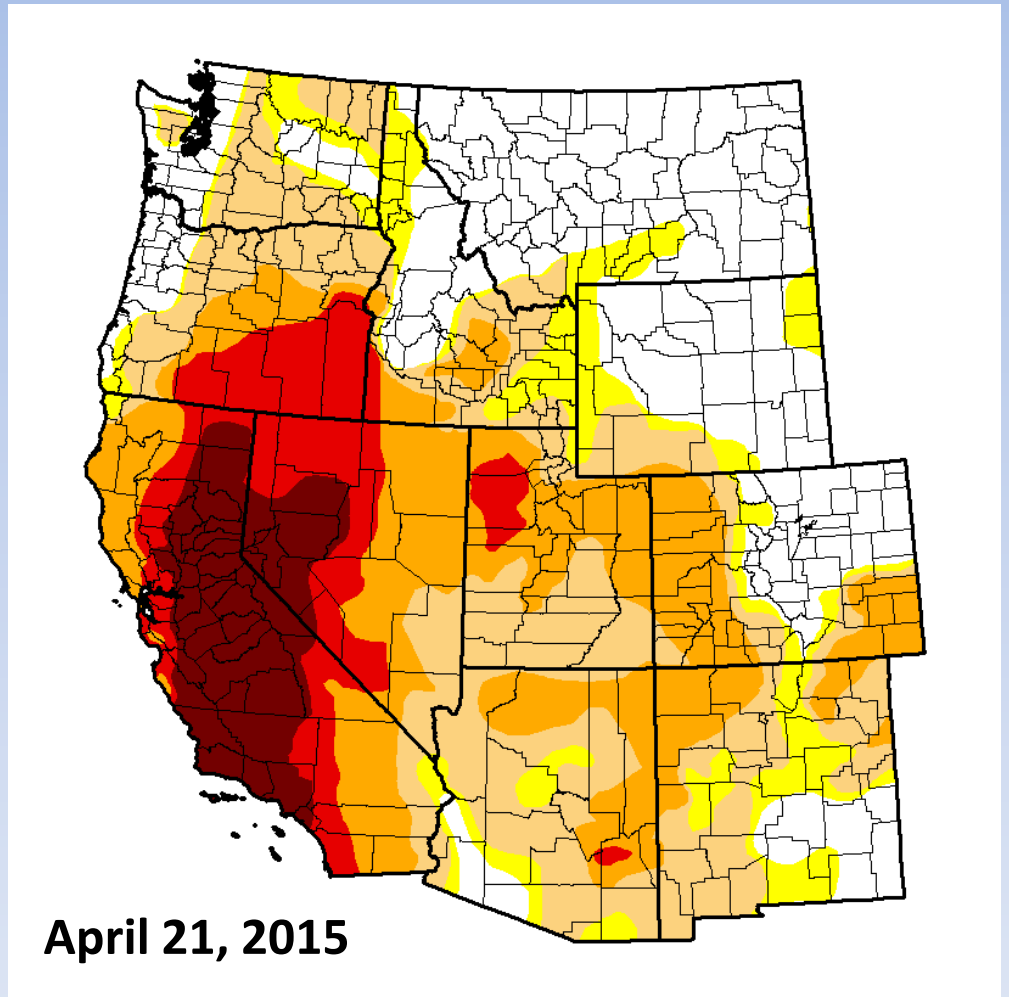
http://www.emc.ncep.noaa.gov/mmb/nldas/drought/

California and other western states are experiencing a multi-year severe to exceptional drought

2011

March 19th of each year

Yosemite Conservancy webcam at Half Dome



U.S. Drought Monitor

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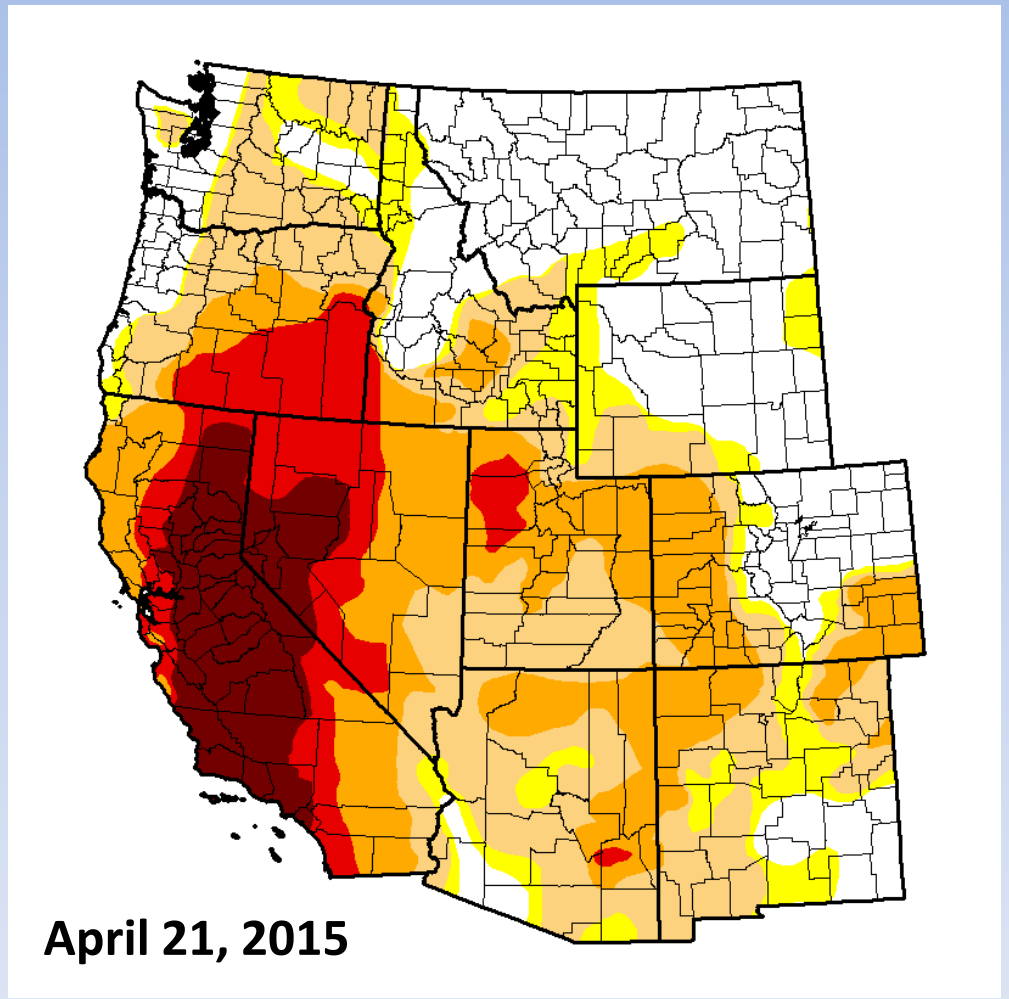

