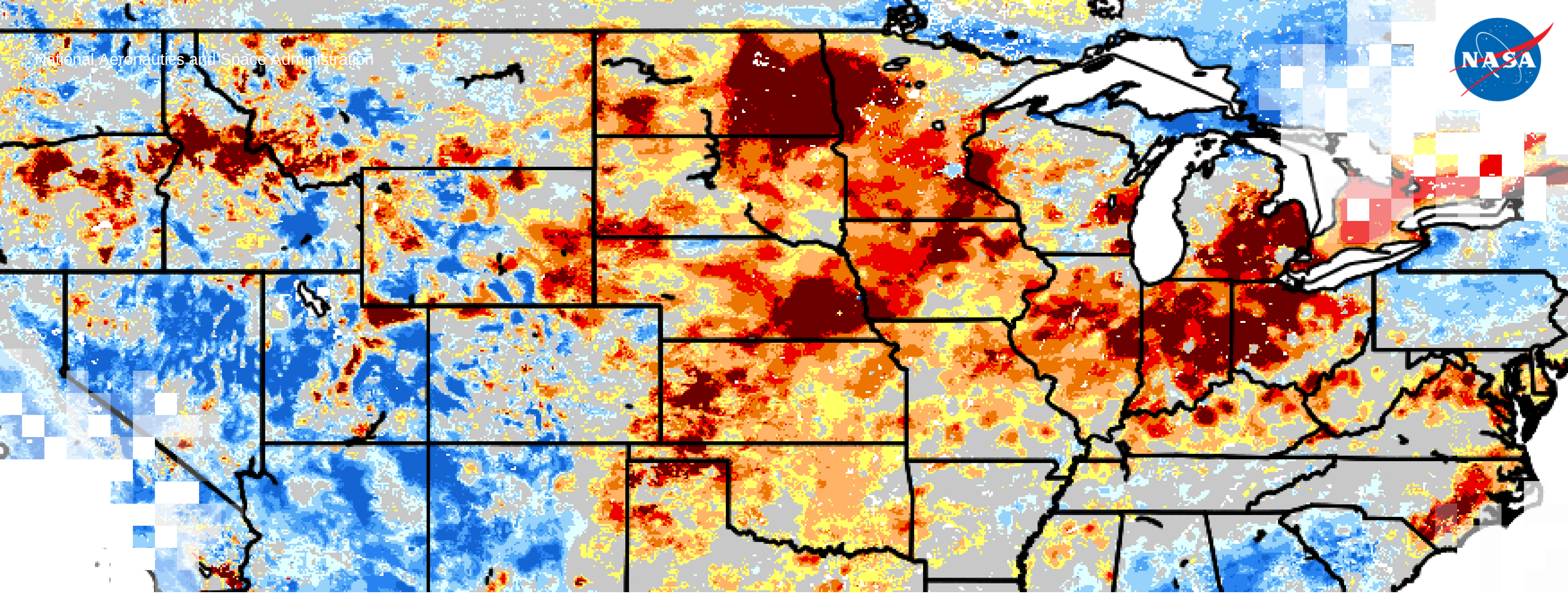
National Aeronautics and Space Administration

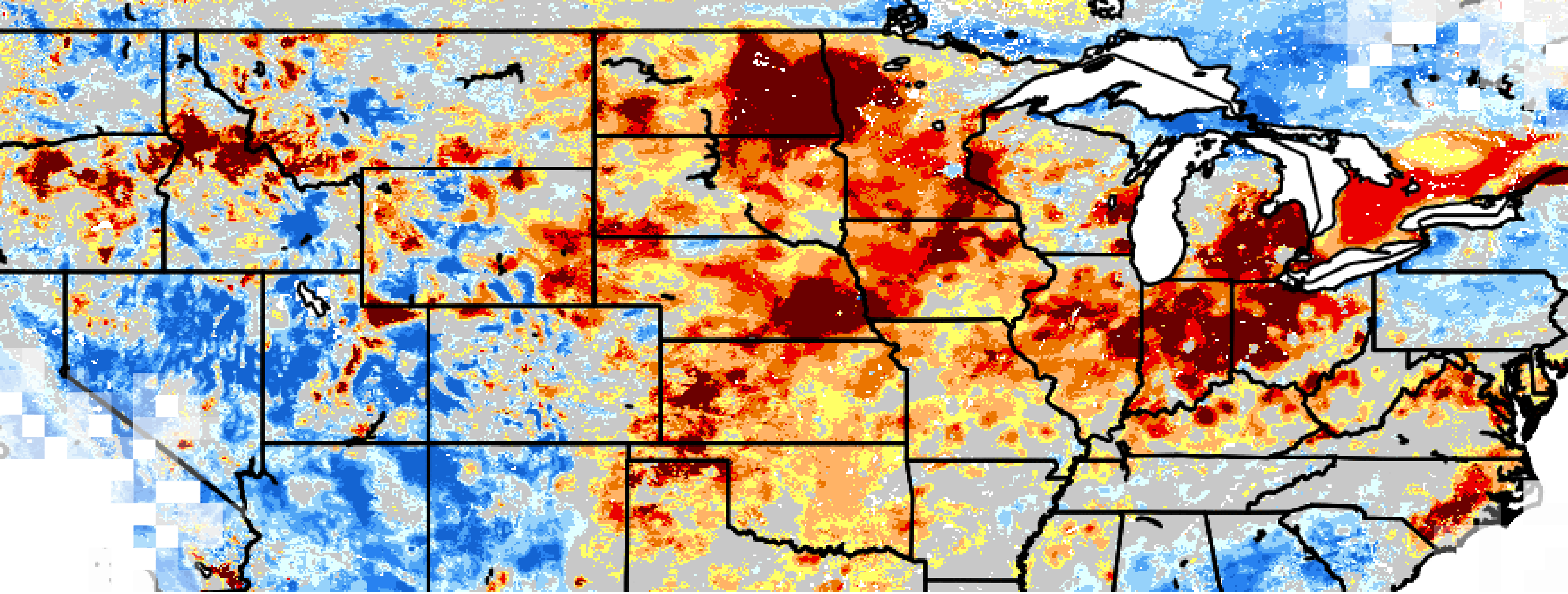


Application of NASA SPoRT-Land Information System (SPoRT-LIS) Soil Moisture Data for Drought

Part 1: Foundational Understanding of LIS (static, forcing, models, output)

Sean McCartney (SSAI/NASA), Chris Hain (NASA SPoRT), Sujay Kumar (NASA GSFC), & Jonathan Case (ENSCO, Inc/NASA SPoRT)

May 17, 2023



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**
- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

HEALTH & AIR QUALITY

WATER RESOURCES

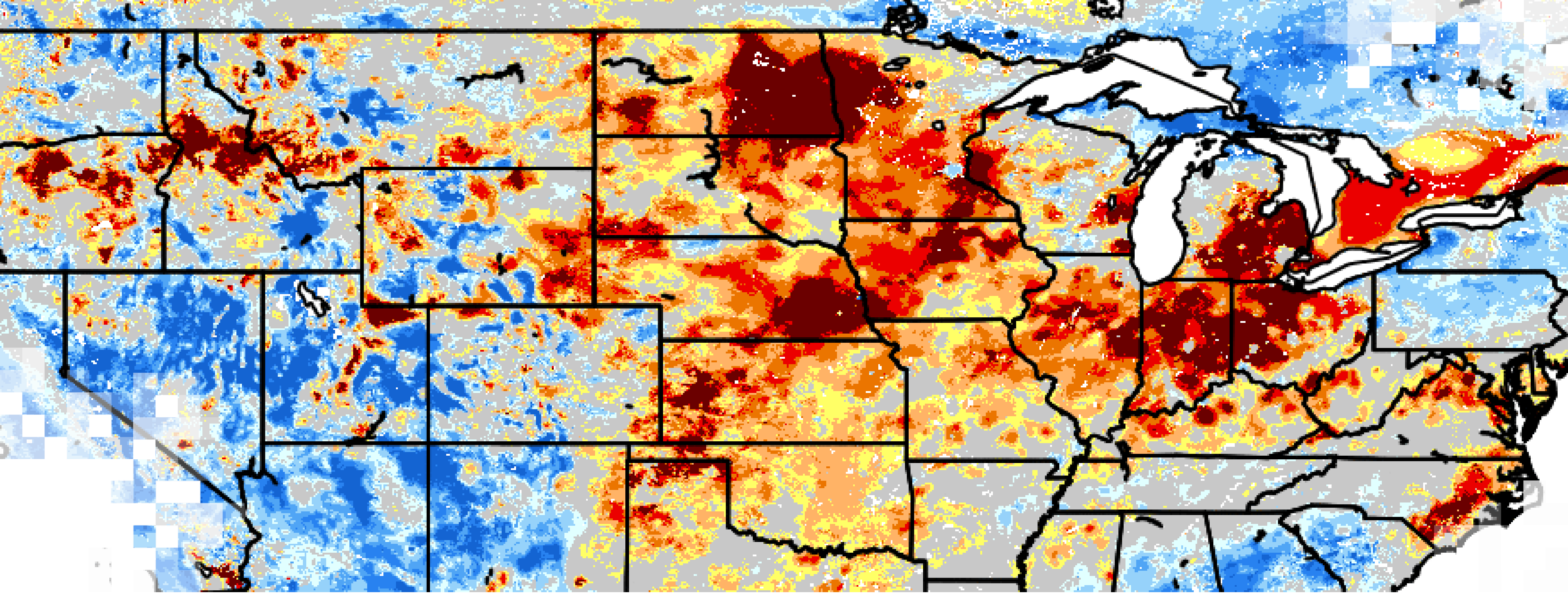
EARTH SCIENCE APPLIED SCIENCES

CAPACITY BUILDING

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

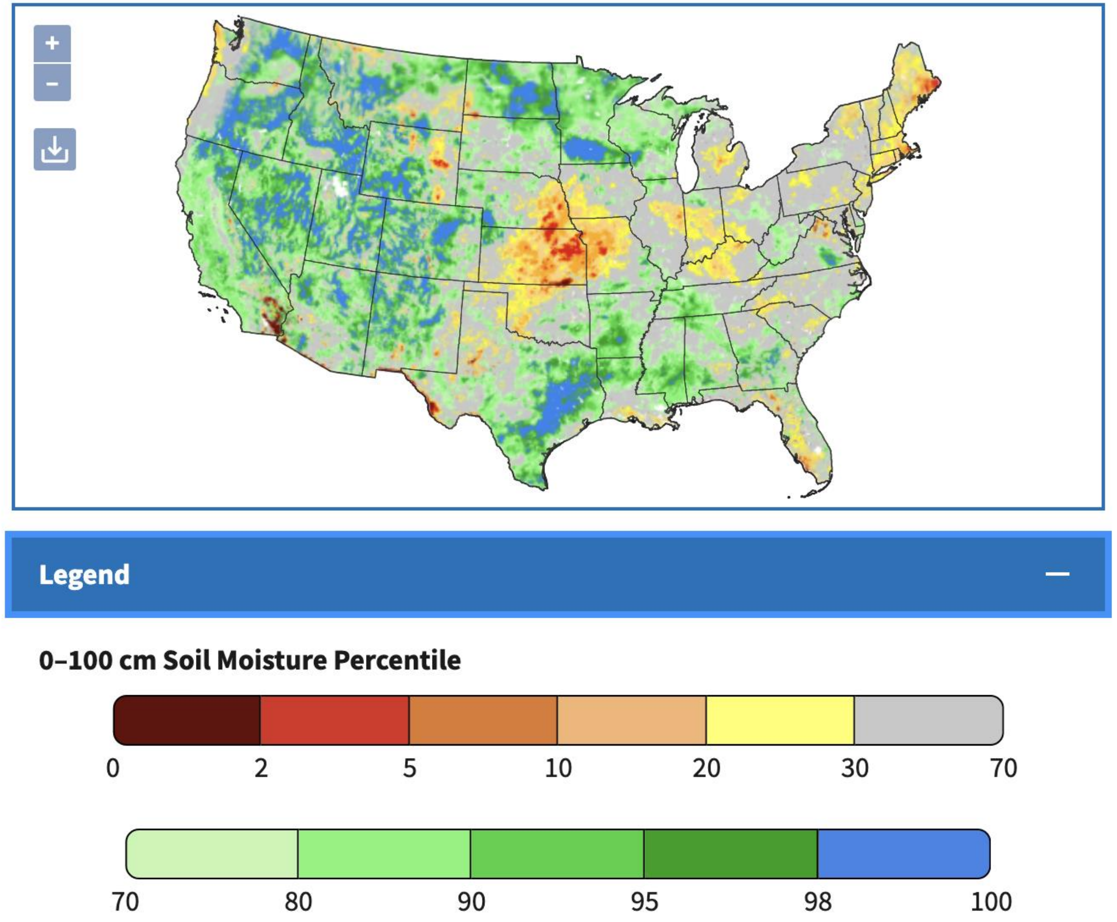
- Visit the ARSET website to learn more.



Overview

Overview

- An estimated 55 million people globally are affected by droughts every year (WHO).
- Soil moisture plays an important role in drought monitoring.
- Relatively high-resolution gridded soil moisture products improve situational awareness.
- SPoRT-LIS provides unique, real-time soil moisture information at relatively high spatial resolution (~3 km).



Credit: NASA

Training Learning Objectives

A user will be able to apply LIS output to efficiently analyze drought over large spatial areas in conjunction with current practices and to integrate this capability with existing data.

- Identify the NASA/LIS basics regarding the framework, input forcing, static fields, LSM structure, and output most relevant to drought
- Summarize the derived soil moisture percentile products and how these are created
- Apply SPoRT-LIS output and/or derived products to both complement existing data and overcome limitations to monitoring drought over large areas
- Recognize 'best practices' for LIS impact related to drought
- Configure LIS output file for viewing within a GIS-based display tool and for tailored output products and graphics

Prerequisites

- Fundamentals of Remote Sensing, Session 1
- Download and install QGIS and all accompanying software
- Register for a Google Colab via Gmail or Gmail-enabled account
- Basic Python experience beneficial but not required

Training Outline

Part 1

Foundational Understanding of LIS (Static, Forcing, Models, Output)

May 17, 2023

Self-Paced Microlesson

Part 2

Early and Established Applications of LIS for Drought Analysis in Operations

May 24, 2023

Self-Paced Microlesson

Part 3

Access Data at Organization and Individual Levels

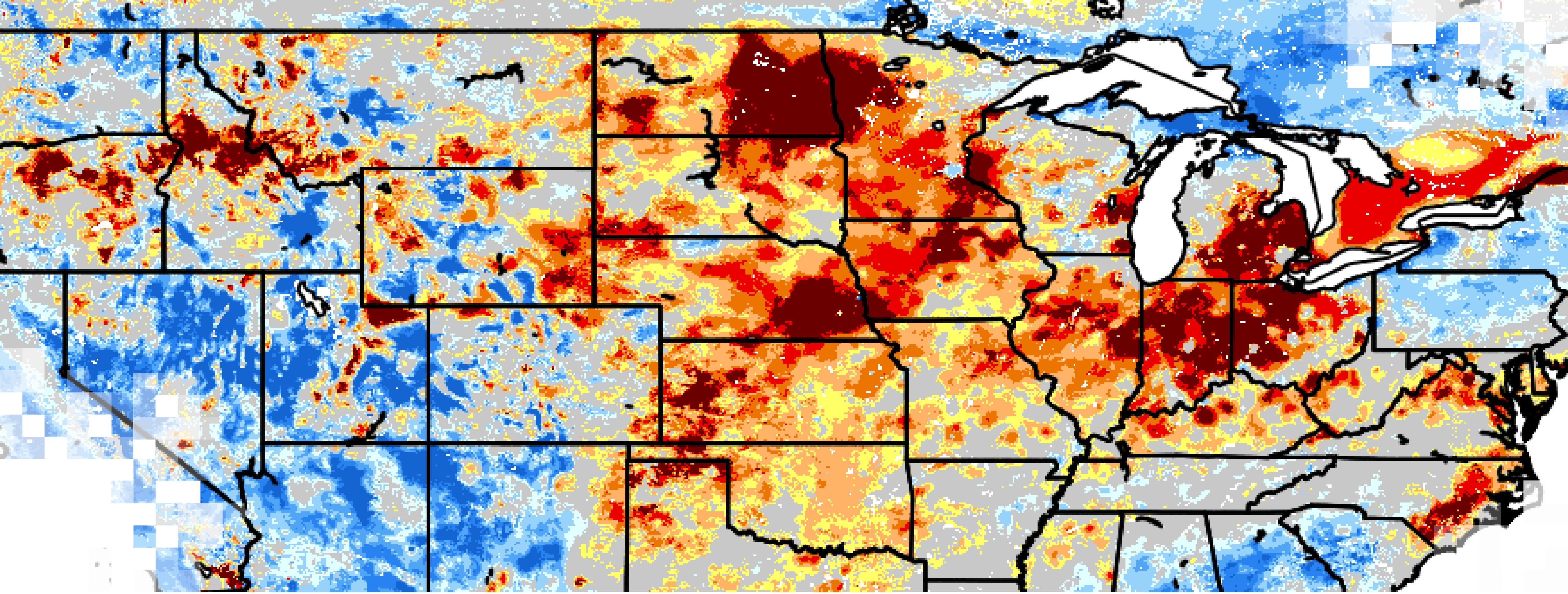
May 31, 2023

Self-Paced Microlesson

Homework

Opens May 31 – Due June 14 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment before the given due date.