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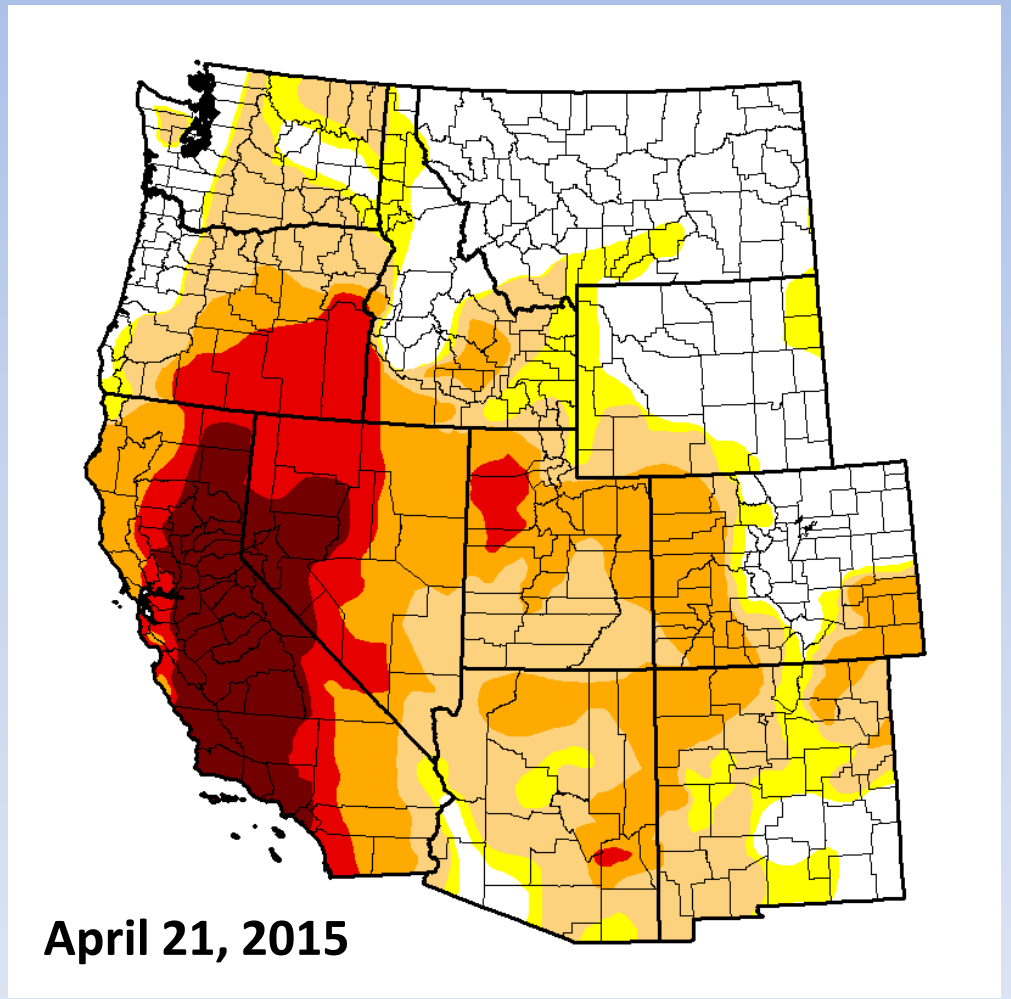


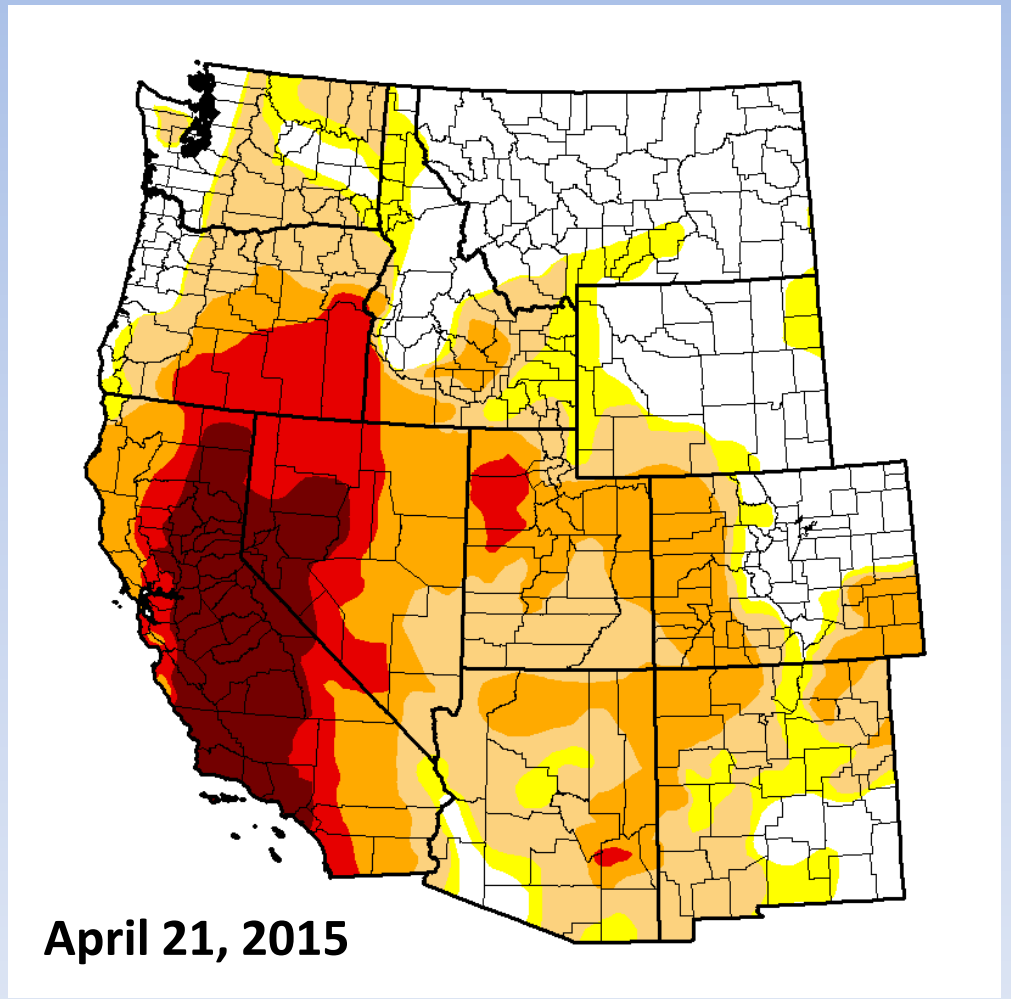
U.S. Drought Monitor

California and other western states are experiencing a multi-year severe to exceptional drought

2014

March 19th of each year

Yosemite Conservancy webcam at Half Dome



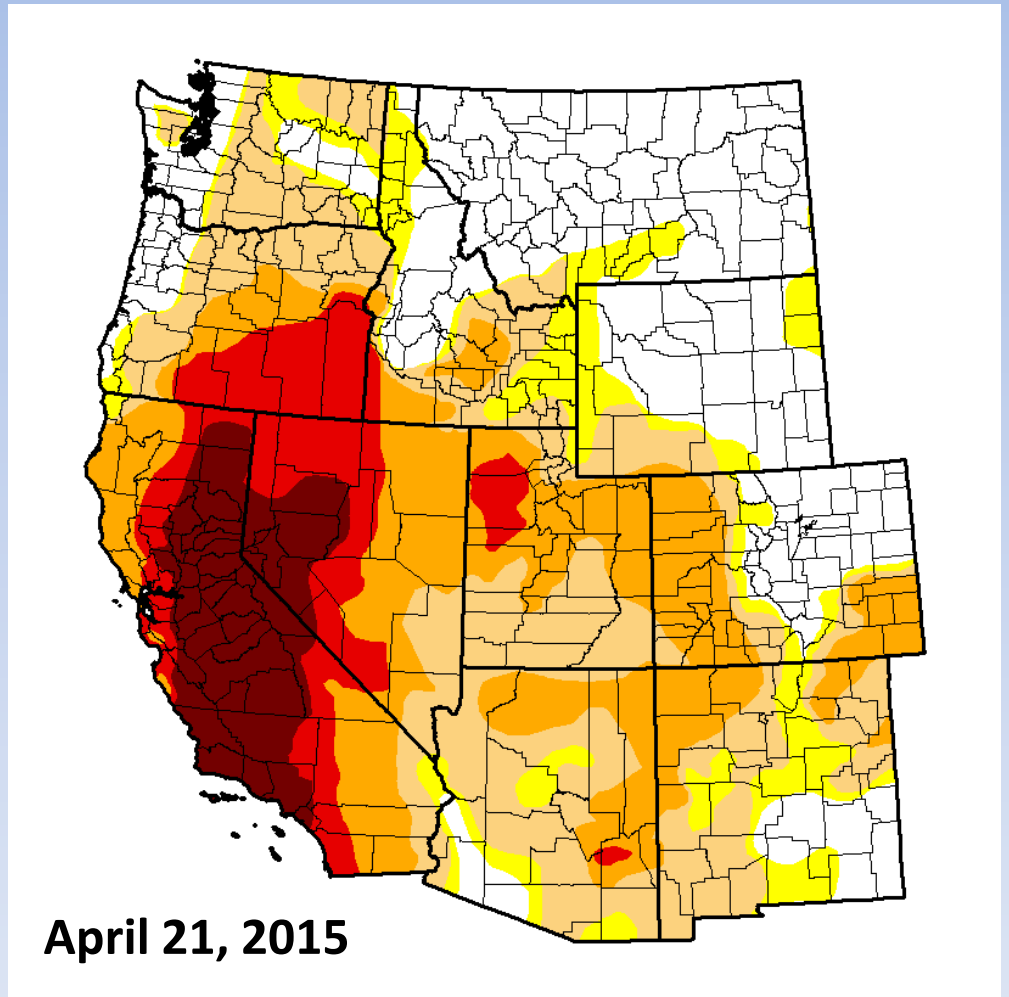
U.S. Drought Monitor

California and other western states are experiencing a multi-year severe to exceptional drought

2015

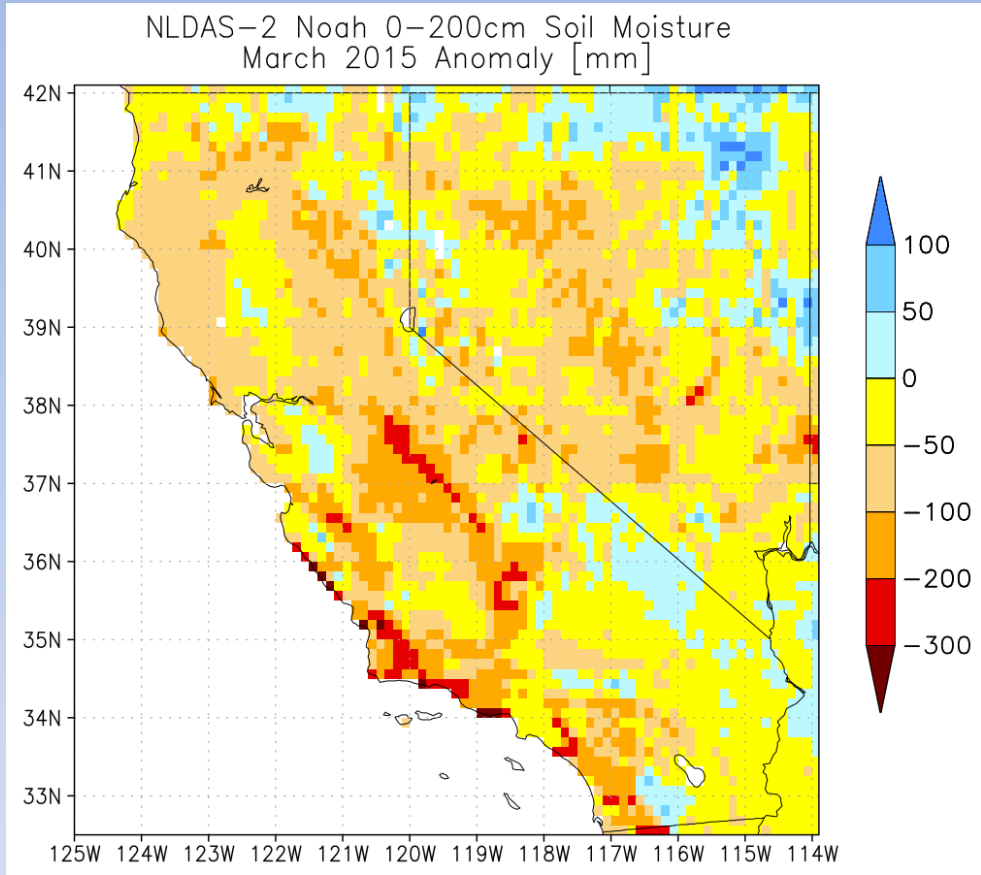
March 19th of each year

Yosemite Conservancy webcam at Half Dome

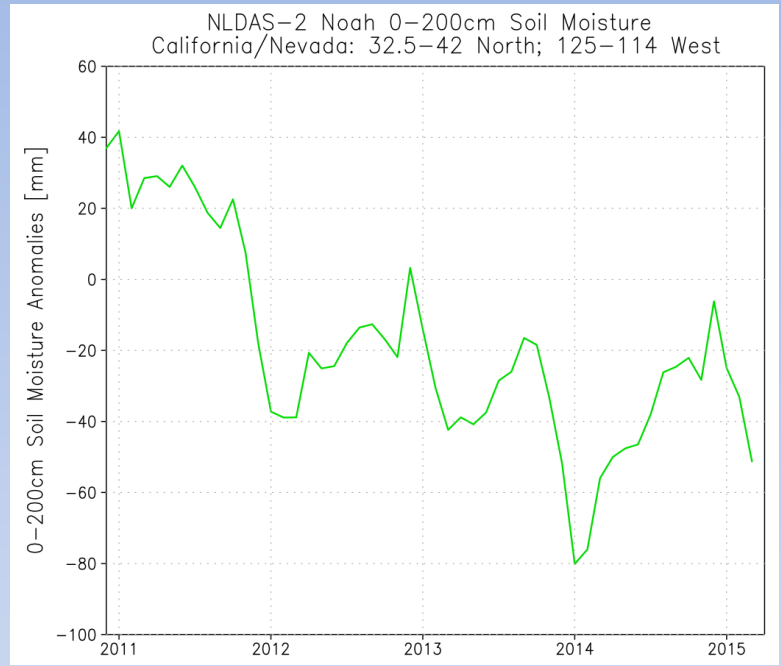


U.S. Drought Monitor

NLDAS datasets show the drought in California and Nevada

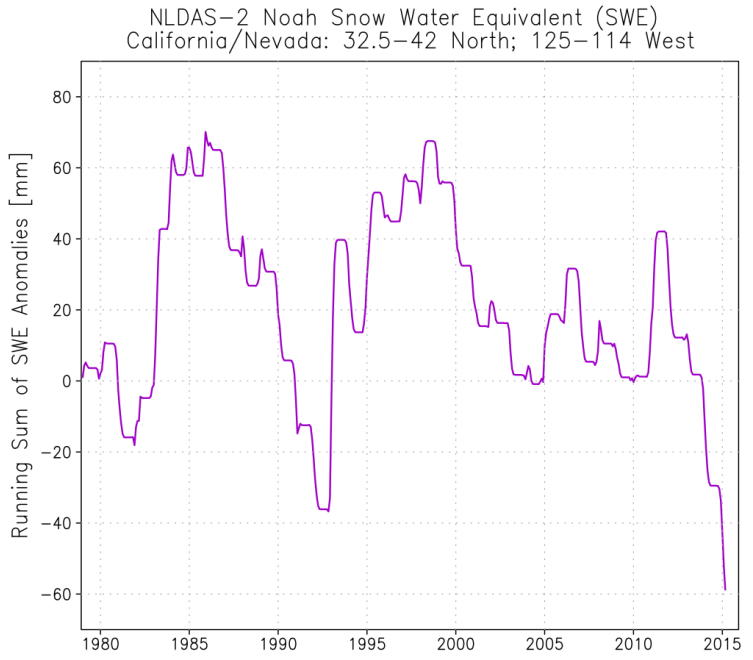


Anomalies with respect to 1980-2009 monthly climatology



Monthly Soil Moisture Anomalies for the past four years (2011-2015)