Part 1: Foundational Understanding of LIS (Static, Forcing, Models, Output)

Part 1 Trainers

Chris Hain

Project Lead, NASA's Short-Term Prediction Research and Transition Center (SPoRT)

Sujay Kumar

Research Physical Scientist

Hydrological Sciences Lab, NASA GSFC

Jonathan Case

Research Meteorologist, NASA's Short-Term Prediction Research and Transition Center (SPoRT)

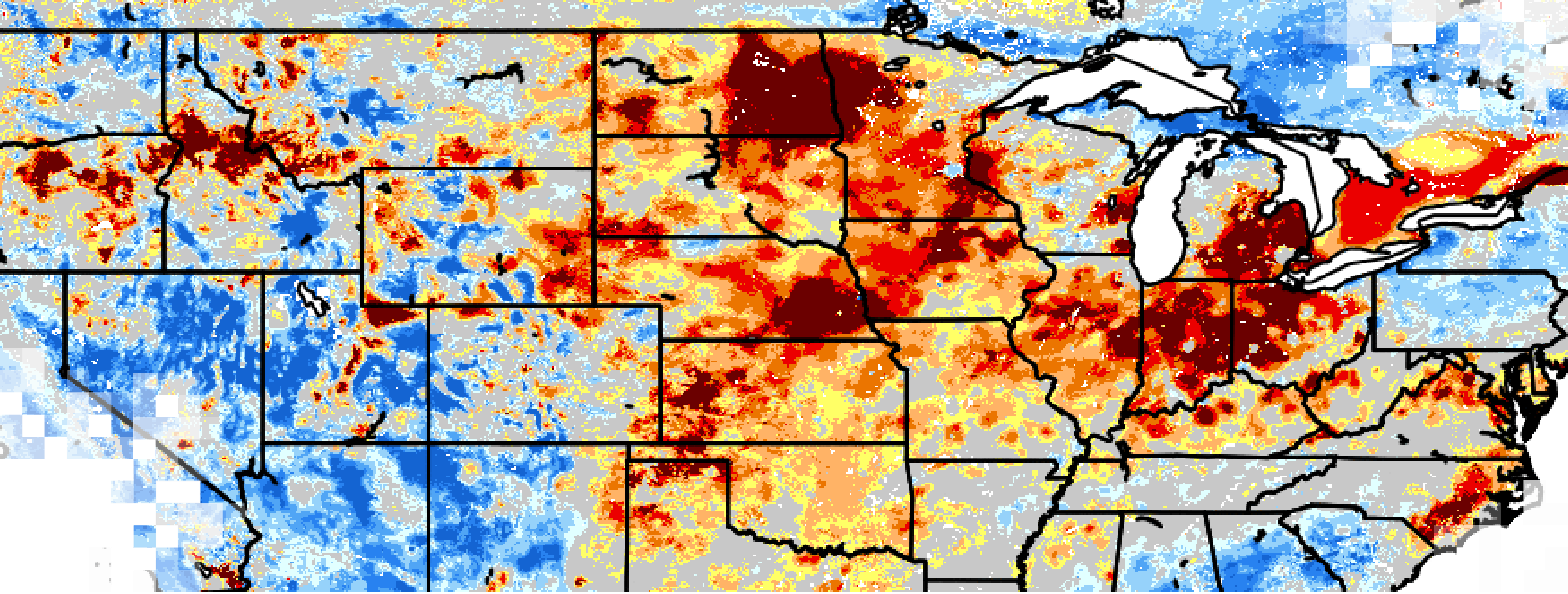
Part 1 Objectives

By the end of Part 1, participants will be able to:

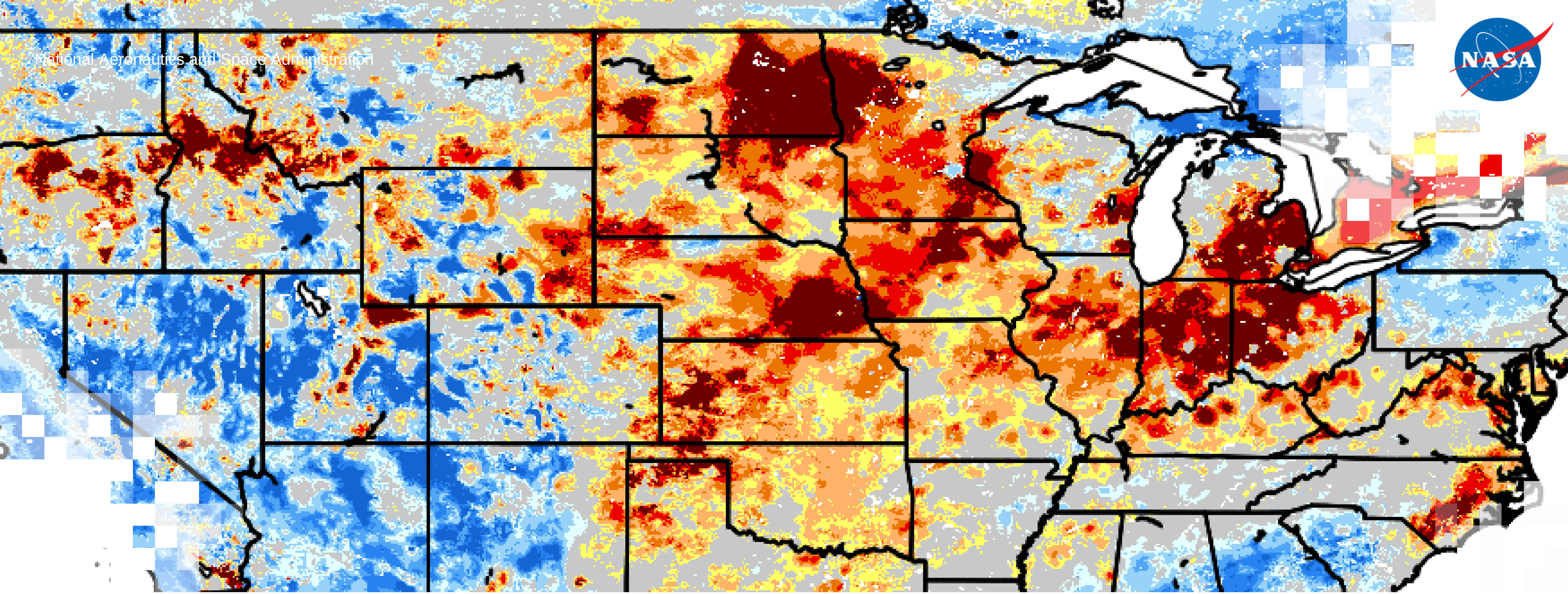
- Identify the NASA/LIS basics regarding the framework, input forcing, static fields, LSM structure, and output most relevant to drought
- Summarize the derived soil moisture percentile products and how these are created

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Part 1
Material



NASA LIS Framework and Outputs

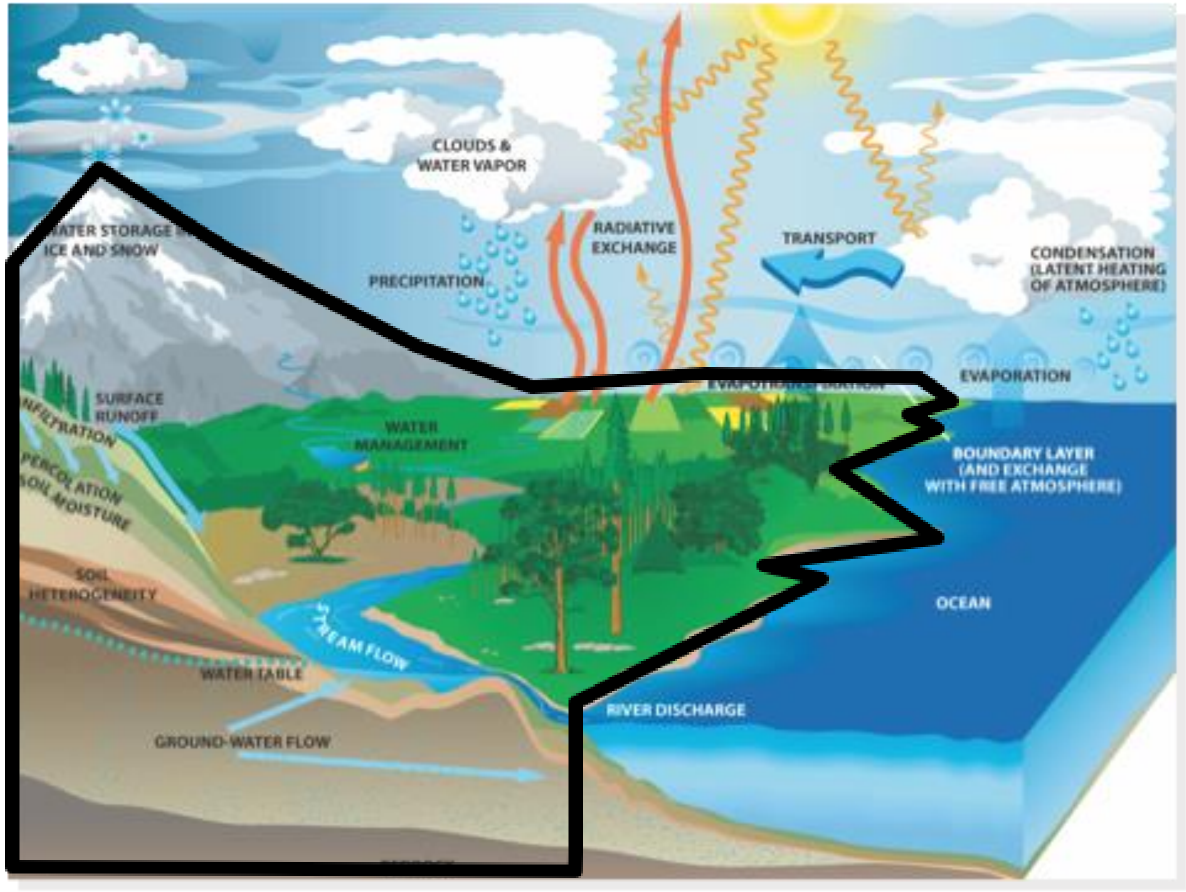
Sujay V. Kumar – Hydrological Sciences Lab, NASA Goddard Space Flight Center

May 17, 2023

Land Information System (LIS)

lis.gsfc.nasa.gov

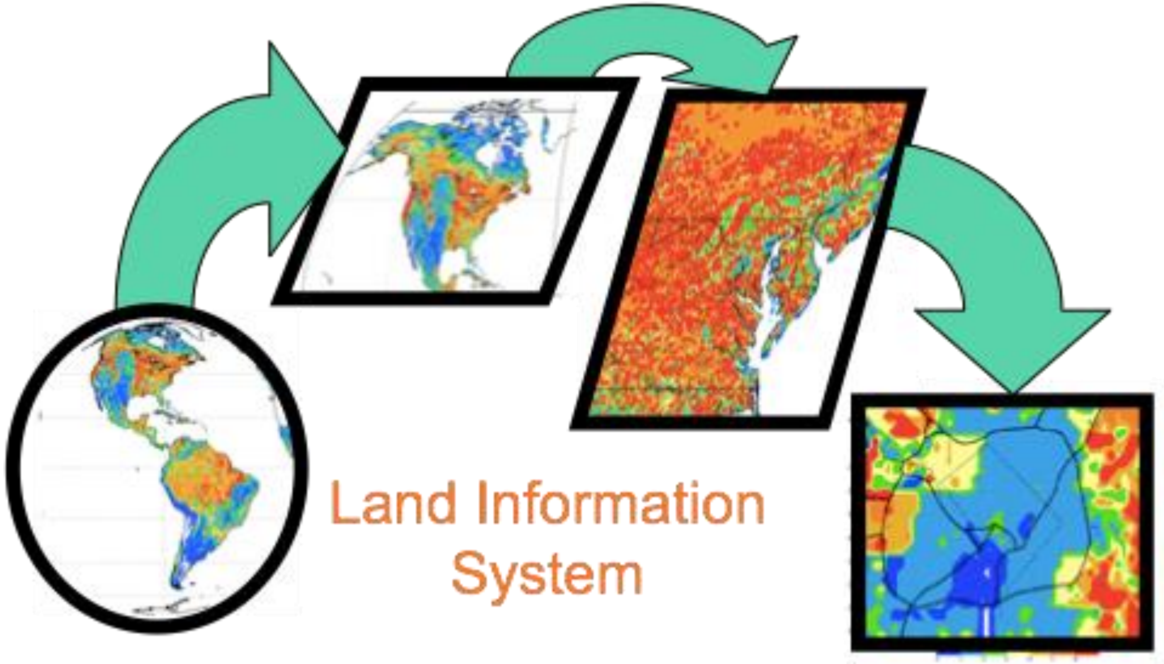
- A system for uncoupled and coupled land modeling and data assimilation
- **Philosophy –**
  - “Use the best available observations” to force and constrain the models
- **Applications –**
  - Weather and Climate Model Initialization
  - Water Resource Management
  - Natural Hazards Management



Kumar, S.V., C.D. Peters-Lidard, Y. Tian, P.R. Houser, J.Geiger, S. Olden, L.Lighty,J.L. Eastman, B. Doty, P.Dirmeyer, J. Adams, K. Mitchell, E.F. Wood, J. Sheffield (2006), Land Information System – An Interoperable Framework for Land Surface Modeling, *Environmental Modeling and Software*, 21, 1402—1415.

LIS Background

- In 2002, evolved from the North American Land Data Assimilation System and the Global Land Data Assimilation System
- **Key Requirements –**
  - Flexible system that is viable at different spatial and temporal resolutions
  - Able to perform explicit characterization of the land surface at the same spatial scales as that of cloud and precipitation processes to improve the characterization of land-atmosphere interactions
  - Support simulations at high spatial and temporal resolutions with high performance computing support
  - Support the incorporation of remote sensing information with computational tools (data assimilation, inverse modeling)



LIS Timeline

2002

NASA funded computational technology project

2005

Strategic partnership with AFWA/557

NASA software of the year

2006-2008

LIS enables the LDAS ecosystem

2009

LIS in operations at AFWA/557

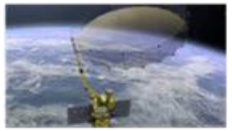
2010

LIS in routine use at NASA SPoRT

2012

LIS-based GRACE informed drought indicators

2019



SMAP data transitioned to 557 operations

2021

LIS as the foundation for Earth Information System (EIS)

2022

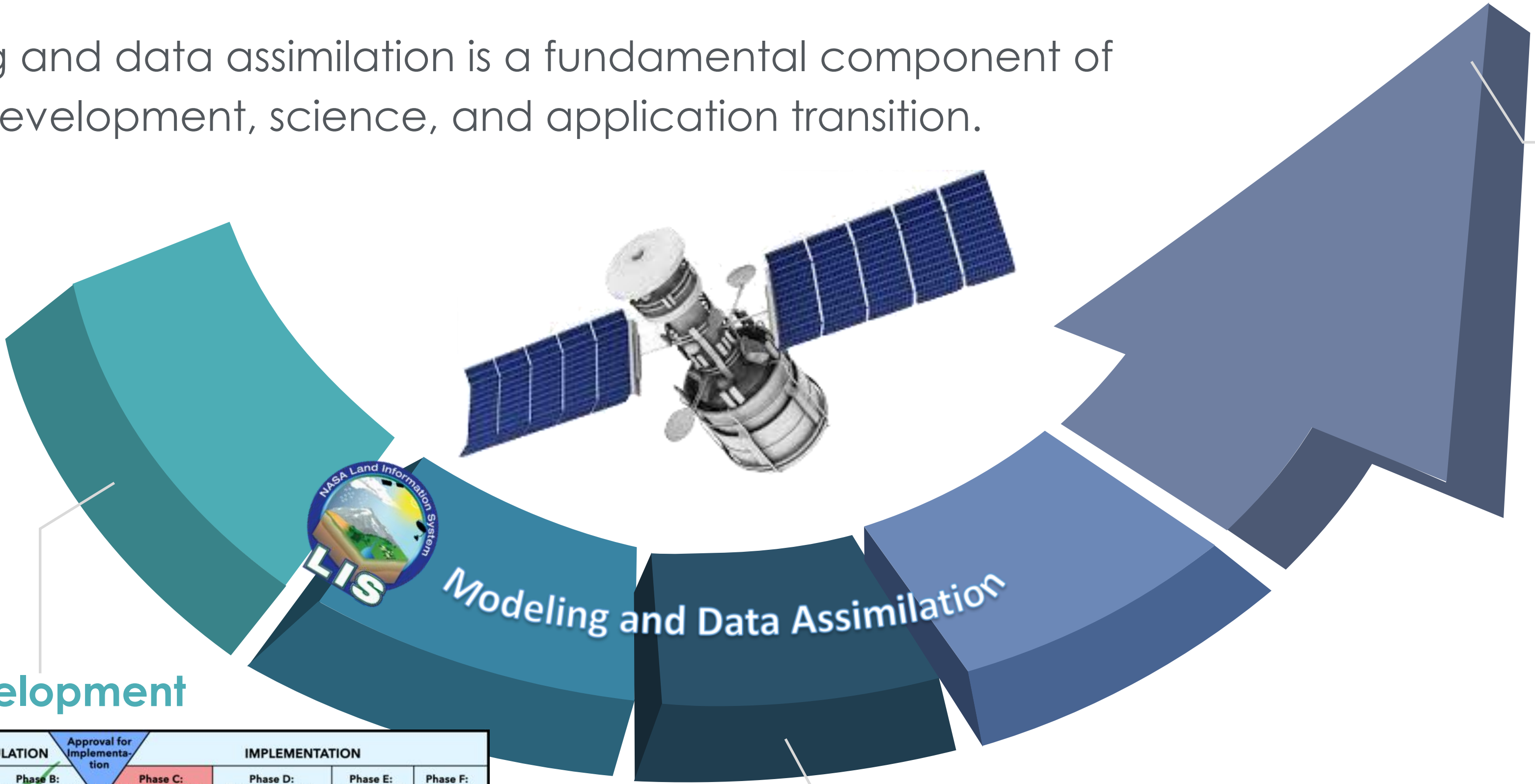
Operational LIS-based Global Hydro Intelligence system (expected)

LIS has evolved into a state-of-the art terrestrial hydrology modeling system with an unprecedented set of capabilities for remote sensing data infusion.

Kumar, S.V. et al. (2006), Land Information System – An Interoperable Framework for Land Surface Modeling, *Environmental Modeling and Software*, 21, 1402—1415.

Extent of LIS Applications

Modeling and data assimilation is a fundamental component of mission development, science, and application transition.



Terrestrial Hydrology Applications

NWP

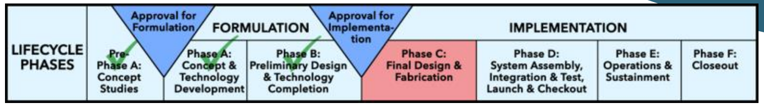
Availability

Quality

Food Security

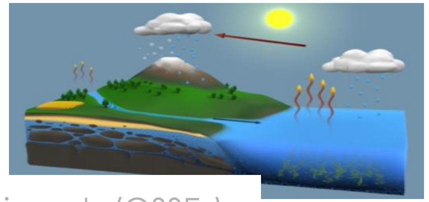
Extremes

Mission Development



Observation System Simulation Experiments (OSSEs) to quantify the utility of anticipated measurements

Science/Research



Improved quantification of terrestrial water budget components and their variability

The "LIS/LDAS Ecosystem"


July 1, 2019

When Drought Threatens Crops: NASA's Role in Famine Warnings

NASA's satellite imagery and model forecasts regularly help agricultural and aid agencies to monitor the performance of crops worldwide and prepare for food shortages.

"In the 1970's the U.S. realized that drought impacts on global agriculture were severely affecting trade and food aid decisions, while ground based information and forecasting of drought was very limited," said Brad Doorn, water resources program manager in the Earth Science Division at NASA Headquarters, Washington. "Earth observations from space provide

Follow the Freshwater: By predicting droughts and floods and tracking blooms of algae, NASA's view of freshwater around the

LIS-based environments support USAID's Famine Early Warning Systems Network (FEWSNET).


NEWS I NOVEMBER 19, 2019

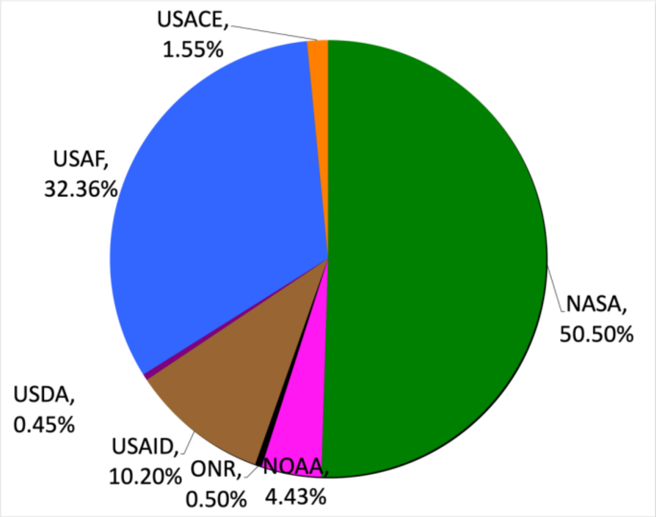
NASA Soil Data Joins the Air Force

Military weather forecasters. Credit: U.S. Air Force

› Larger view

LIS-based environment at US Air Force Weather employs SMAP and GPM data to support NWP, transboundary water, food security, and other military applications.

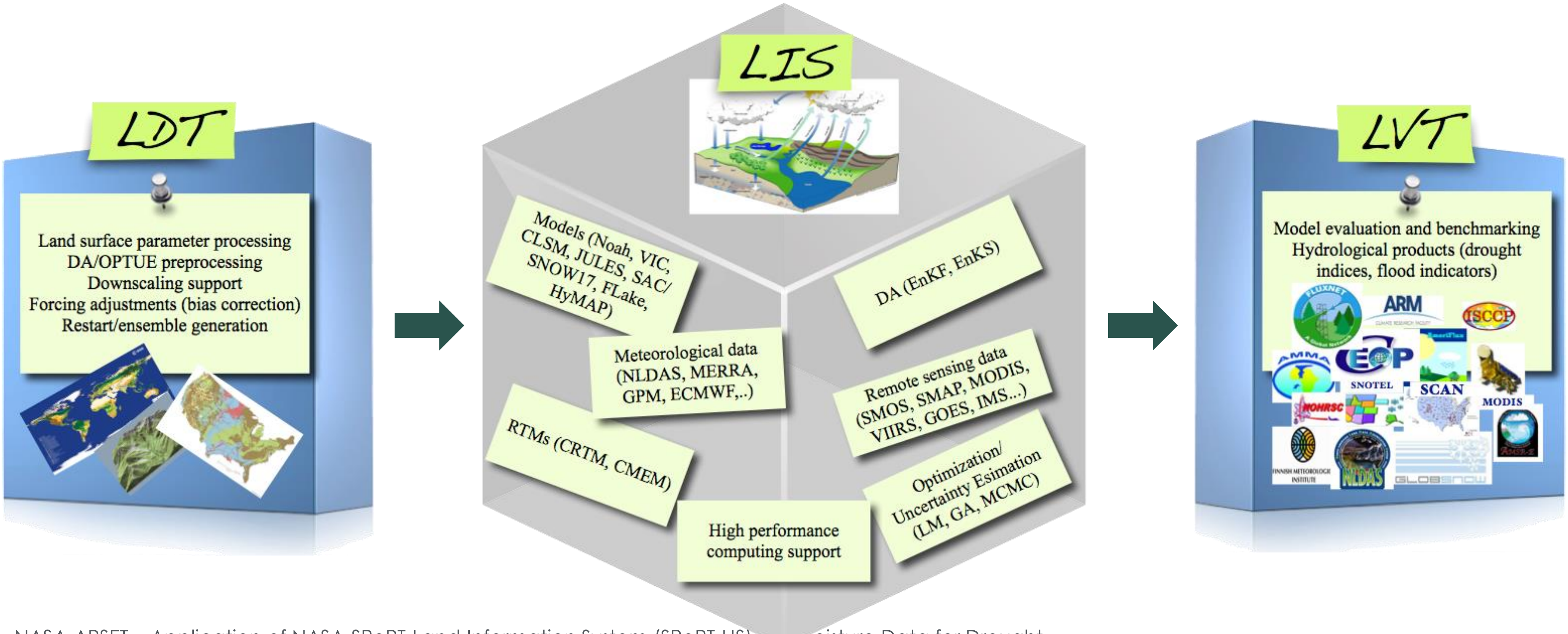
Other: NOAA, NRL, NCAR, UK met office, Bureau of Meteorology Australia, Universities..



Significant investments (> 60 million across the years) by NASA and the partner agencies have contributed to LIS development.

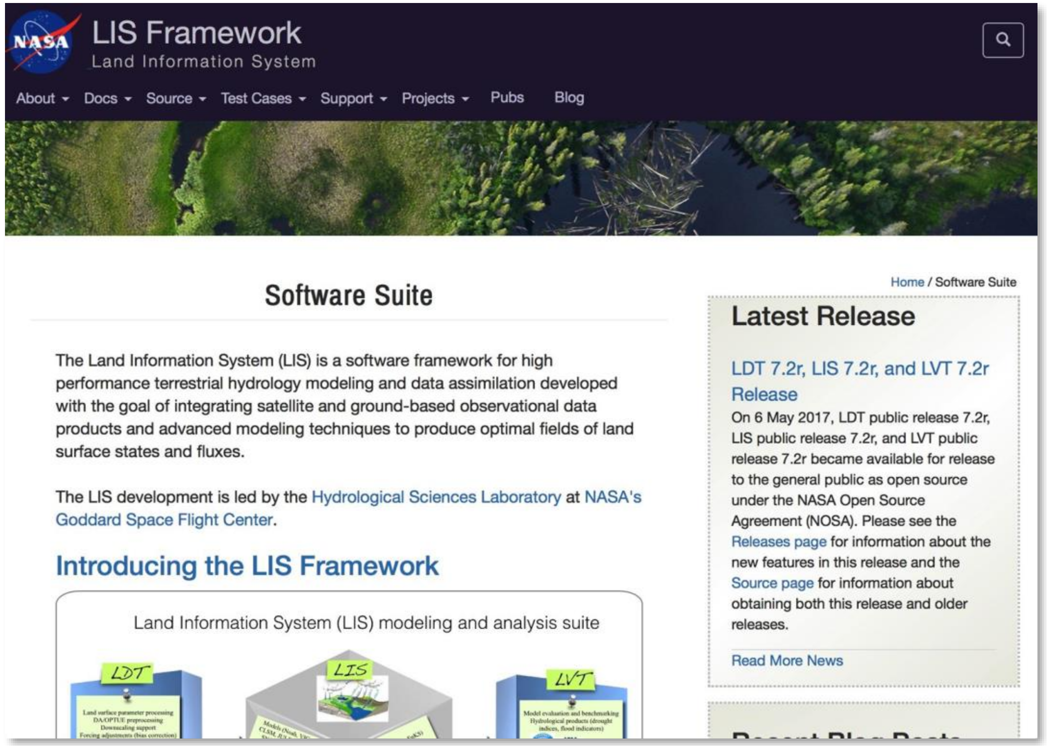
The LIS Modeling Suite

- **LIS** – The modeling and data assimilation framework
- **LDT** – Supports the data preprocessing needs for LIS (parameter data processing, data assimilation support, forcing bias correction, etc.)
- **LVT** – Environment for model benchmarking and evaluation

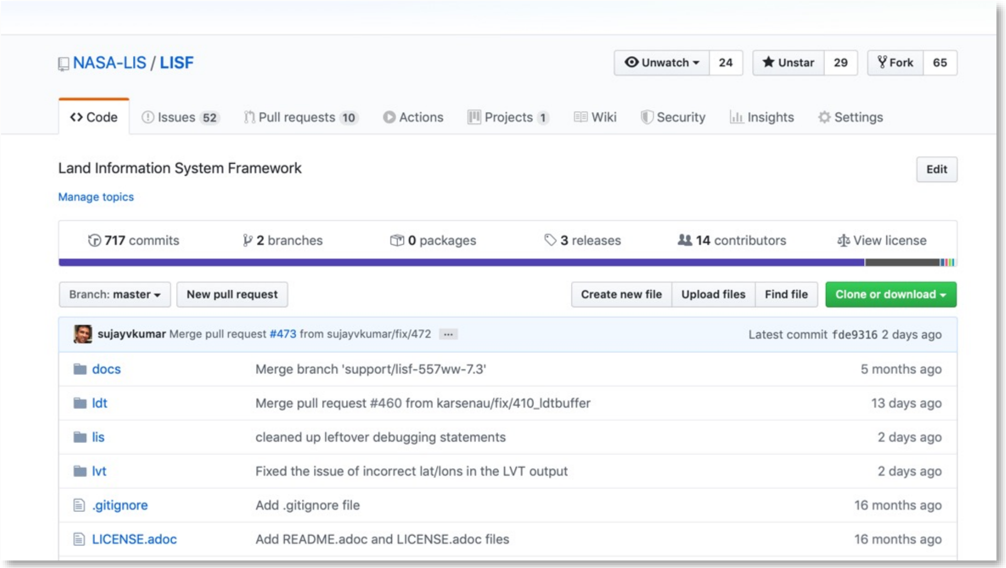


LIS Source Code

http://lis.gsfc.nasa.gov

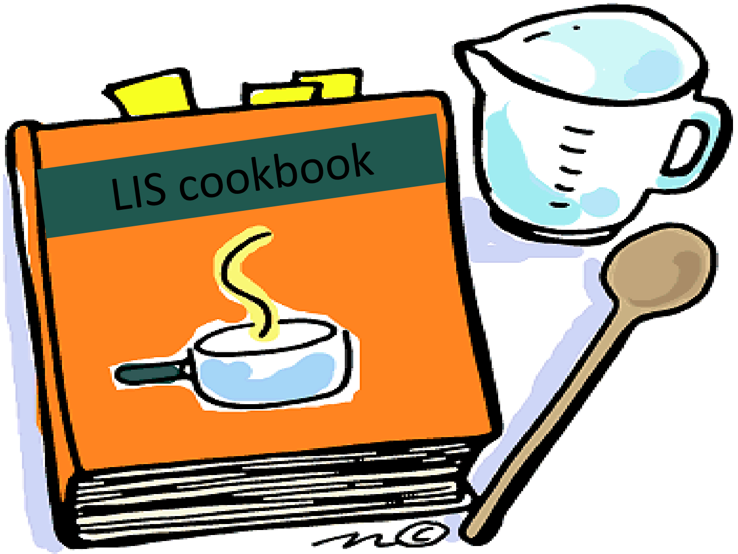


https://github.com/NASA-LIS/LISF

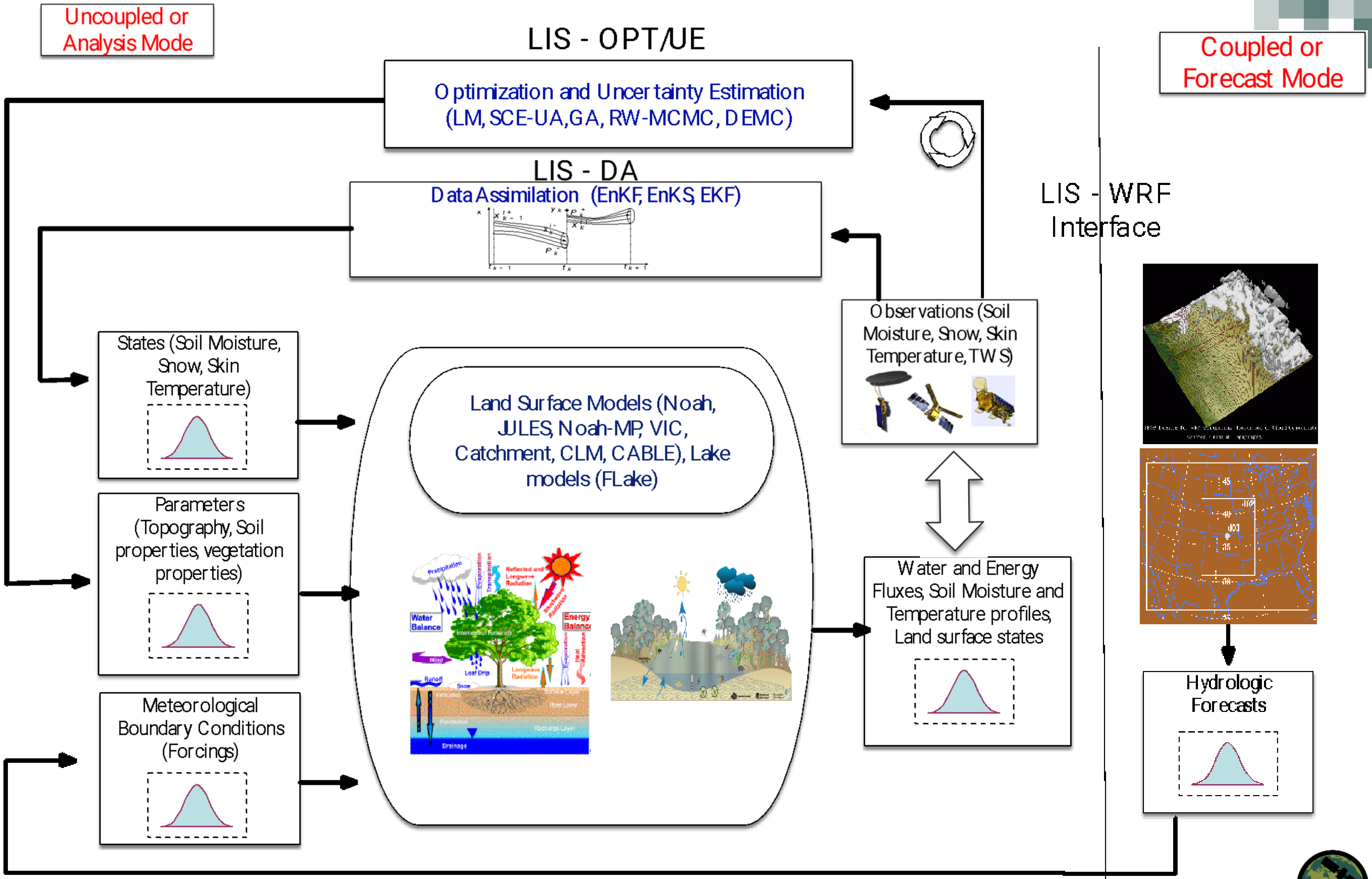


Software Requirements

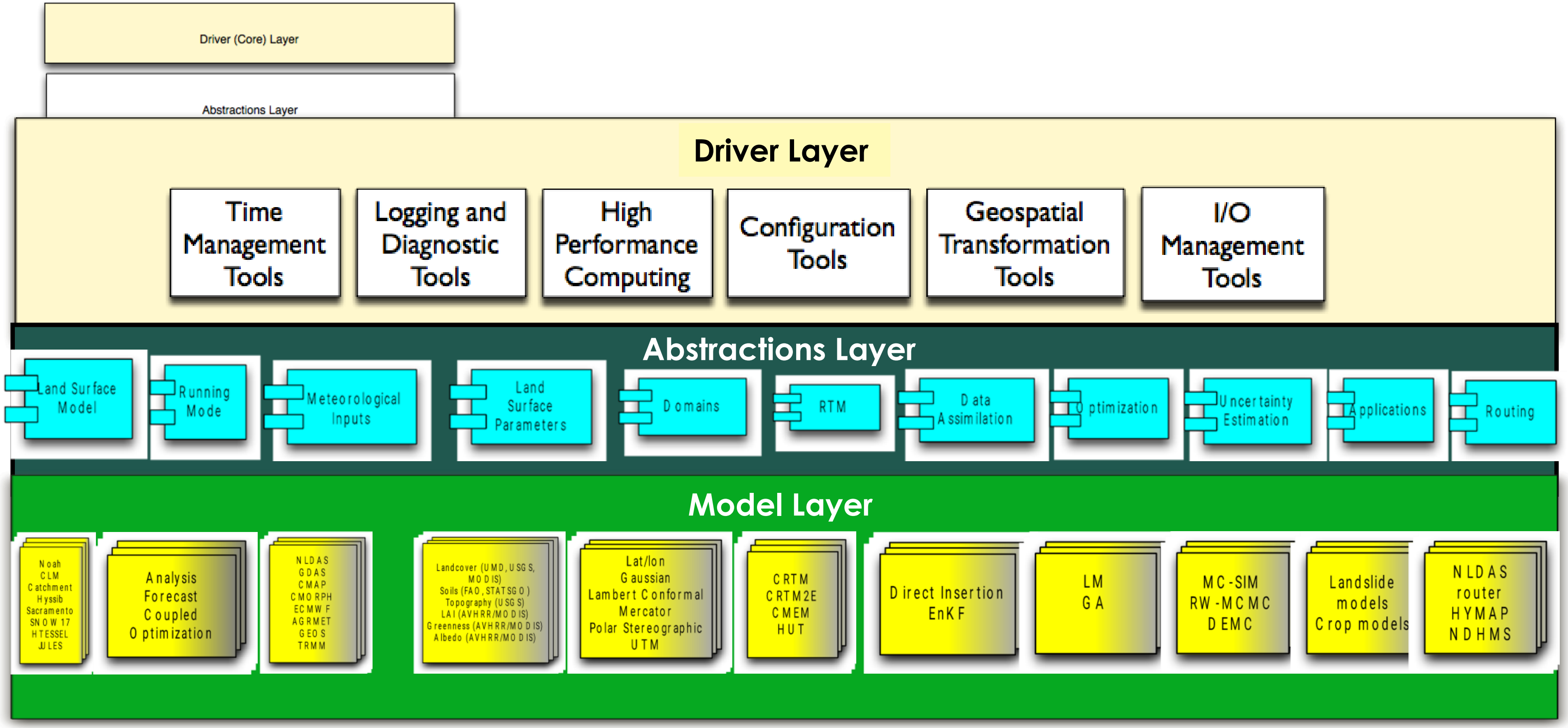
- Fortran 90/95 Compiler
  - Preferred: Intel, gfortran, pgi, lahey, absoft
- C Compiler
- MPI (if parallel processing capability is desired)
- Earth System Modeling Framework (ESMF)
  - 5.x or higher
- LIS supports Grib1, Grib2, NetCDF, HDF, and GEOTIFF formats
  - NetCDF mandatory
  - Grib/HDF optional