Running Sum of Snow Anomalies for the entire NLDAS-2 record



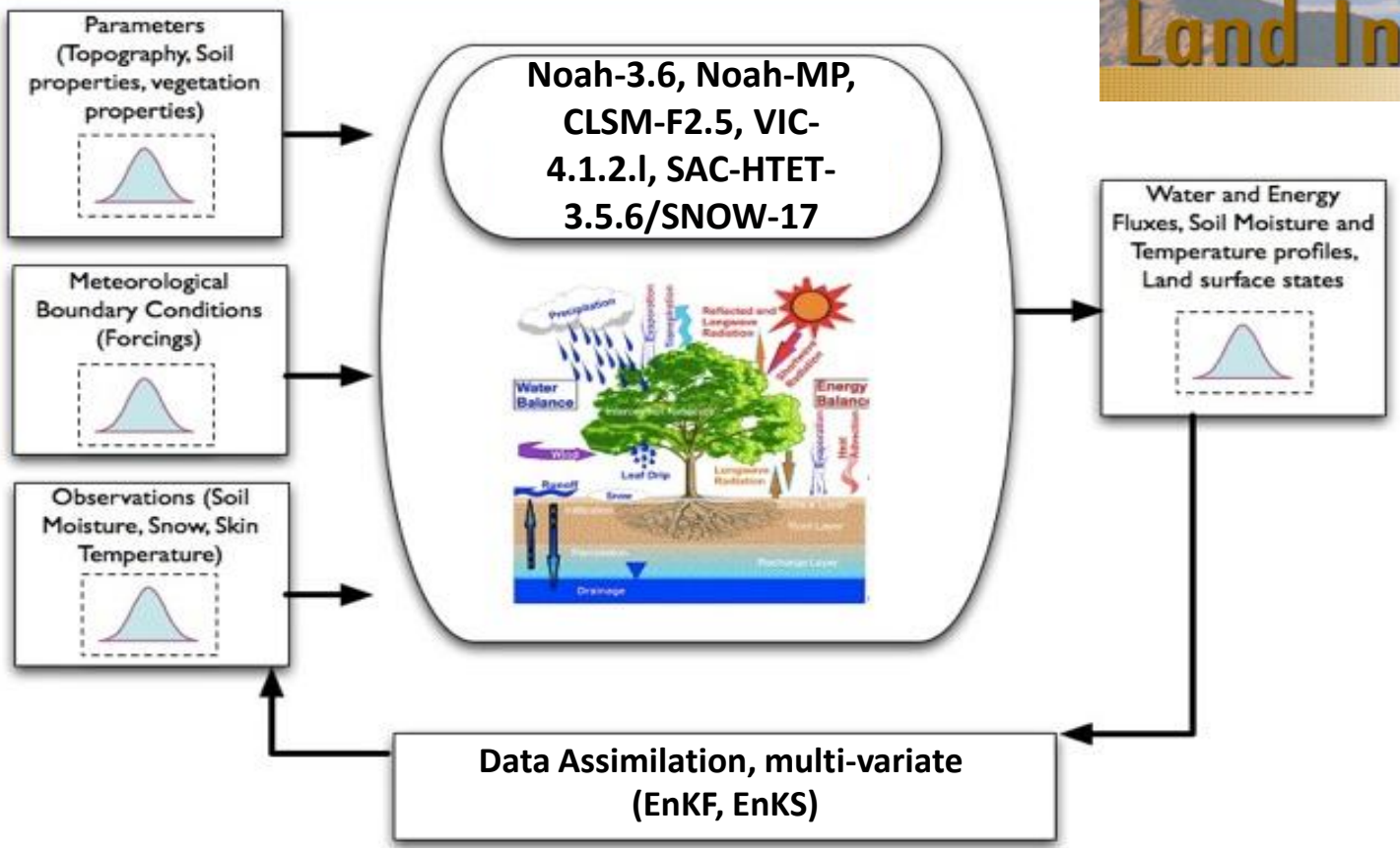
The next phase of NLDAS will use updated models and data assimilation using NASA's Land Information System