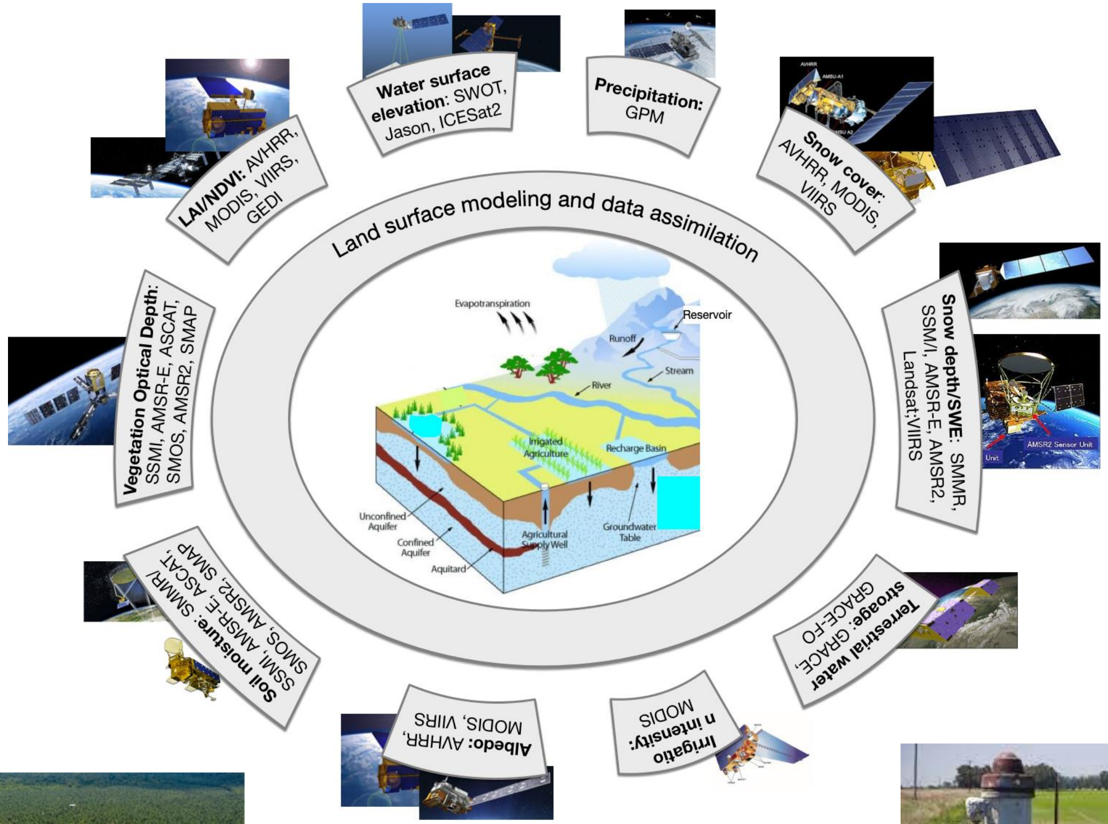
LIS Structure



LIS Software Architecture



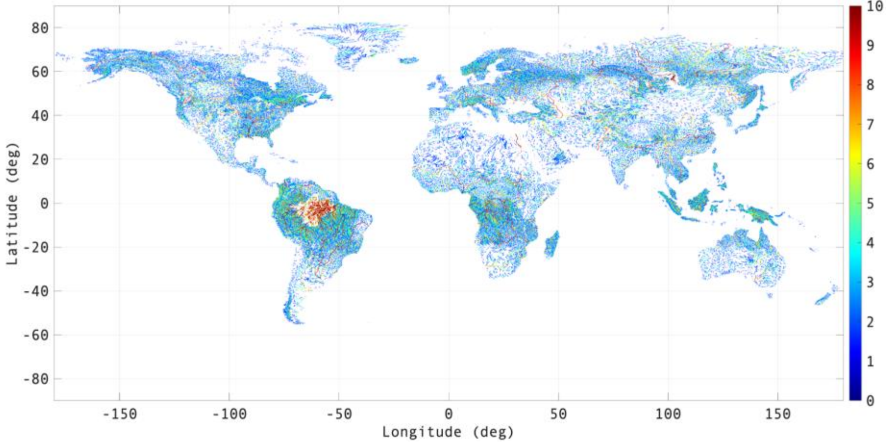
Land Data Assimilation with NASA LIS

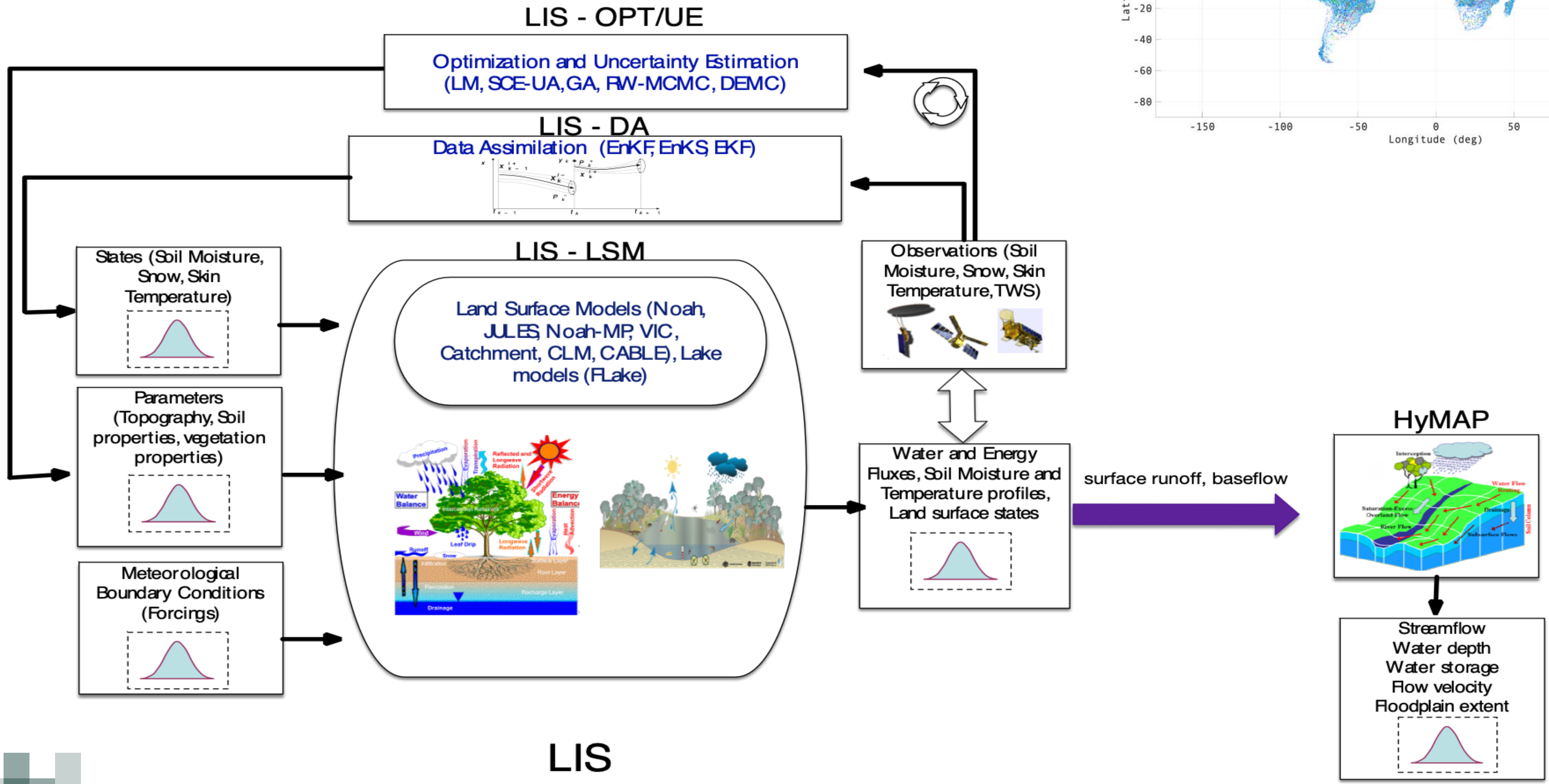


Precipitation-based LDAS (NLDAS, GLDAS)	Rodell et al. 2004, Mitchell et al. 2004
Soil moisture DA	Kumar et al. 2009
SWE, snow cover DA	Liu et al. 2015, Kumar et al. 2015
Skin temperature DA	Reichle et al. 2010
Terrestrial water storage DA	Kumar et al. 2016, Li et al. 2019
Vegetation DA	Kumar et al. 2019, 2020
Albedo DA	Kumar et al. 2020
Water level DA	Ongoing
Multivariate DA	Kumar et al. 2019 Jasinski et al. 2019

- **Vision** – Use all available information to provide simultaneous constraints on the water budget

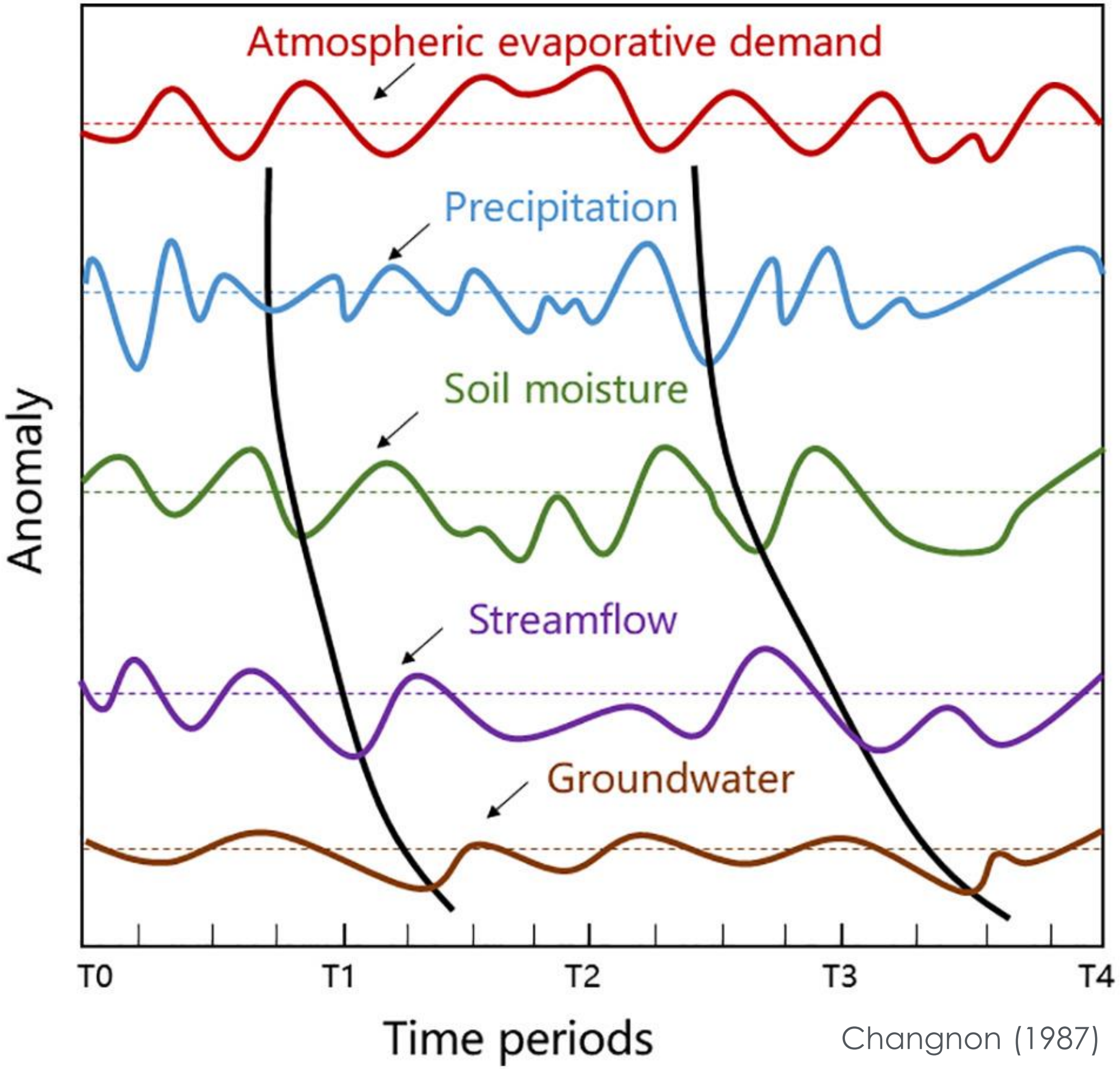
Coupled Land-Hydrology Support





Characterization of Drought from Land Surface Variables

- Precipitation deficiencies (meteorological drought) are translated into deficits in land surface variables (agricultural/hydrological drought) in a delayed manner.
  - Meteorological Drought (Precipitation)
  - Agricultural Drought (Soil Moisture)
  - Hydrological Drought (Streamflow)
- Anthropogenic processes (e.g., agriculture) also impact drought propagation.



Changnon (1987)

Estimating Drought from Land Surface Model Outputs

- Evaluate the time series of the geophysical variable of interest (soil moisture, TWS) and categorize time periods where the conditions are abnormally drier than average conditions.
- U.S. Drought Monitor categorizes 5 different levels of drought.

Category	Description
D0	Abnormally Dry
D1	Moderate Drought
D2	Severe Drought
D3	Extreme Drought
D4	Exceptional Drought

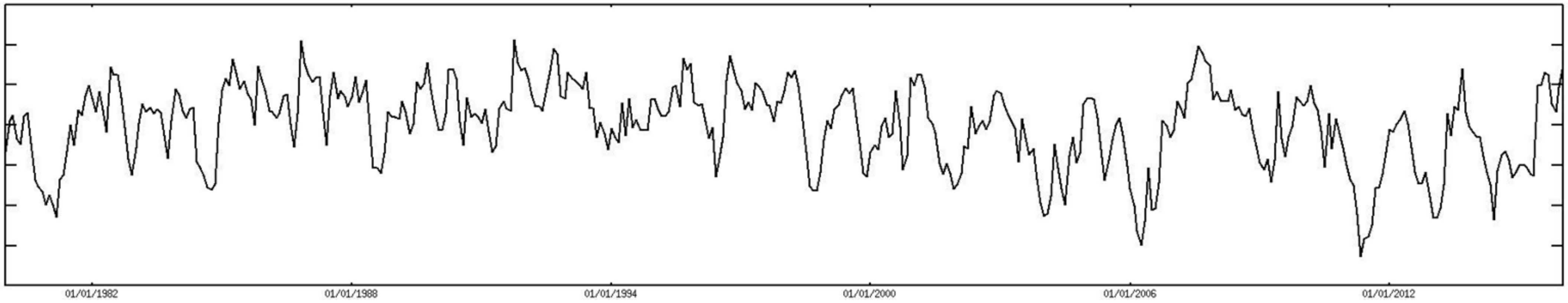
Percentile < 30%

Percentile < 20%

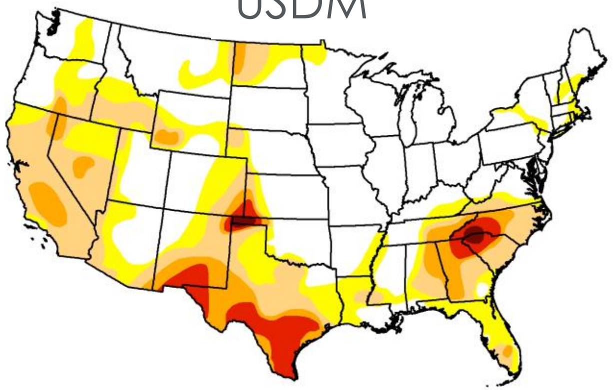
Percentile < 10%

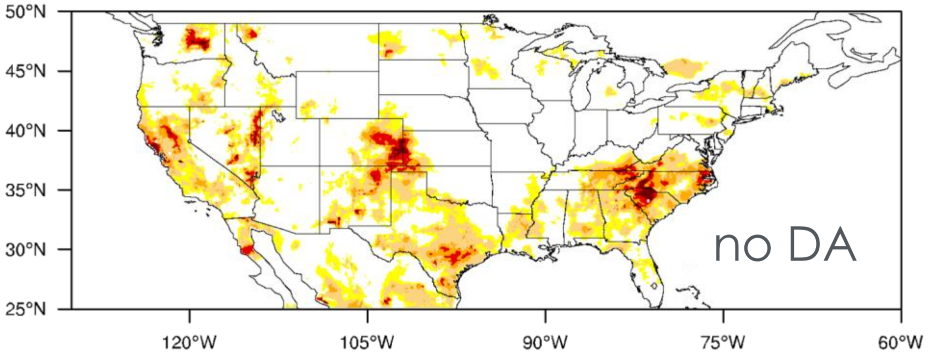
Percentile < 5%

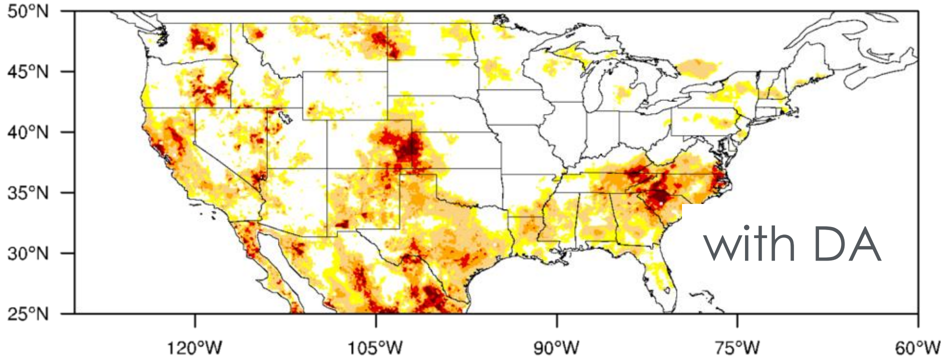
Percentile < 2%



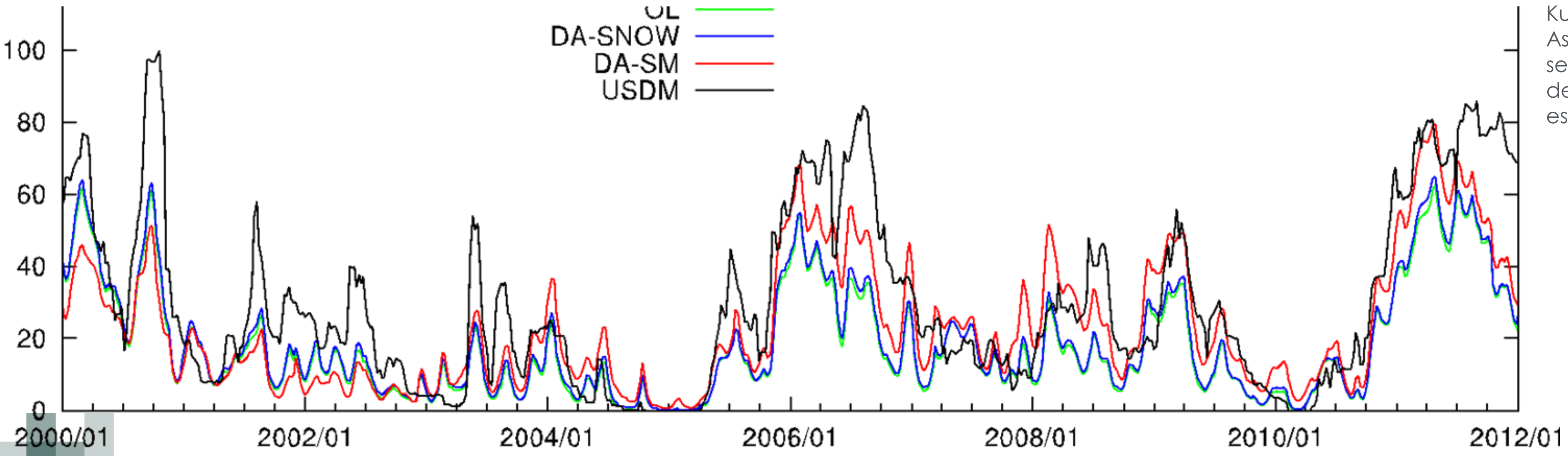
Assimilation of soil moisture data improves drought estimates.







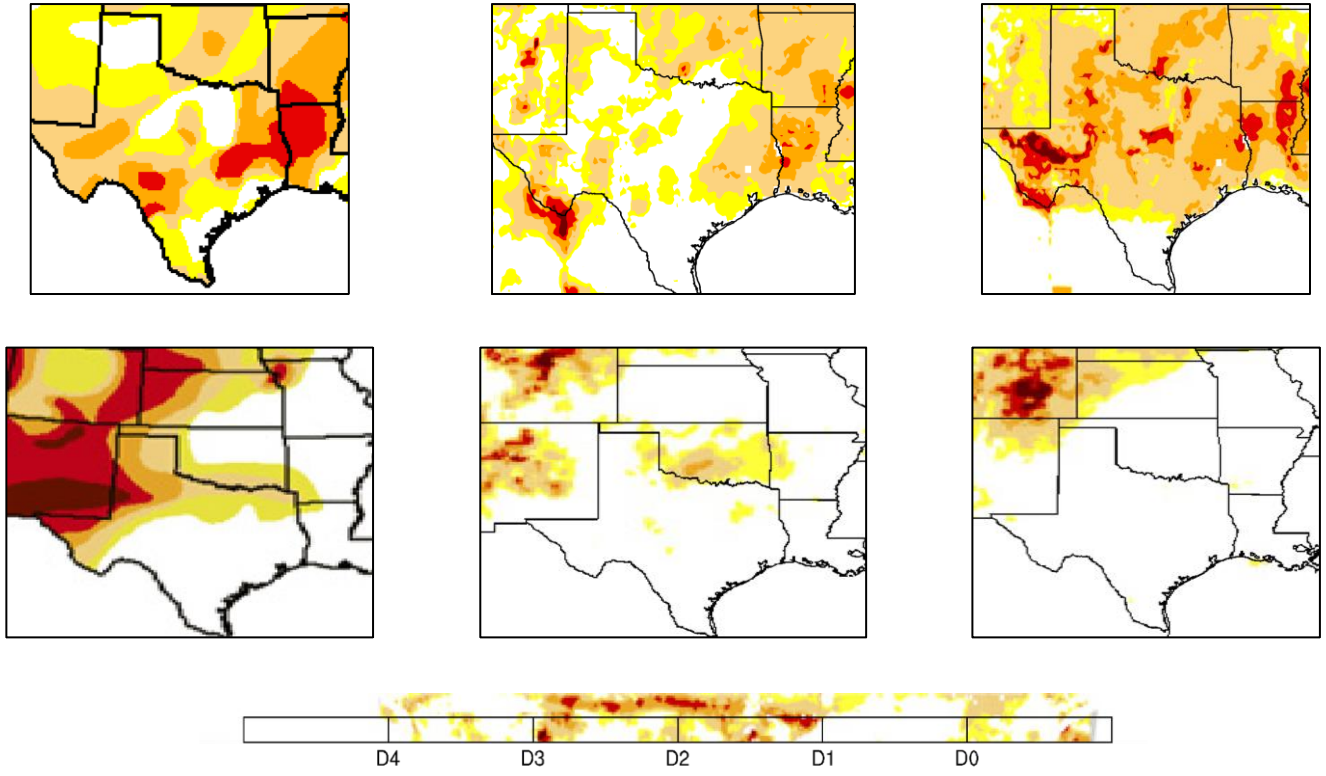
Improvements in Streamflow Drought Percentiles (Southern US) from Soil Moisture Data Assimilation



Kumar, S.V et al. (2014), Assimilation of remotely sensed soil moisture and snow depth retrievals for drought estimation, J. Hydrometeror.