LIS-based next phase of NLDAS

1979 – Present Updated w/ Larger Domain Forcings and Parameters at 4-km

Satellite EDRs*

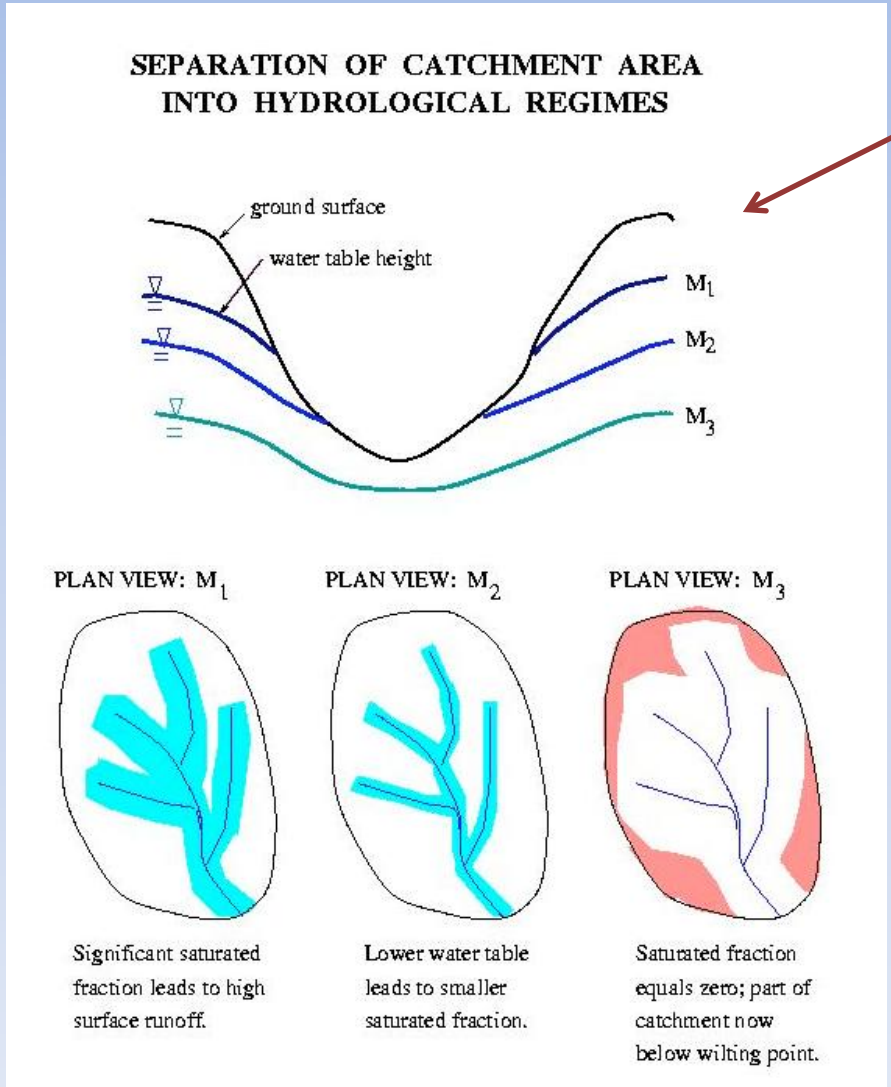
SM, SCA, SWE, TWS, and II



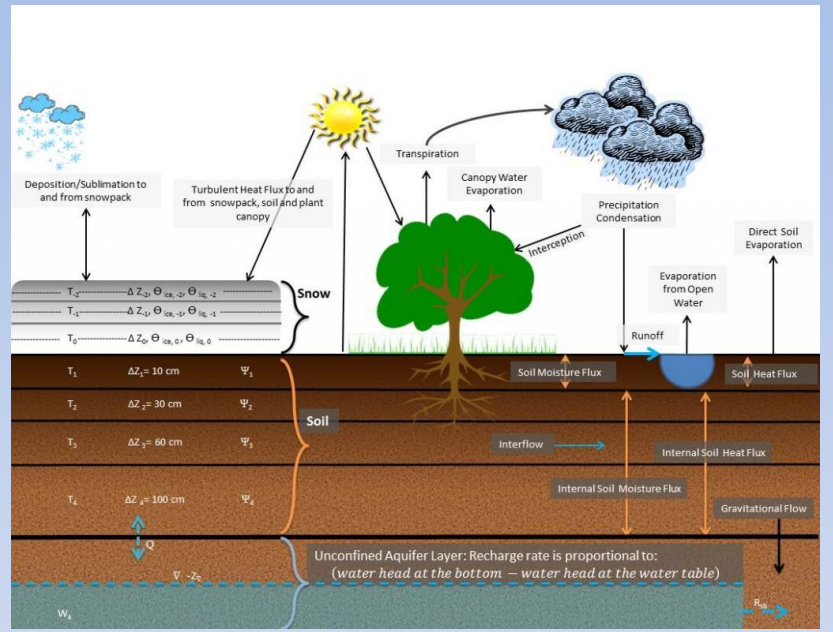
* Satellite-based Environmental Data Records (EDRs): soil moisture (SM), snow-covered area (SCA), snow water equivalent (SWE), terrestrial water storage (TWS), & irrigation intensity (II)

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.

NASA GMAO's Catchment LSM is being added to the NLDAS suite, and other LSMs are being upgraded to later versions



The **Catchment land-surface model (CLSM)** is developed by the NASA Global Modeling and Assimilation Office (GMAO), and is the land-surface component of the NASA GEOS-5 GCM.

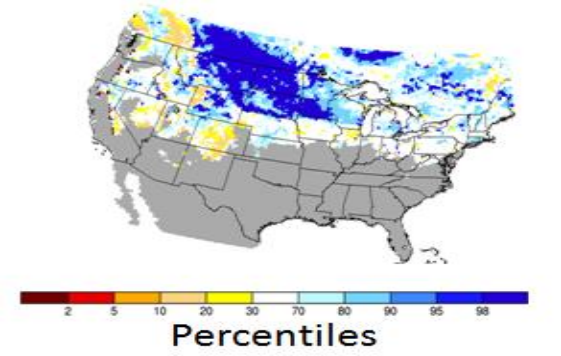


Noah-MP is a LSM option within WRF, with Multiple Physics options, including for dynamic vegetation.

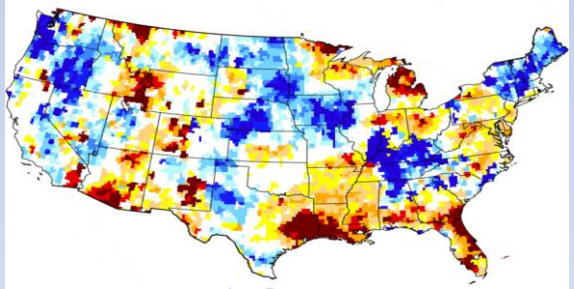
VIC-4.1.2.l, SAC-HTET-3.5.6, and Noah-3.6 have also been implemented in LIS and contain numerous upgrades, such as to soil temperatures, vegetation, and snow-physics.

Remotely-sensed snow, soil moisture, and terrestrial water storage states are used for data assimilation in LIS

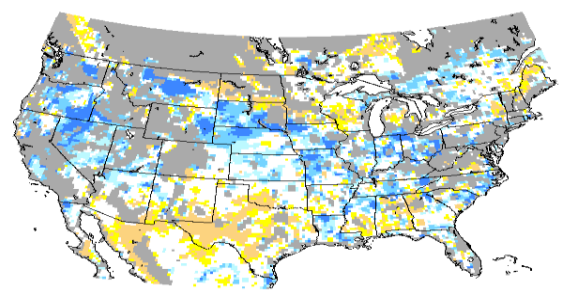
Satellite-based Environmental Data Records (EDRs) are used to update the model states



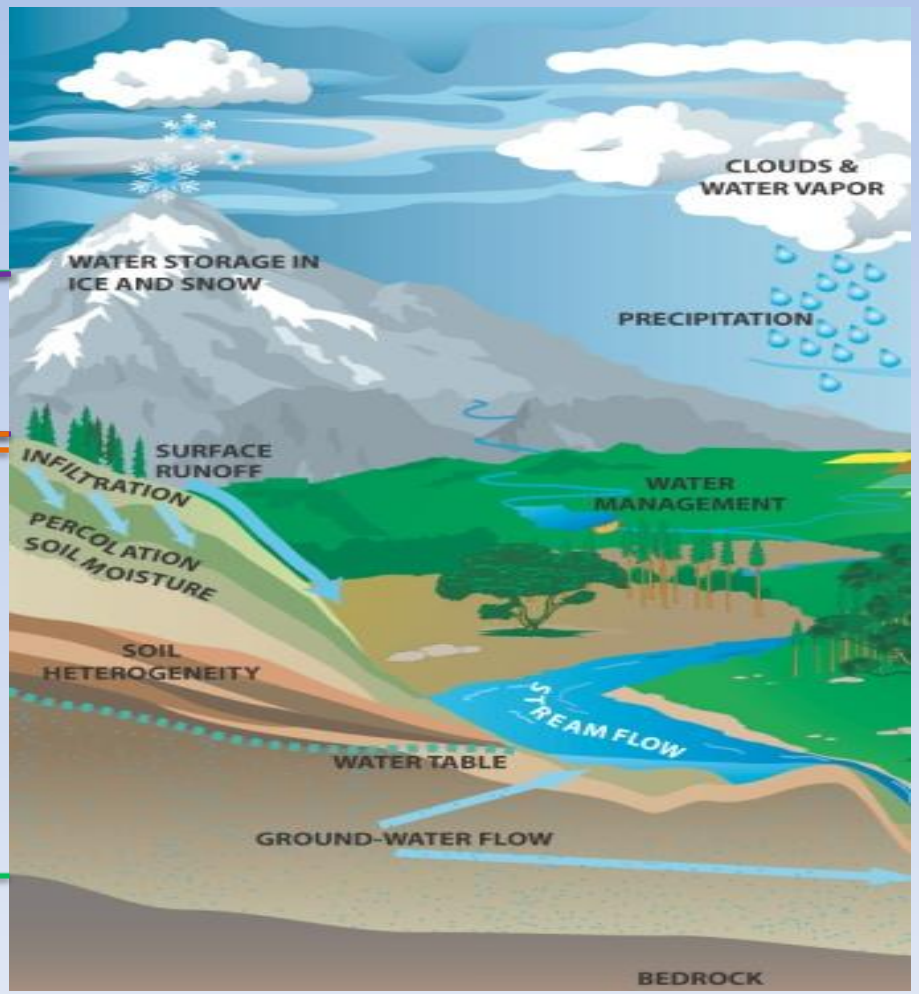
March 2011 Snow Water Equiv. Mean Percentile from LPRM v5 – NASA Aqua/AMSR-E EDR