Assimilation of GRACE data improves drought estimates.

US Drought Monitor | Land Model-Based Drought Estimate (no DA) | Drought Estimate with GRACE Data Assimilation



(Jan 2011)

(Sep 2012)

- **2011** – Onset of the drought is improved by GRACE DA
- **2012** – GRACE DA improves drought severity representation over Texas, Kansas, and Oklahoma

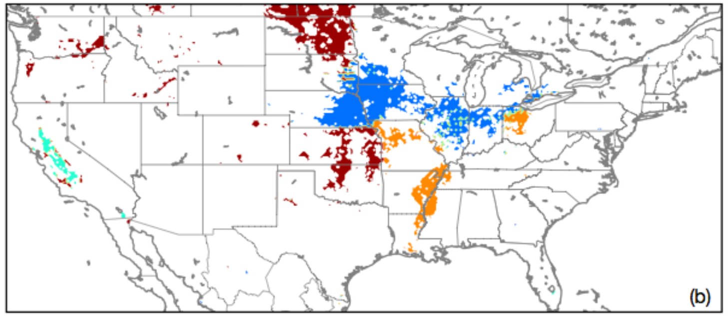
Kumar, S.V. et al. (2017), Assimilation of gridded GRACE terrestrial water storage estimates in the North American Land Data Assimilation System, J. Hydrometeror.

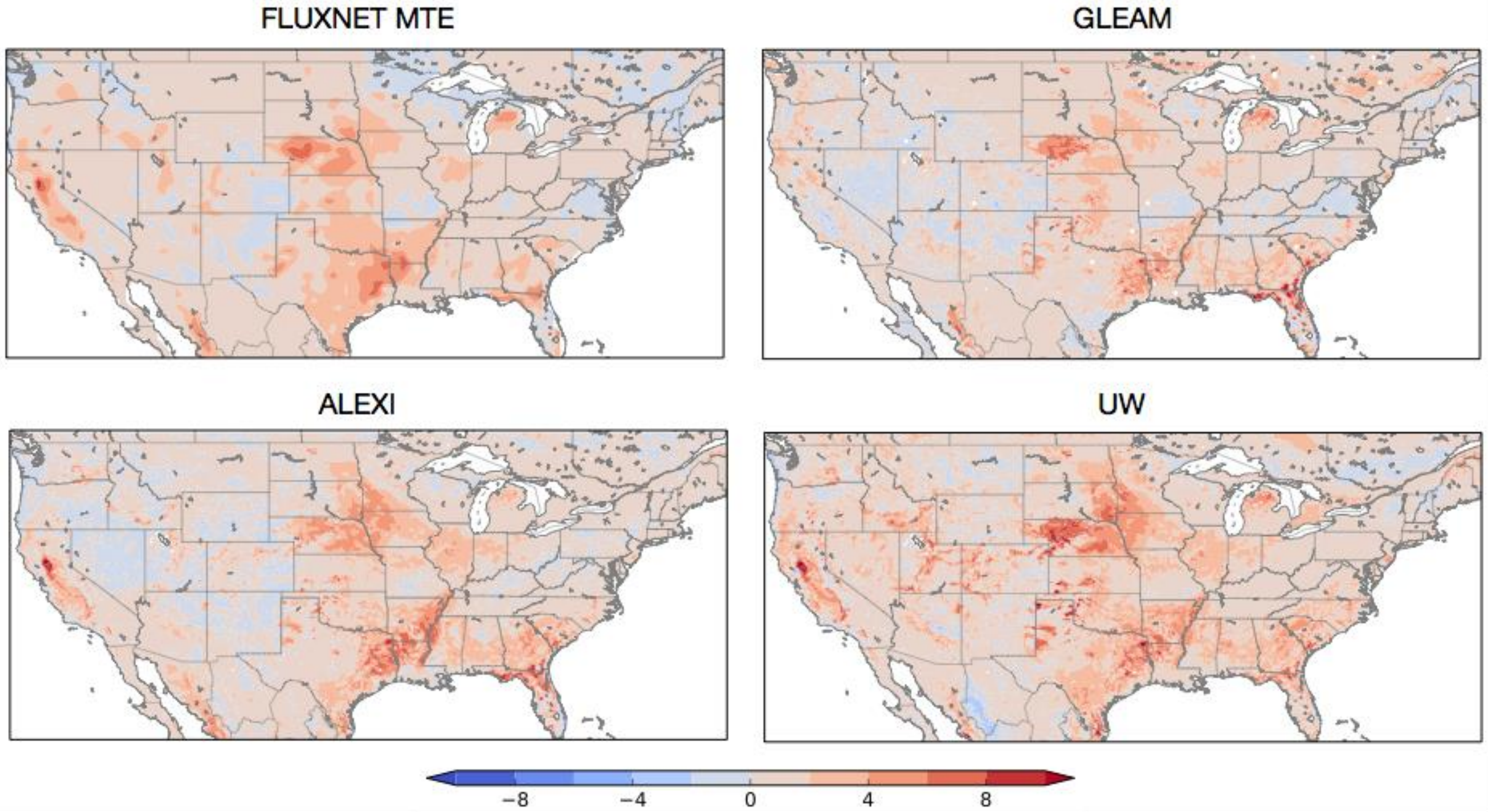
Assimilation of Remotely-Sensed Leaf Area Index (LAI)

LAI estimates from AVHRR/MODIS were assimilated into the Noah-MP land surface model during 1980-2017.

- Systematic and consistent improvements over the Central Plains, Lower Mississippi, and Central California Valley. Larger improvements over agricultural areas of maize and soybean.

Change in RMSE (W/m2) Warm colors indicate improvements; cool colors indicate degradations from DA

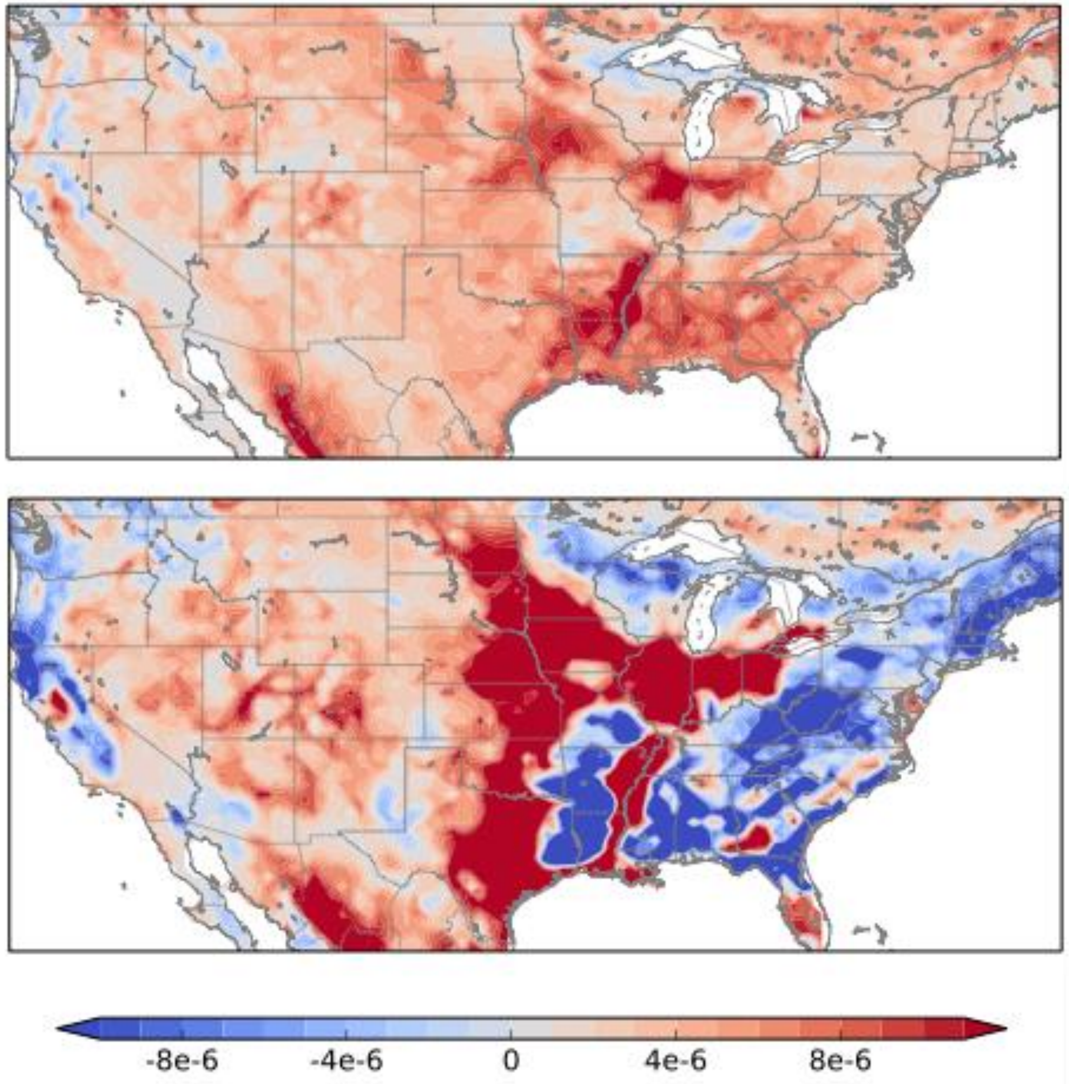




Kumar, S.V., D. Mocko, S. Wang, C.D. Peters-Lidard (2019), Assimilation of remotely sensed leaf areas index into the Noah-MP land surface model: Impacts on water, energy and carbon fluxes and states over the Continental U.S., J. Hydrometeror.

LAI Assimilation Impacts on GPP

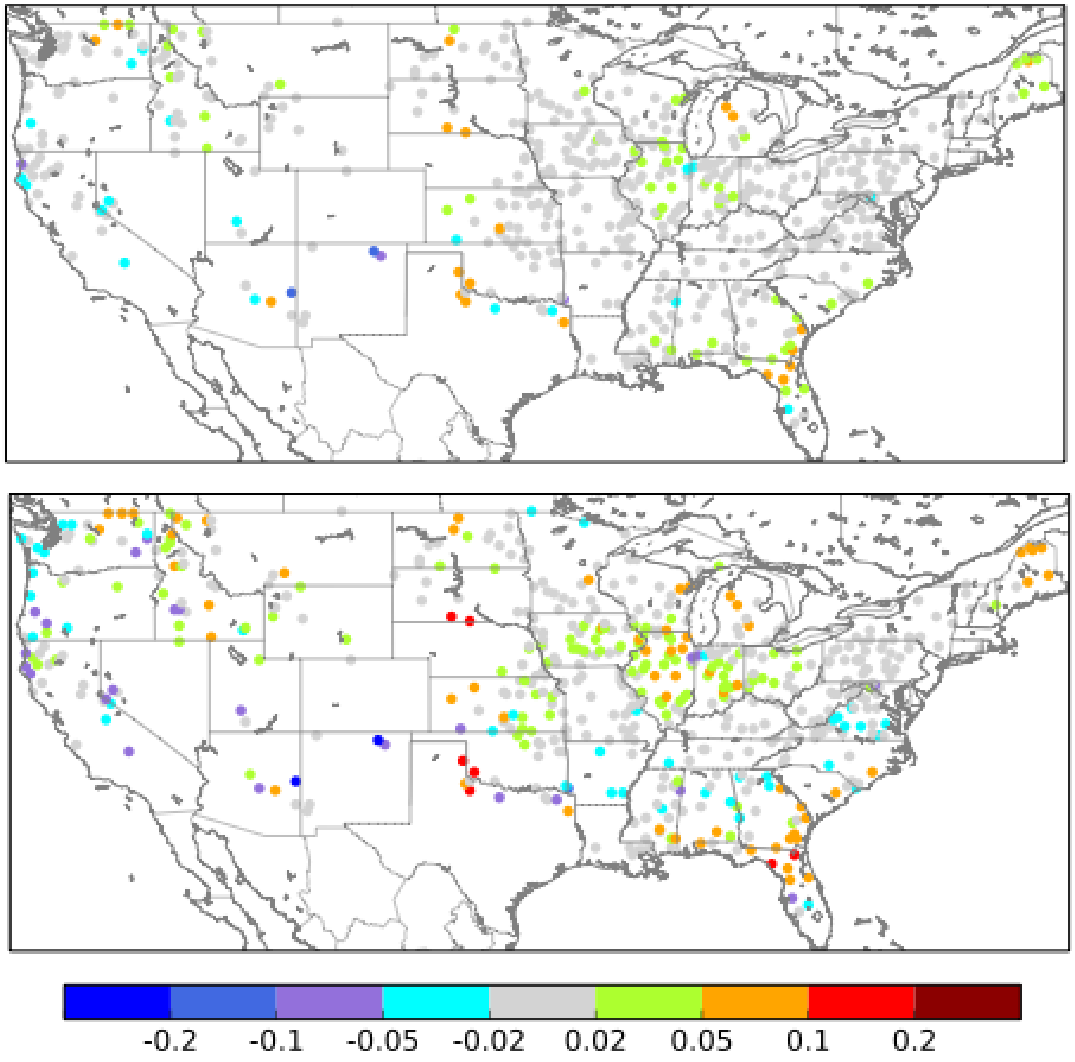
- Strong improvements in GPP over irrigated agricultural areas



Change in RMSE (g/m2) of GPP and NEE compared to FLUXCOM. Warm colors indicate improvements; cool colors indicate degradations from DA.

LAI Assimilation Impacts on Streamflow

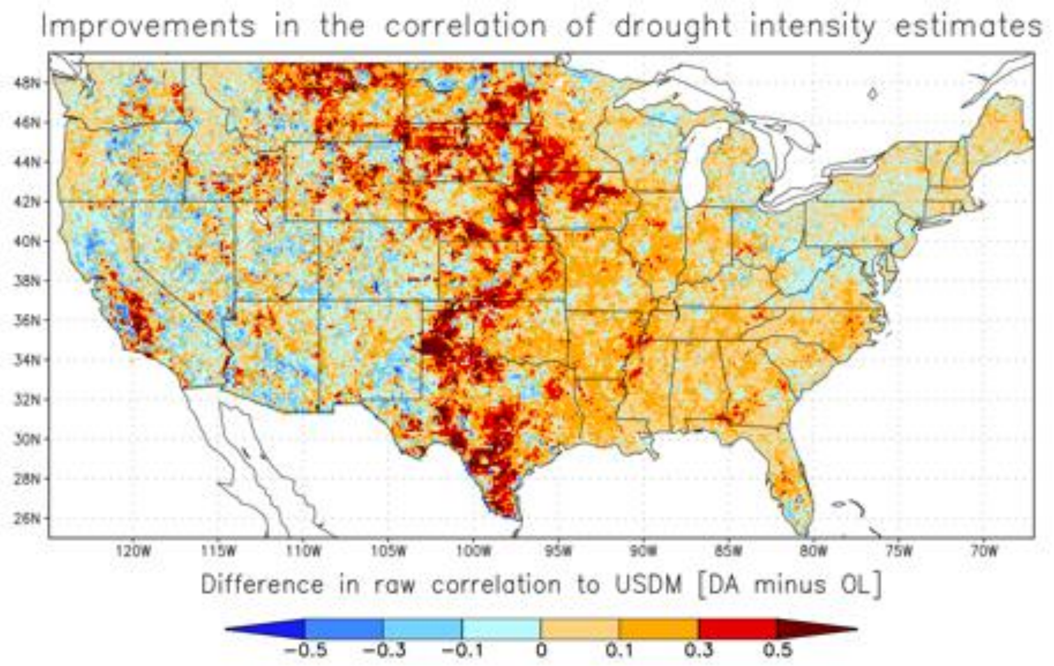
- Streamflow skill is improved over several river basins (Upper Mississippi, Ohio, Columbia, Upper Missouri, South Atlantic)



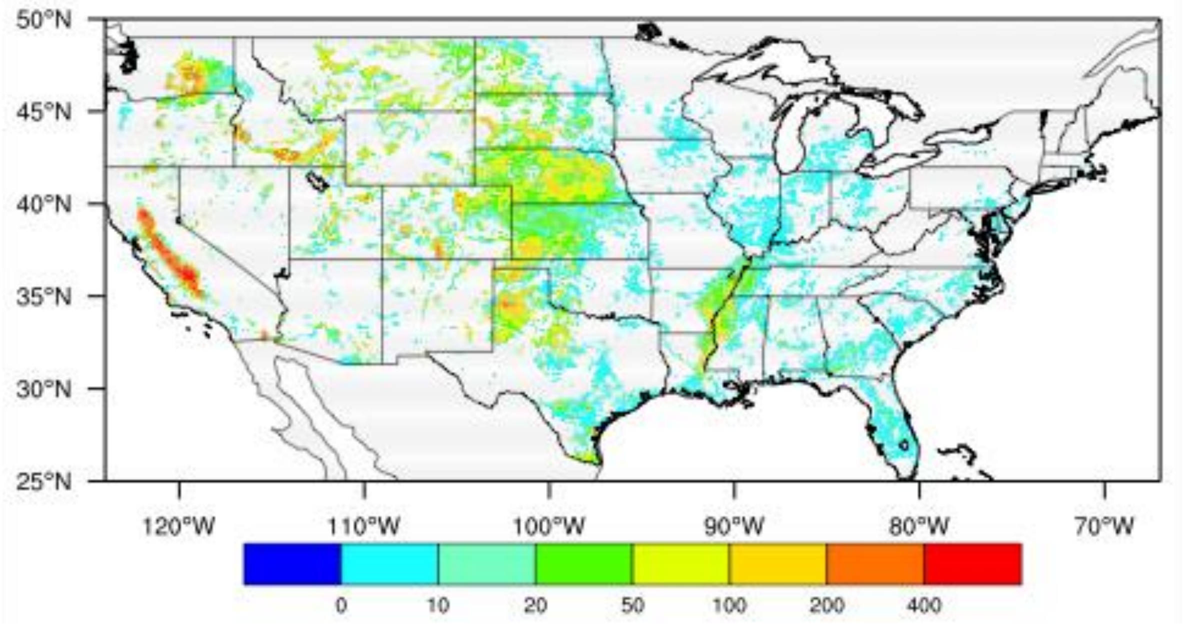
Normalized improvements in streamflow NSE and RMSE (using USGS streamflow as the reference)

LAI Assimilation Improves Drought Estimation

- Irrigated area in NCA-LDAS is determined by MODIS. Areas with both high irrigated amounts and improvements in the raw correlation of soil moisture percentiles against USDM from LAI data assimilation include:
  - Central California Valley
  - Nebraska
  - Lower Mississippi Basin
  - Northwest Texas