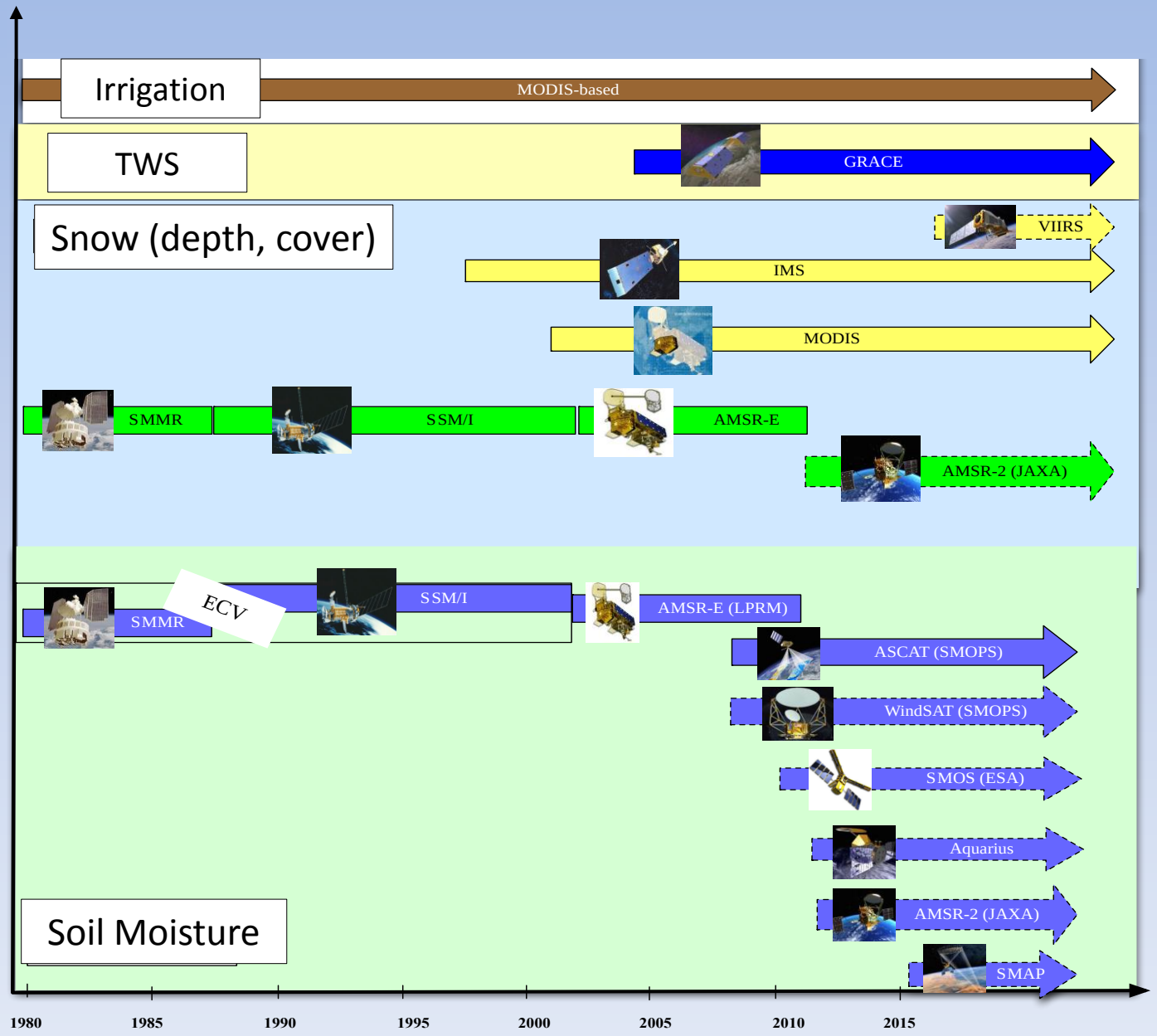
March 2011 Surface SM Percentile from LPRM v5 – NASA Aqua/AMSR-E EDR



March 2011 GRACE-based Groundwater Percentile from GRACE TWS EDR



Data assimilation testing/plans for the next phase of NLDAS



Model domain: Continental United States (CONUS) at 1/8th-degree spatial resolution, including parts of Canada/Mexico (25-53° N)

Forcing data: NLDAS Phase 2 meteorological forcing data.

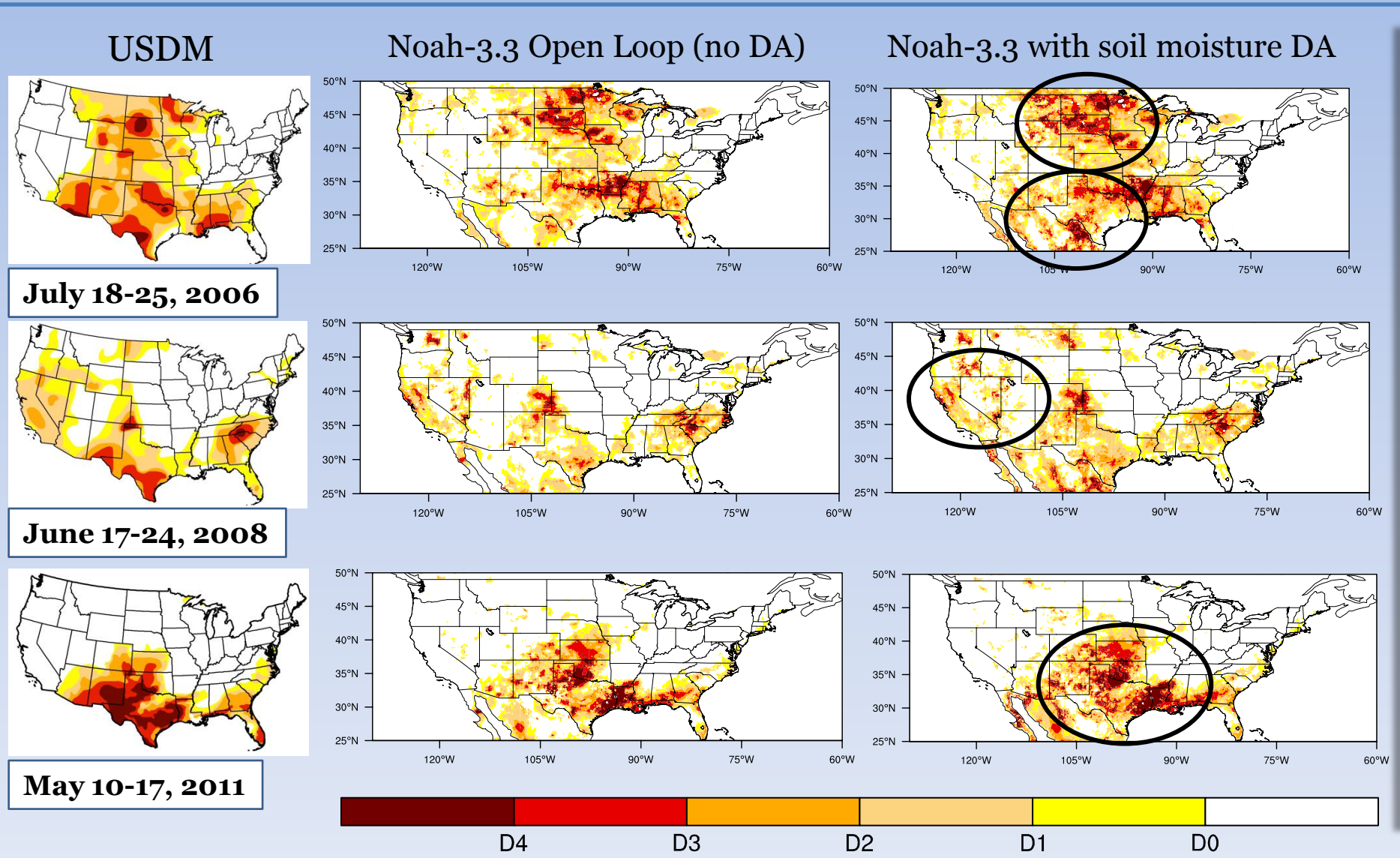
Models: Noah LSM version 3.3, and CLSM Fortuna-2.5: a 60-year spin-up, followed by 34 years of simulation; streamflow simulations using HyMAP (Getirana et al., 2012)