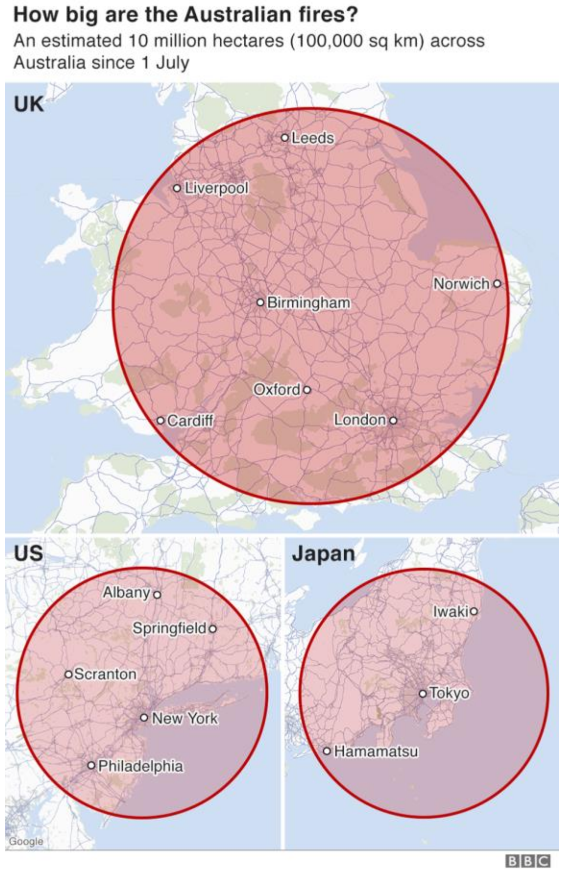
Average annual irrigated water use (mm/year) from NCA-LDAS (Kumar et al. 2018, JHM)

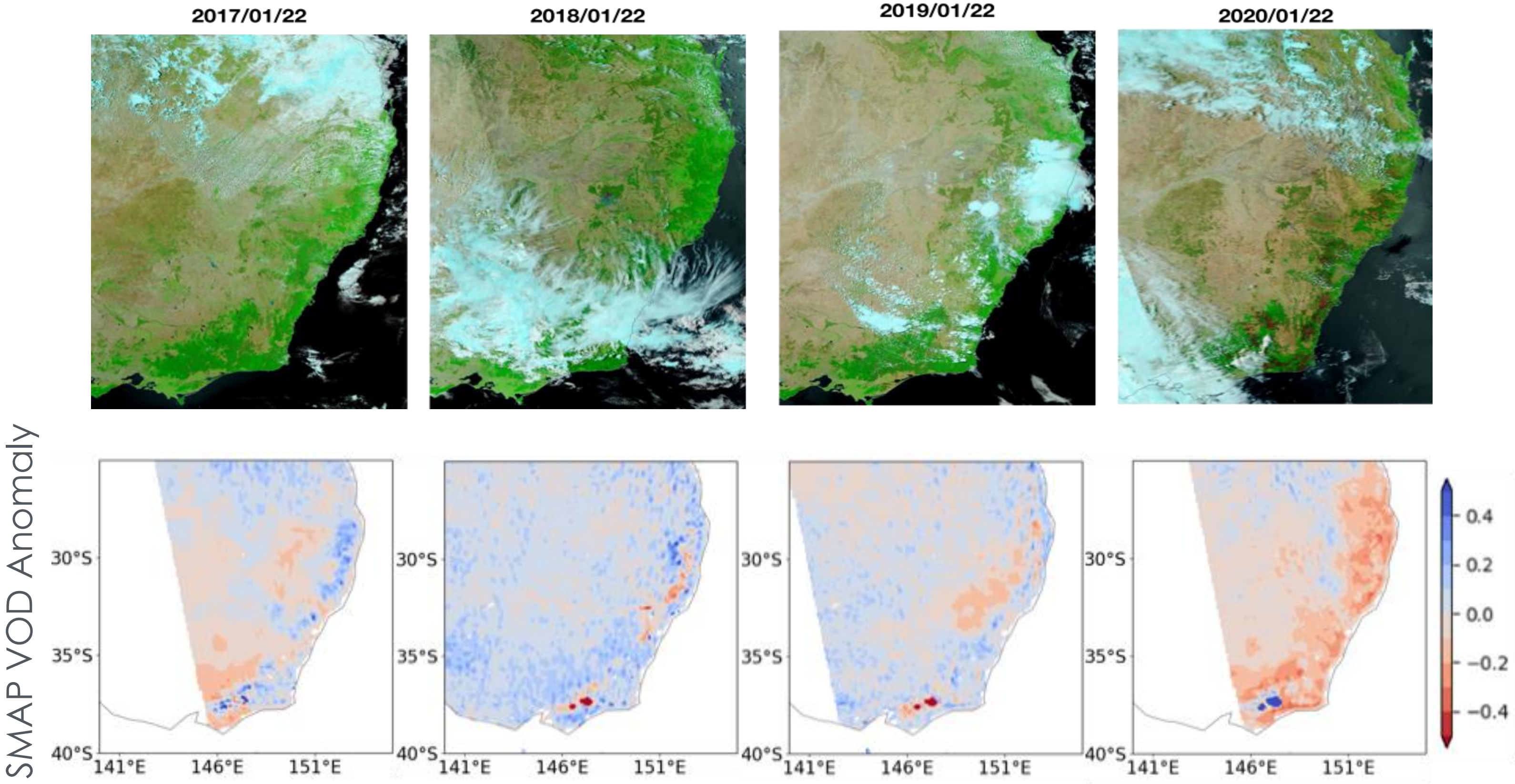


Mocko et al. (2021): Assimilation of vegetation conditions improves the representation of drought over agricultural areas, J. Hydrometeor., doi:10.1175/JHM-D-20-0065.1

Capturing the Impact of Vegetation Disturbances (2019-2020 Australian Bushfires)

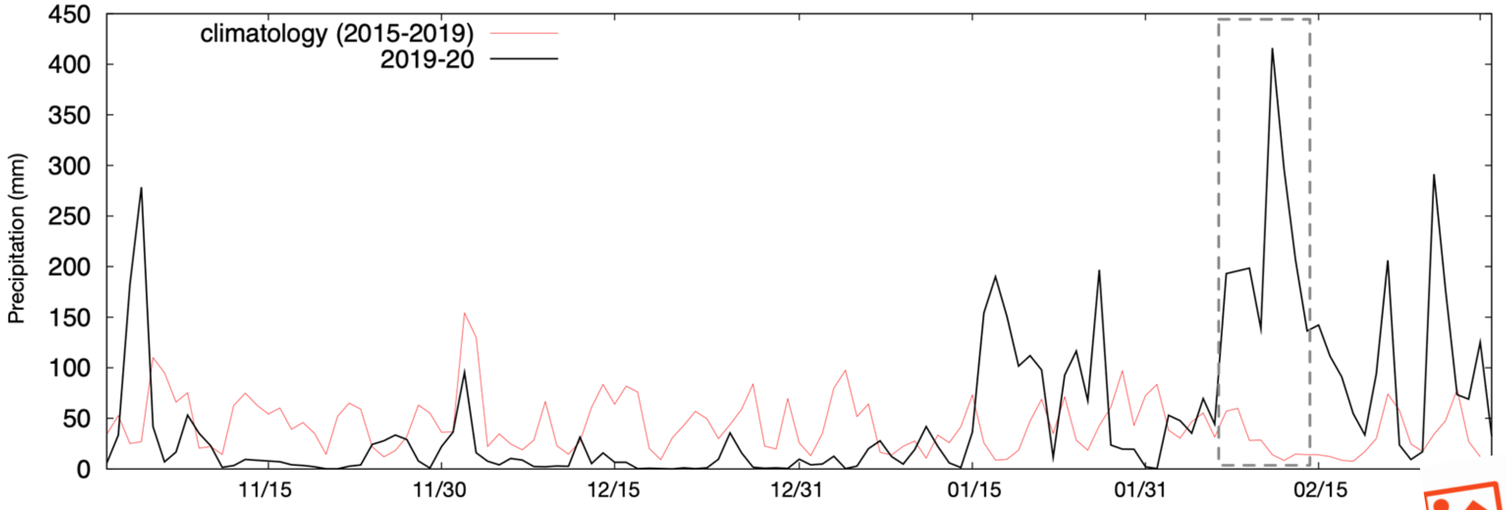
- SMAP VOD captures the vegetation disturbances from the 2019-2020 bushfires.



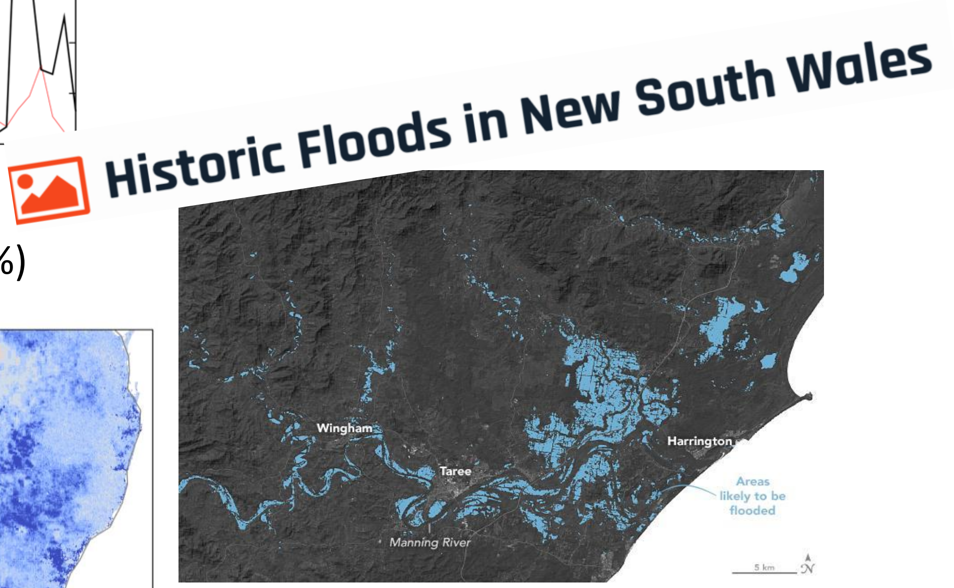


Kumar et al. (2021): The 2019-2020 Australian drought and bushfires altered the partitioning of hydrological fluxes. *Geophys. Res. Lett.*, 48(1), 10.1029/2020GL091411

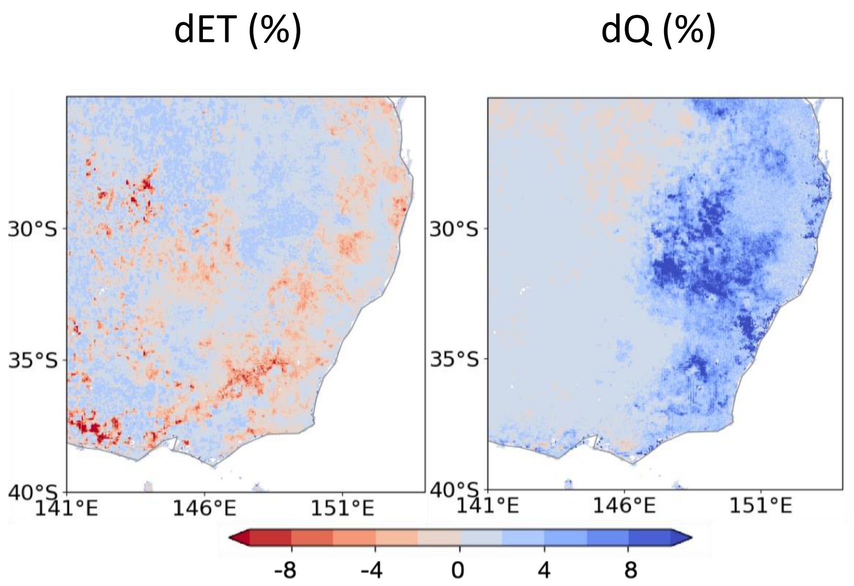
Impact of Bushfire Disturbances on the Water Cycle



SMAP VOD retrievals are assimilated into NoahMP LSM to examine the impact on evaporative and runoff fluxes.

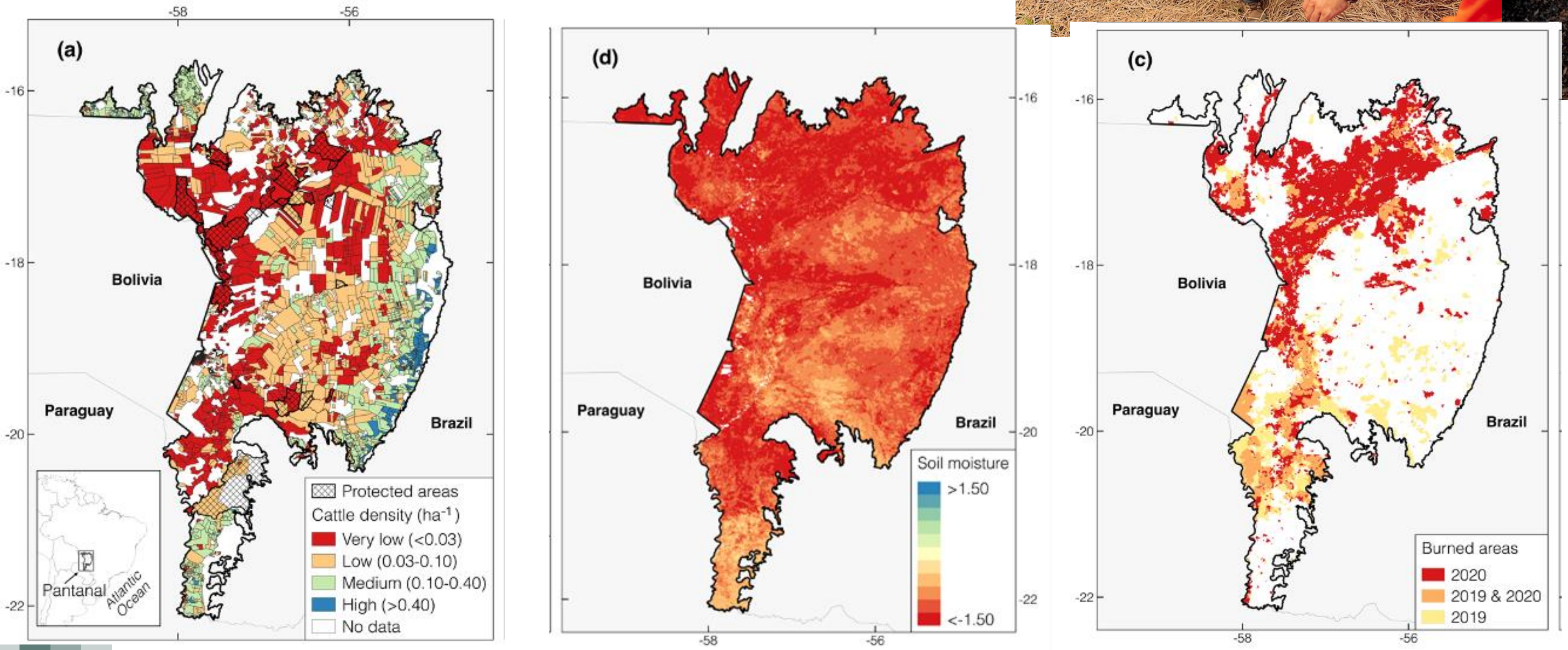


- Removal of vegetation leads to increased runoff, increased bare soil evaporation, and reduced transpiration.



The 2020 Pantanal Fires

- **Pantanal** – The largest contiguous wetland in the world with the highest concentration of wildlife in South America.



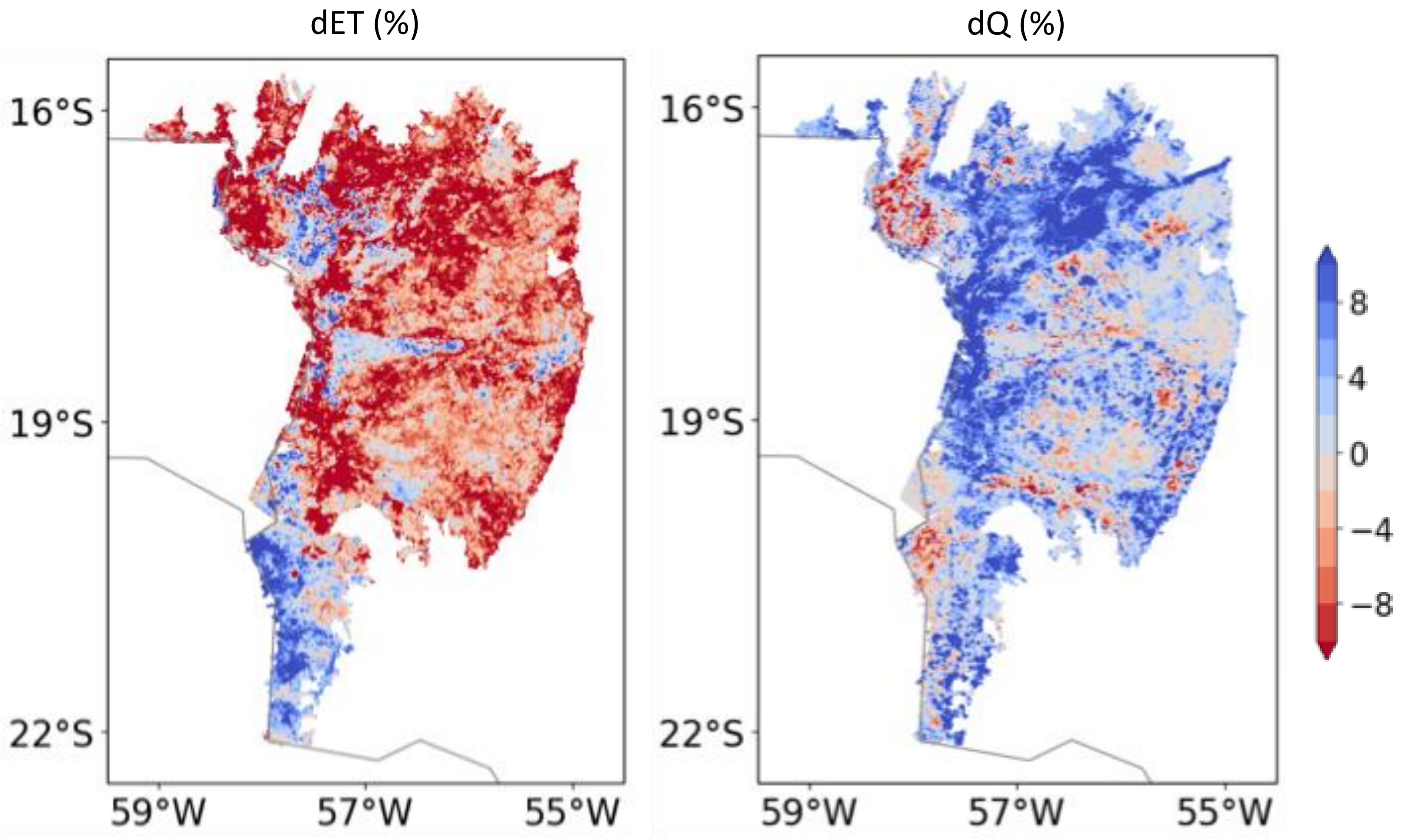
Unprecedented drought and extreme wildfires in Pantanal, particularly over the natural and conserved areas

~29% of the region burned in 2020.

Kumar et al. (2022). Changes in land use enhance the sensitivity of tropical ecosystems to fire-climate extremes, Sci Reports

The 2020 Pantanal Fires – Changes to Hydrology

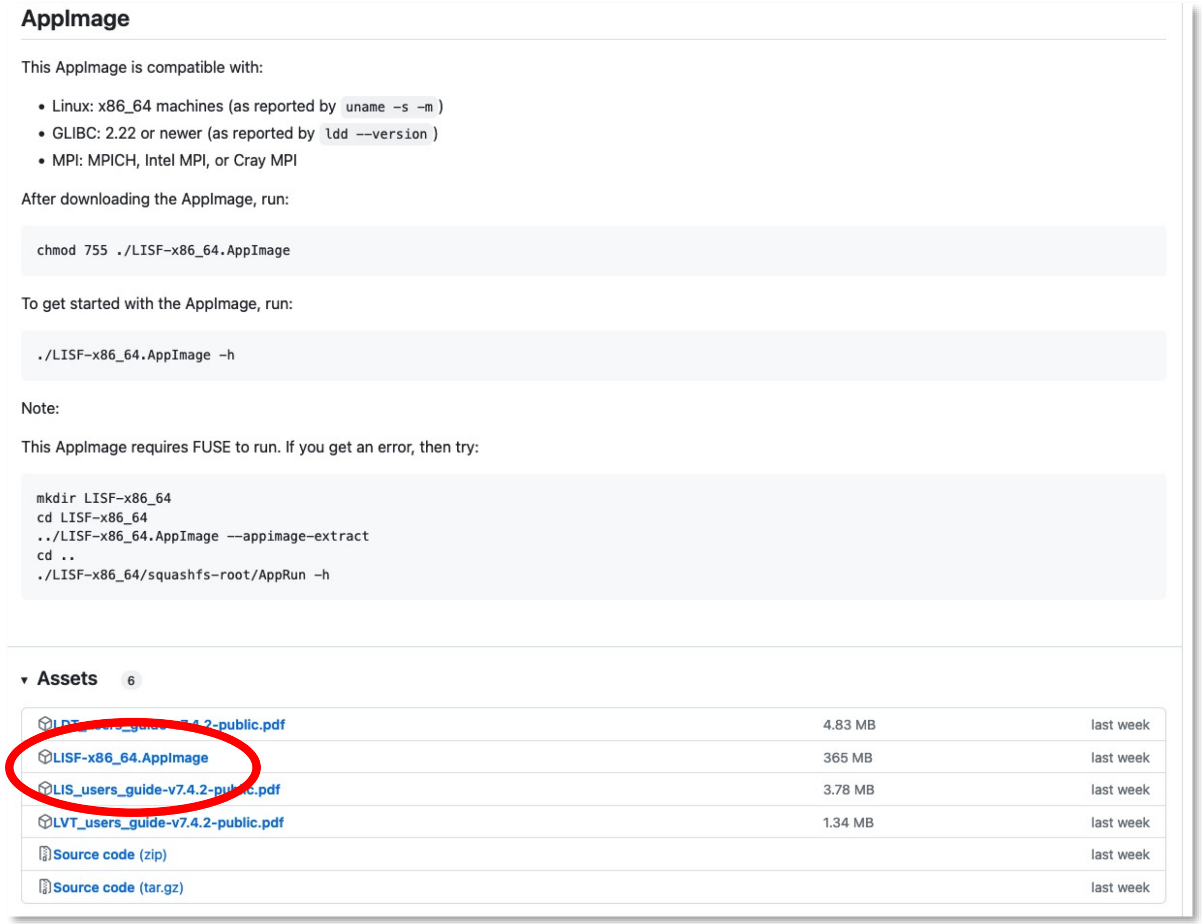
- Fundamental Changes to the Local Hydrology:
  - Evaporation is reduced
  - Runoff is increased with concerns about increased land degradation (captured through the assimilation of MODIS LAI)



Containerized Version of LIS

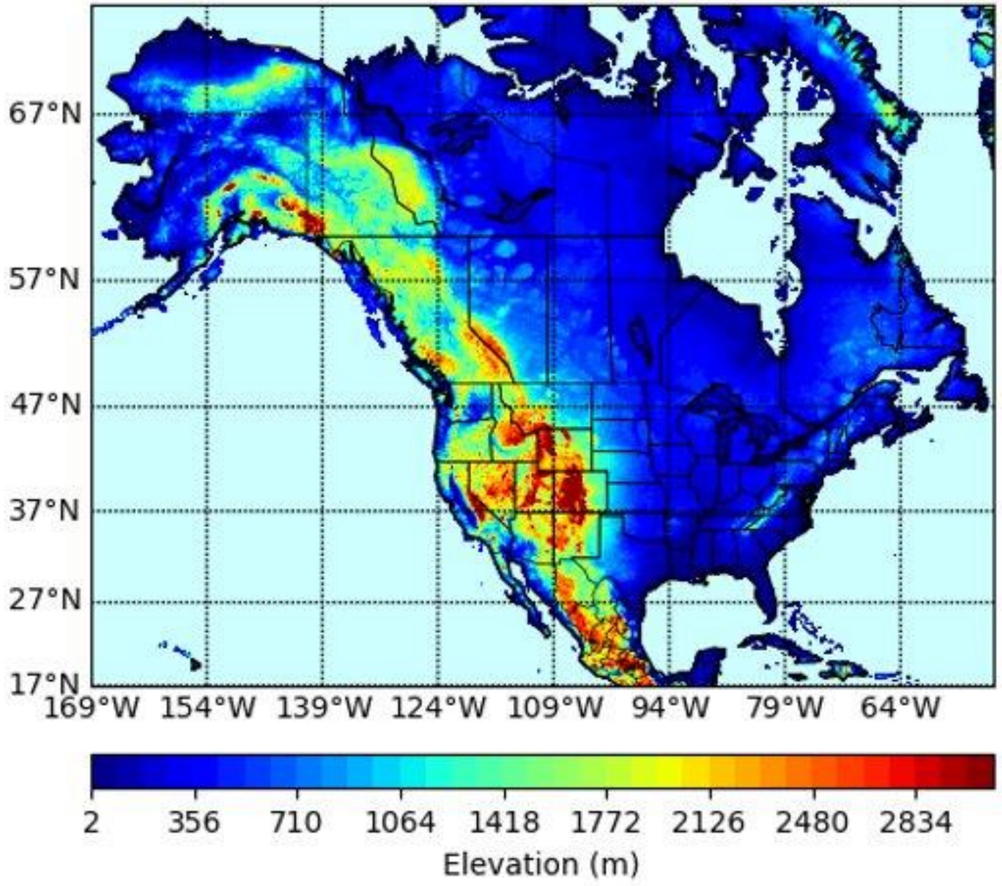
- LIS is a large modeling system (~7000 files and 1.5 million lines of code).
  - Implementing it natively is a significant effort.

- The LIS team developed a containerized version of LIS to improve the ease of use, developed as an AppImage container.



Next Generation Drought Modeling Support

- The LIS team is developing a configuration of LIS that truly enables the vision of NLDAS, by modeling over the entirety of North America and by enabling multi-variate data assimilation.
- An experimental, high-resolution precipitation product that integrates GPM IMERG, MERRA2, GEOS-IT, and the Canadian Precipitation Analysis (CaPA) has been developed.
- This new product mitigates the issues in the current NLDAS2 system and will enable a high-resolution, accurate land data assimilation environment for routine drought characterization at NASA SPoRT.

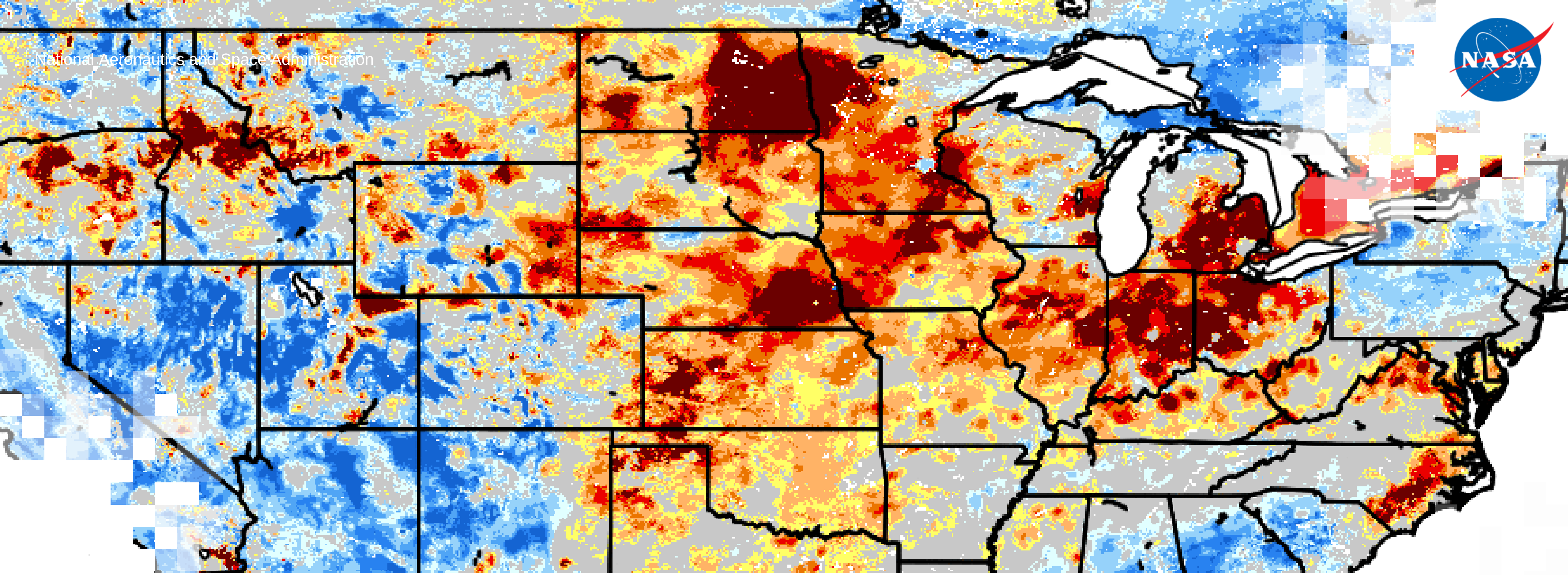


Summary

- The NASA Land Information System (LIS) provides a framework for the comprehensive characterization of the land surface and the characterization of hydrological extremes such as droughts.

- The capability of remote sensing data infusion through data assimilation enables the representation of land surface heterogeneity and human management impacts.

National Aeronautics and Space Administration



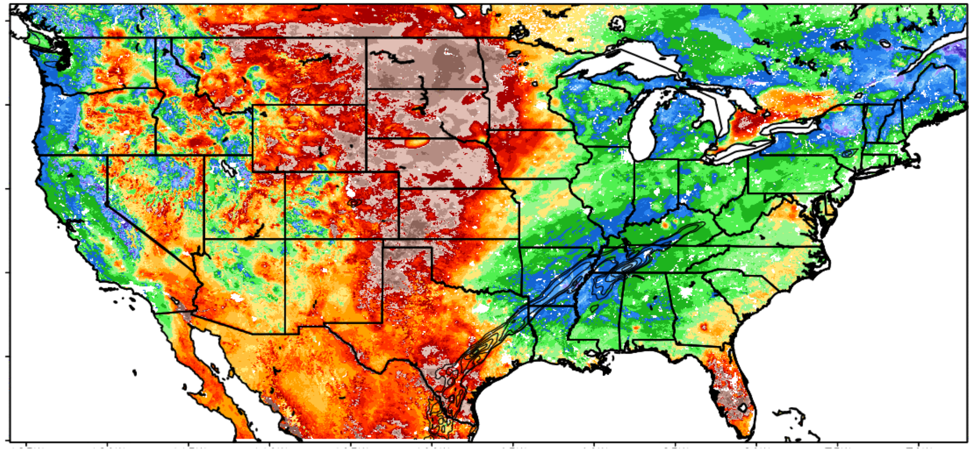
SPoRT-Land Information System (SPoRT-LIS) Soil Moisture Analyses for Enhanced Drought Situational Awareness

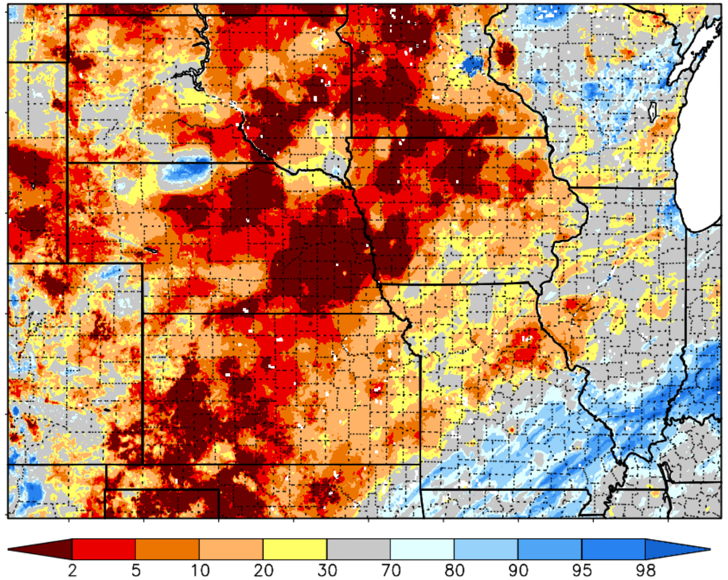
Jonathan L. Case – ENSCO, Inc./NASA Short-term Prediction Research and Transition (SPoRT) Center

May 17, 2023

Outline of Topics

- The SPoRT-LIS Motivation: Why did it get started?
- SPoRT-LIS Climatology and Real-Time Setup
- Aspects of SPoRT-LIS
  - 33-year climatology (1981-2013)
  - Real-time analyses with minimal data latency
  - Satellite-derived Green Vegetation Fraction (GVF)
  - Experimental 2-week forecasts
  - Output variables
- Percentiles: Placing soil moisture into historical context
- Validation: Comparison to U.S. Drought Monitor analyses



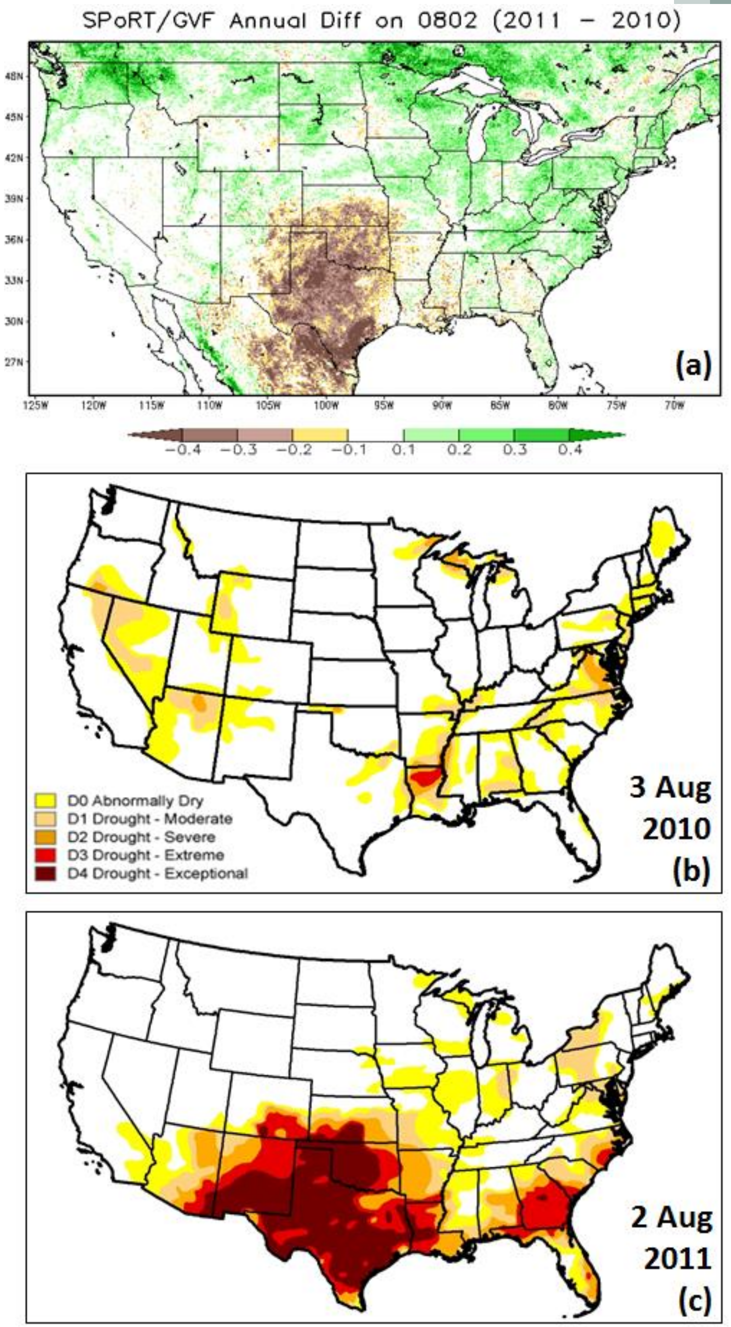


SPoRT-LIS Motivation and Brief History

- Early motivation to improve regional forecast models
  - Demonstrated that high-res Land Surface Model (LSM) initial fields led to improved numerical forecasts

    Case et al. 2008 (*J. Hydrometeor.*)
    Case et al. 2011 (*Wea. Forecasting)*
  - Impact of real-time vs. monthly average vegetation

    Case et al. 2014; IEEE Trans. Geosci. Rem. Sens.
- SPoRT users applied LIS to situational awareness
  - Thunderstorm initiation at NWS Birmingham, AL
  - Drought analysis at NWS offices in Huntsville, AL; Raleigh, NC; Houston, TX
  - Pluvial applications to identify local river flooding
  - Expanded to full CONUS and OCONUS domains 2015+



Case, J. L., et al., 2008: *J. Hydrometeor.*, **9**, 1249-1266, doi:10.1175/2008JHM990.1.
Case, J. L. et al. 2011: *Wea. Forecasting*, **26**, 785-807, doi:10.1175/2011WAF2222455.1.
Case, J. L., et al., 2014: *Geosci. Remote Sens.*, **52(3)**, 1772-1786, doi:10.1109/TGRS.2013.2255059.