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

Time period: 2 Jan 1979 to 1 Jan 2013

All simulations performed using the **NASA Land Information System (LIS; http://lis.gsfc.nasa.gov/)**

Data assimilation of snow and soil moisture improves NLDAS drought comparisons to the U.S. Drought Monitor

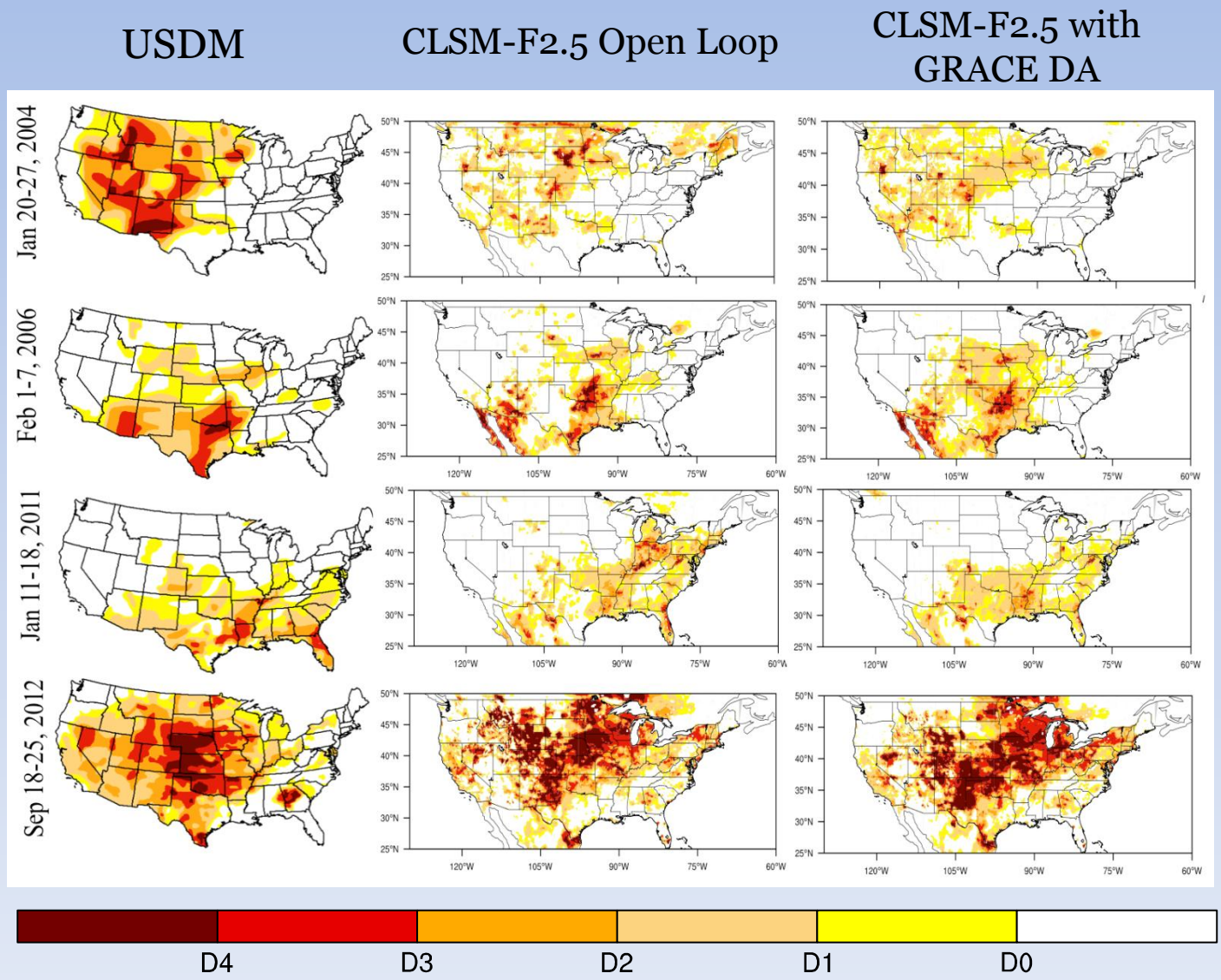


July 18-25, 2006:
DA improves estimates over Texas, Nebraska, Dakotas (D0 and D1)

June 17-24, 2008:
DA indicates more intense drought over North Dakota and Montana, reduces severity over Nevada, increases spatial extent over Texas and New Mexico.

May 10-17, 2011:
DA predicts increased severity of drought over Texas and Oklahoma

Data assimilation of GRACE terrestrial water storage anomalies also improves the NLDAS drought depiction



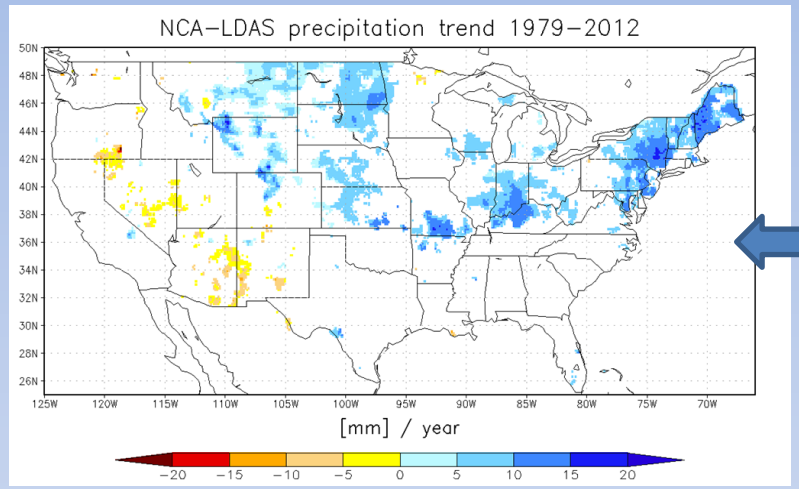
January 20-27, 2004:
DA indicates more intense drought in the SW, while reducing exceptional drought intensity in parts of northern Great Plans.

February 1-7, 2006:
DA diagnoses a stronger drought in the central U.S. (e.g., Nebraska).

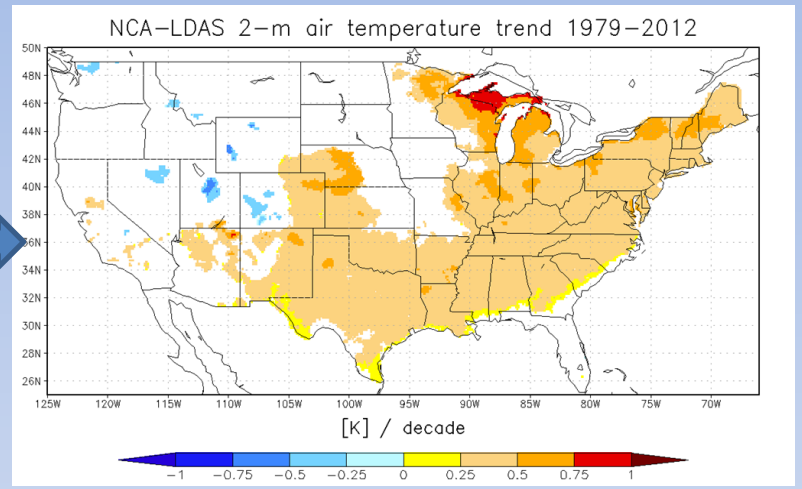
January 11-18, 2011:
DA correctly reduces drought intensity over Iowa and Ohio

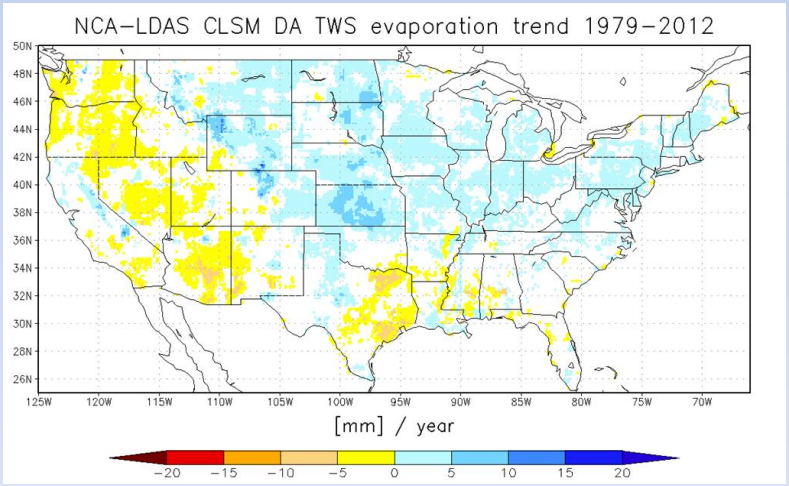
September 18-25, 2012:
DA reduces drought intensity over the NW, while improving exceptional drought structure over Kansas and Oklahoma.

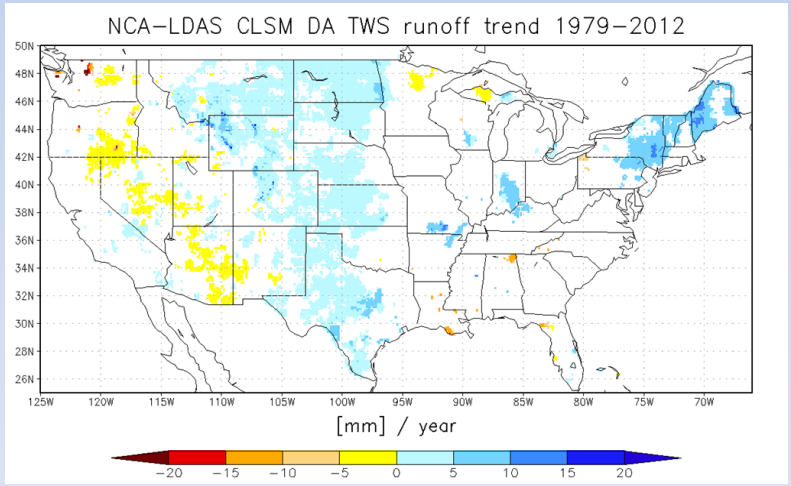
NLDAS datasets also contribute to our group's National Climate Assessment project (NCA-LDAS)

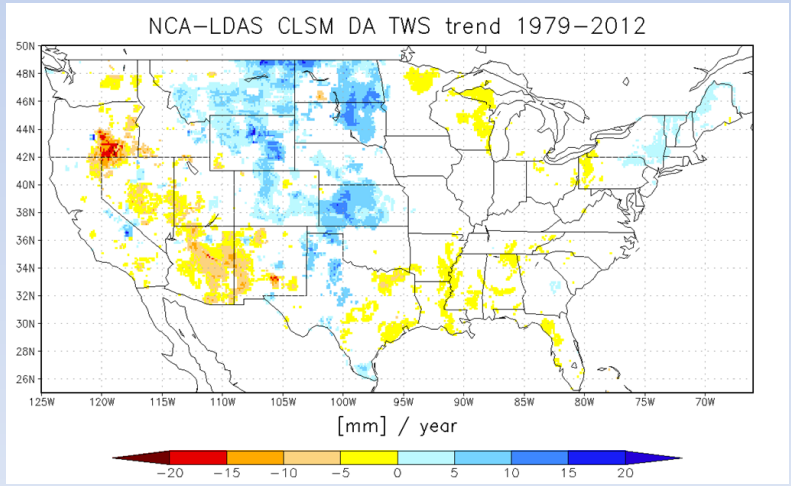


Trends in the surface forcings of precipitation and temperature from NLDAS-2 data









Above: Example trend analysis from CLSM with assimilation of GRACE terrestrial water storage (TWS) anomalies. Trends calculated using Mann-Kendall trend test; Only areas with 10% confidence interval plotted.

List of NLDAS publications

NLDAS-2 Introduction and Evaluations

- Introduction and Streamflow Evaluation: Xia et al. (2012a&b, JGR)
- Soil Temperatures: Xia et al. (2013, JAMC)
- Soil Moistures: Xia et al. (2014, HP)
- Evapotranspiration: Xia et al. (2014, HP); Matsui and Mocko (2014, book chapter)
- Diurnal cycle of precipitation: Matsui et al. (2010, GRL)

Next phase of NLDAS studies

- Evapotranspiration: Peters-Lidard et al. (2011, HP)
- Soil Moisture and Snow Depth DA: Kumar et al. (2014, JHM)
- Snow Depth and Cover DA: Liu et al. (2015, WRR); Kumar et al. (2015, JHM)
- GRACE DA: Kumar et al. (2015, WRR, submitted)

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

Take-away Messages about the NLDAS Drought Monitor

- The North American Data Assimilation System (NLDAS) provides hourly data from January 1979 to present (with a ~3.5-day lag)
- NLDAS datasets have been extensively evaluated, and are used for a wide-range of applications, including a Drought Monitor
- The NLDAS Drought Monitor webpage is updated daily, and is one of the inputs to the weekly U.S. Drought Monitor
- The next phase of NLDAS will put the “N(A)” and the “DA” fully into “NLDAS”, by expanding the domain to all of North America, & by using Data Assimilation of remotely-sensed soil moisture, snow, terrestrial water storage, & irrigation
- DA of these water states results in improved diagnosis of drought with NLDAS
- LIS-based NLDAS will be transferred into operations at NOAA/NCEP

http://ldas.gsfc.nasa.gov/nldas/ David.Mocko@nasa.gov