SPoRT-Land Information System (SPoRT-LIS): High-level Overview – Process Flow

Prepare static and time-varying forcing datasets on LIS domain

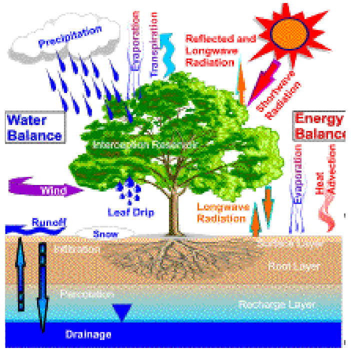
Soil States
(Soil Moisture, Soil Temperature)

Static Parameters
(Topography, Soil Properties, Vegetation Properties)

Meteorological Boundary Conditions
(Forcings)

LIS - LSM

Noah LSM



Water and Energy Fluxes, Soil Moisture and Temperature Profiles, Land Surface States

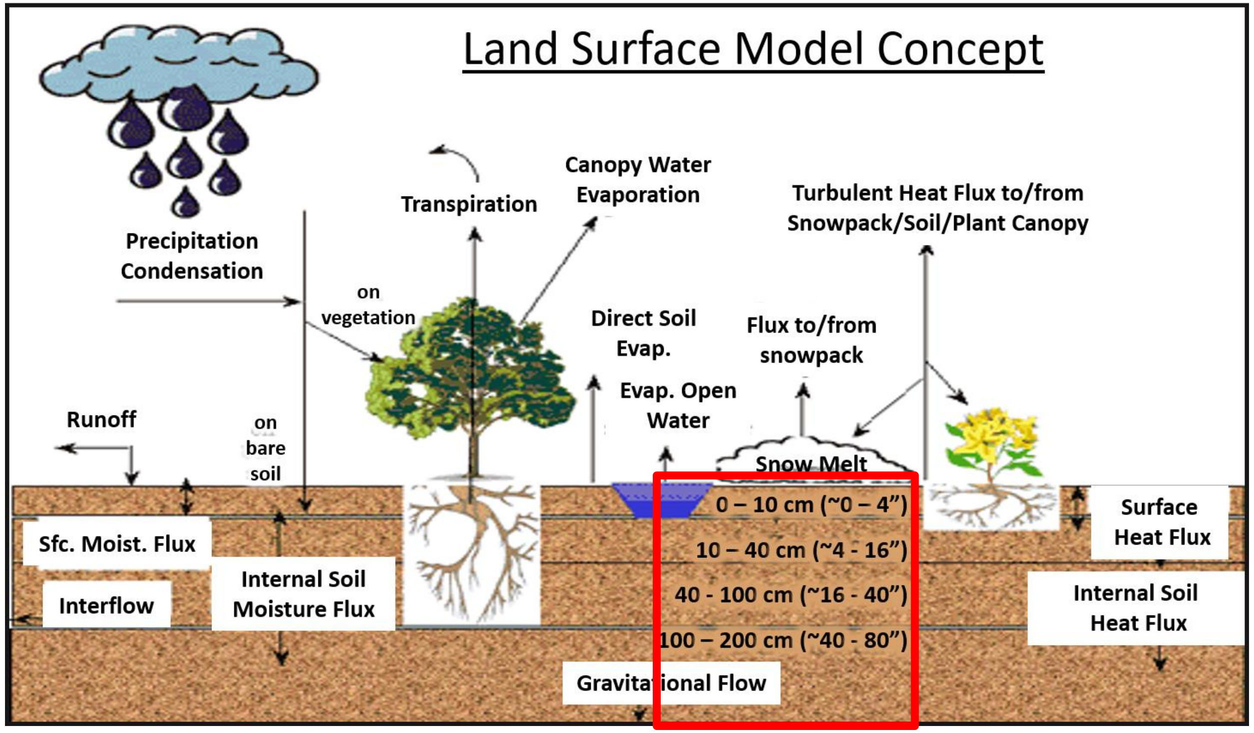
Post-Processing:
- Derived fields
- New data formats
- Delivery and dissemination

Observations-Constrained Land Surface Model (LSM) Driven by Meteorological Analysis Inputs (Forcings)

Noah Land Surface Model: Core of SPoRT-LIS (Ek. et al. 2003)

Noah Land Surface Model (LSM) **Offline: Observation/Analysis-Driven**

- Legacy Noah LSM as run operationally in NCEP/EMC weather prediction models
  - e.g., NAM, GFS, GEFS, and CFS models
- Physical processes represented by Noah related to **soil-vegetation-snowpack**
- Four standard soil layers:
  - 0-10, 10-40, 40-100, 100-200 cm depth
- Given static and time-varying inputs, Noah LSM solves physical equations for:
  - Soil moisture content and soil temperature
  - Snow depth/water equivalent
  - Heat and moisture transport to the atmosphere

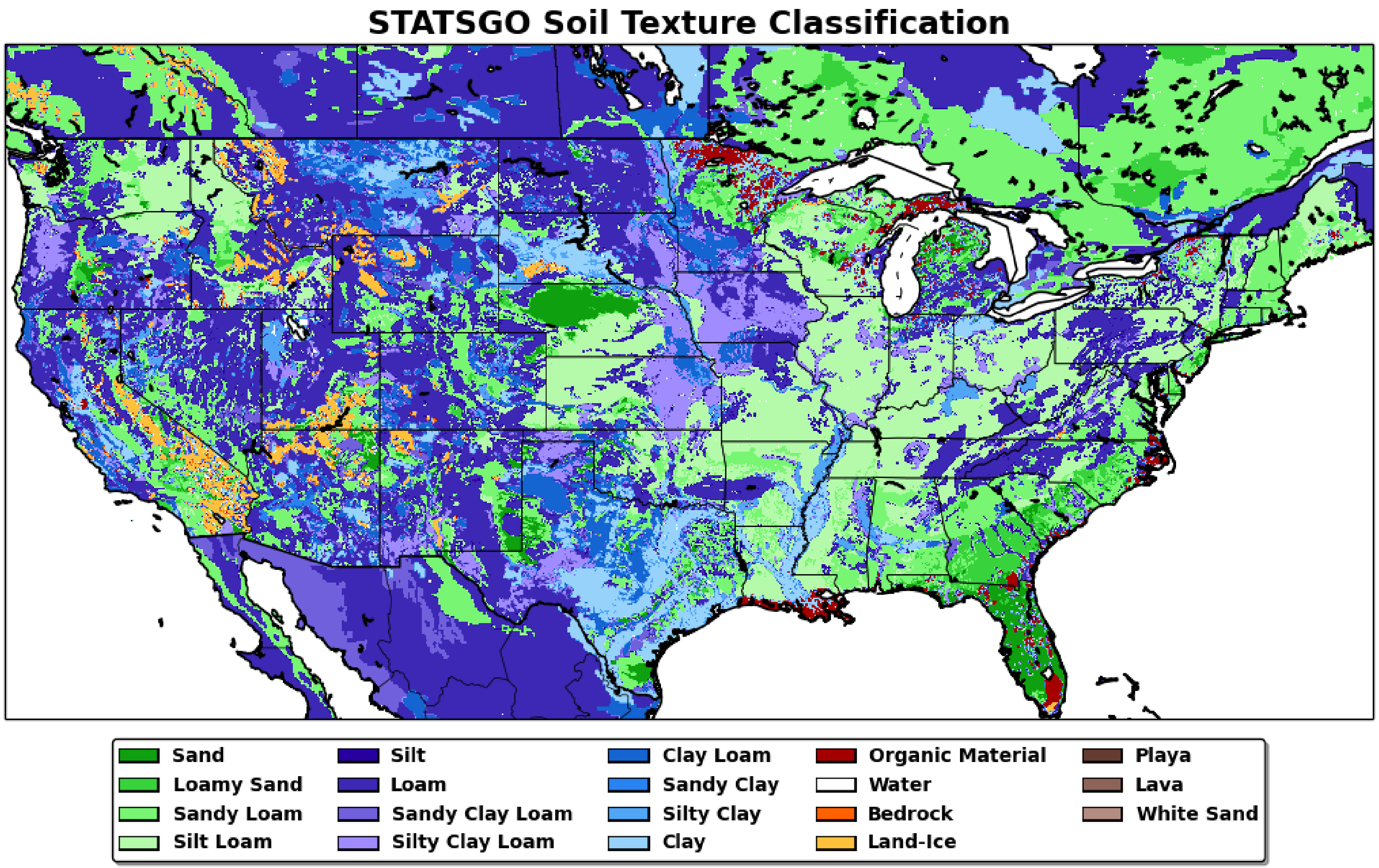


Ek, M. B., et al., 2003: *J. Geophy. Res.*., **108**, 8851, doi:10.1029/2002JD003296.

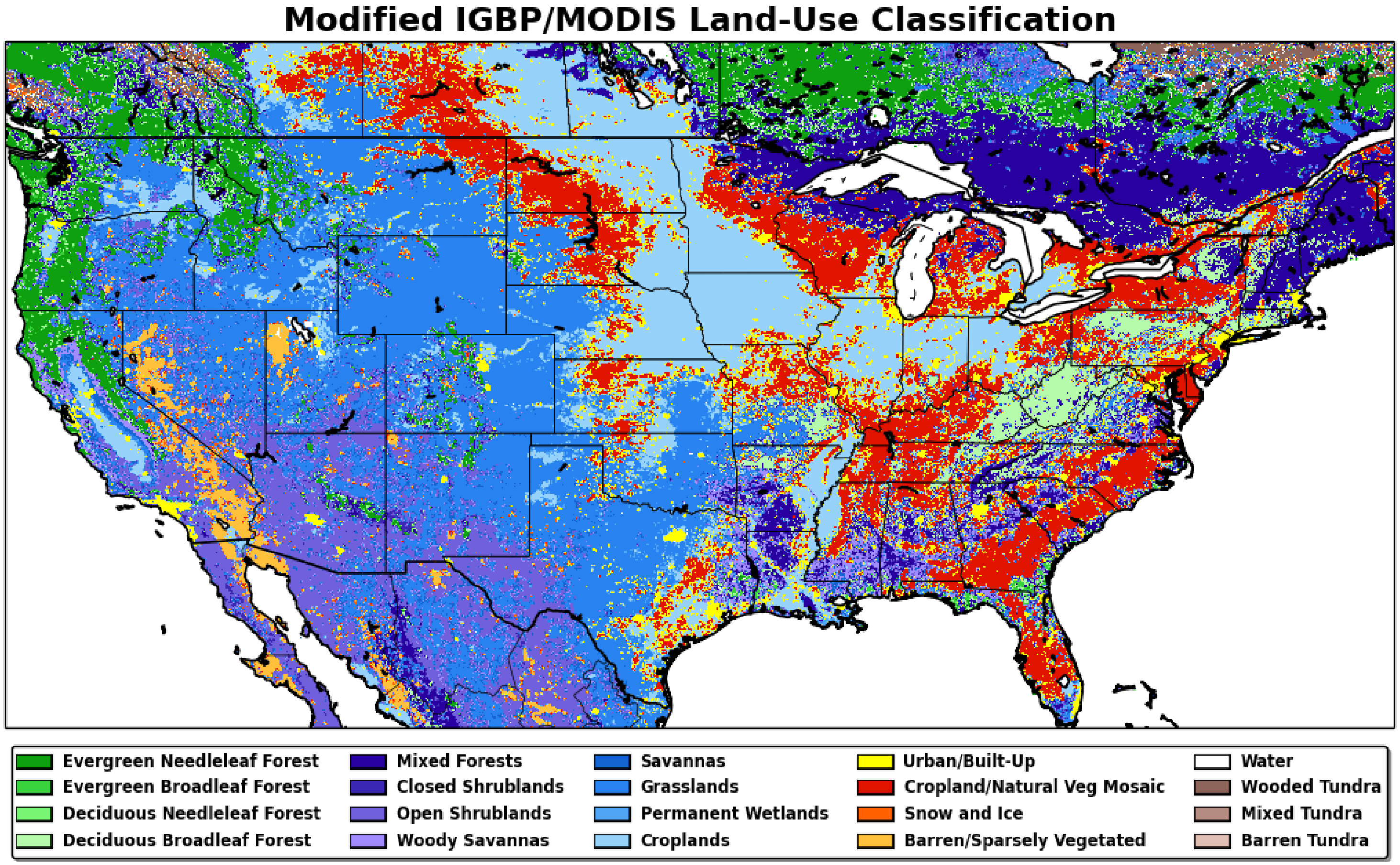
Static Inputs – Soil Classification

State Soil Geographic (STATSGO) Database

- Sand-silt-clay combination in 19 unique classes
- Look-up table defines physical soil properties
- In SPoRT-LIS, soil classification only varies horizontally
  - Soil composition is same in all layers of the column



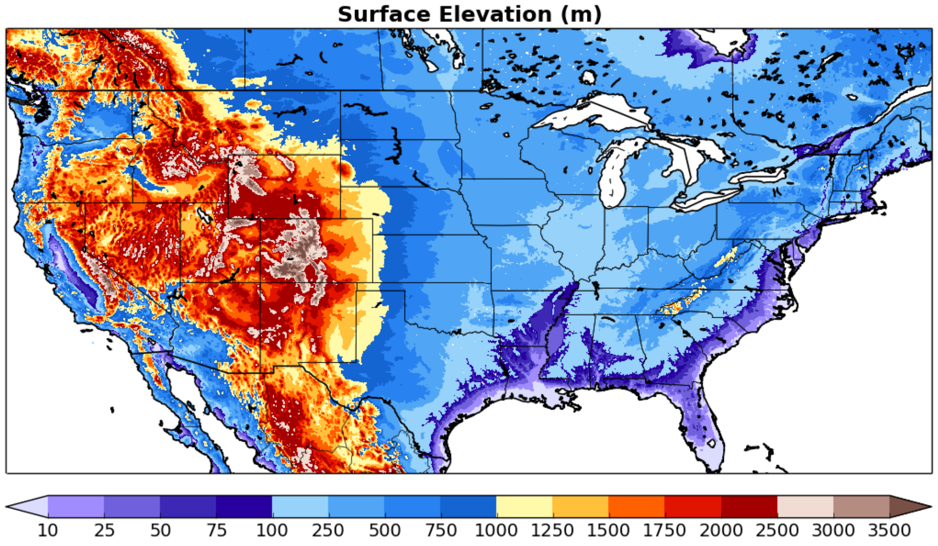
Static Inputs – Vegetation Classification

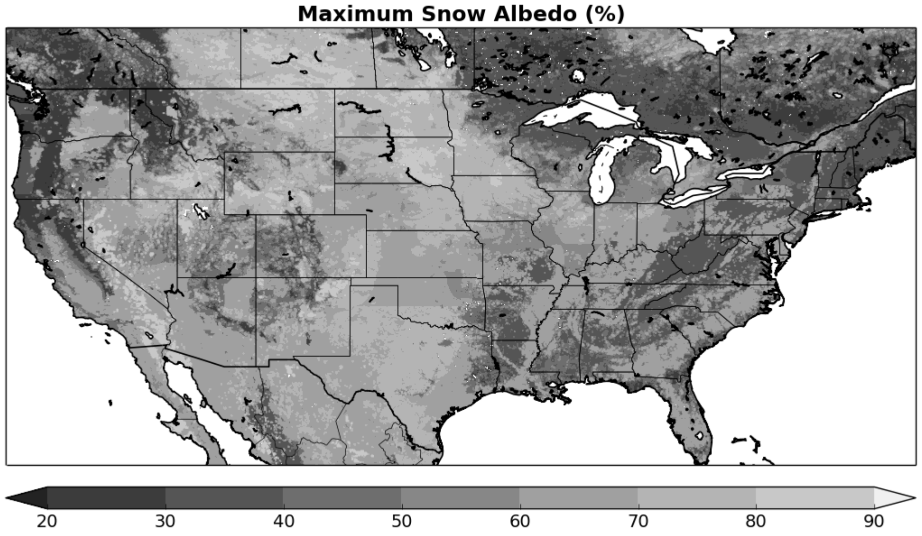


International Geosphere-Biosphere Programme (IGBP) Database

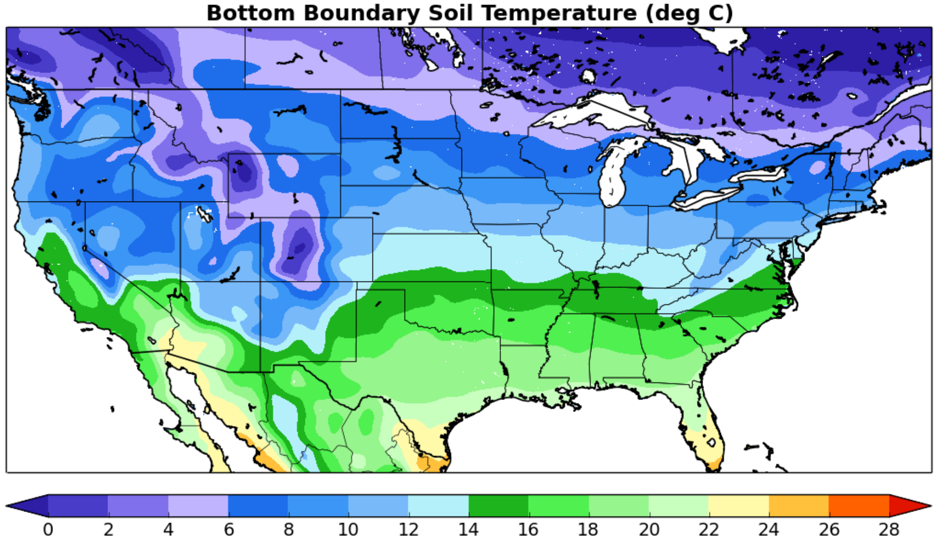
- Land-use in 20 unique classes
- Derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS)
- Look-up table defines physical properties of vegetation such as:
  - Vertical Density
  - Reflectance
  - Resistance to Transpiration

Static Inputs – Other Constraints





Topography, Up-Scaled to LIS Grid

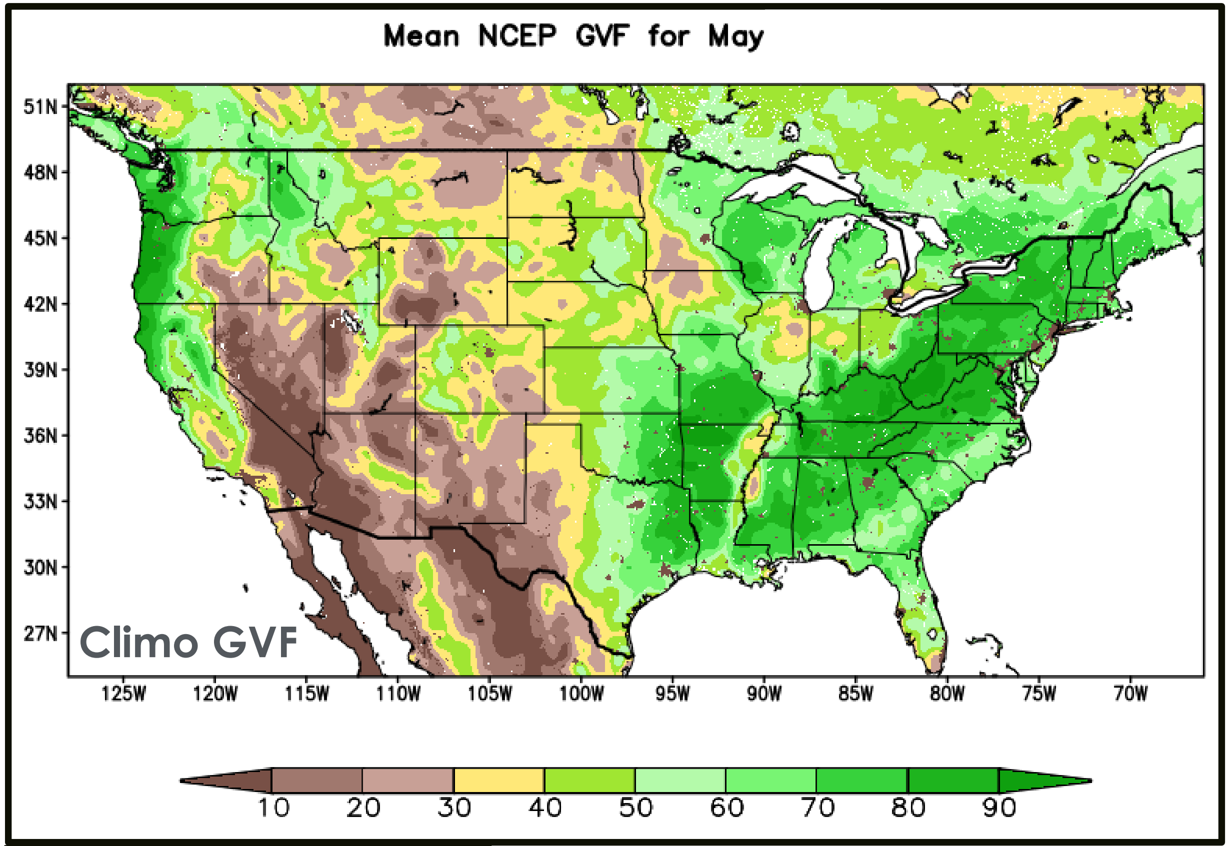


Maximum snow albedo derived from MODIS

Bottom Soil Temperature Climatology

Time-Varying Inputs – Green Vegetation Fraction (GVF)

- GVF defined as percent coverage of healthy, actively-transpiring vegetation
  - Partitions incoming energy into sensible, latent, and ground heat fluxes
- MODIS-based monthly GVF climatology
  - Spin-up run and SPoRT-LIS climatology 1981 through August 2012
- Daily-updated NESDIS/VIIRS GVF
  - Vargas et al. 2015; *20th Conf. Sat. Met.*
  - September 2012 to present



Monthly Climatological GVF for May Shown

Vargas, M., et al., 2015: *20th Conf. Sat. Met.*, P210, https://ams.confex.com/ams/95Annual/webprogram/Paper259494.html

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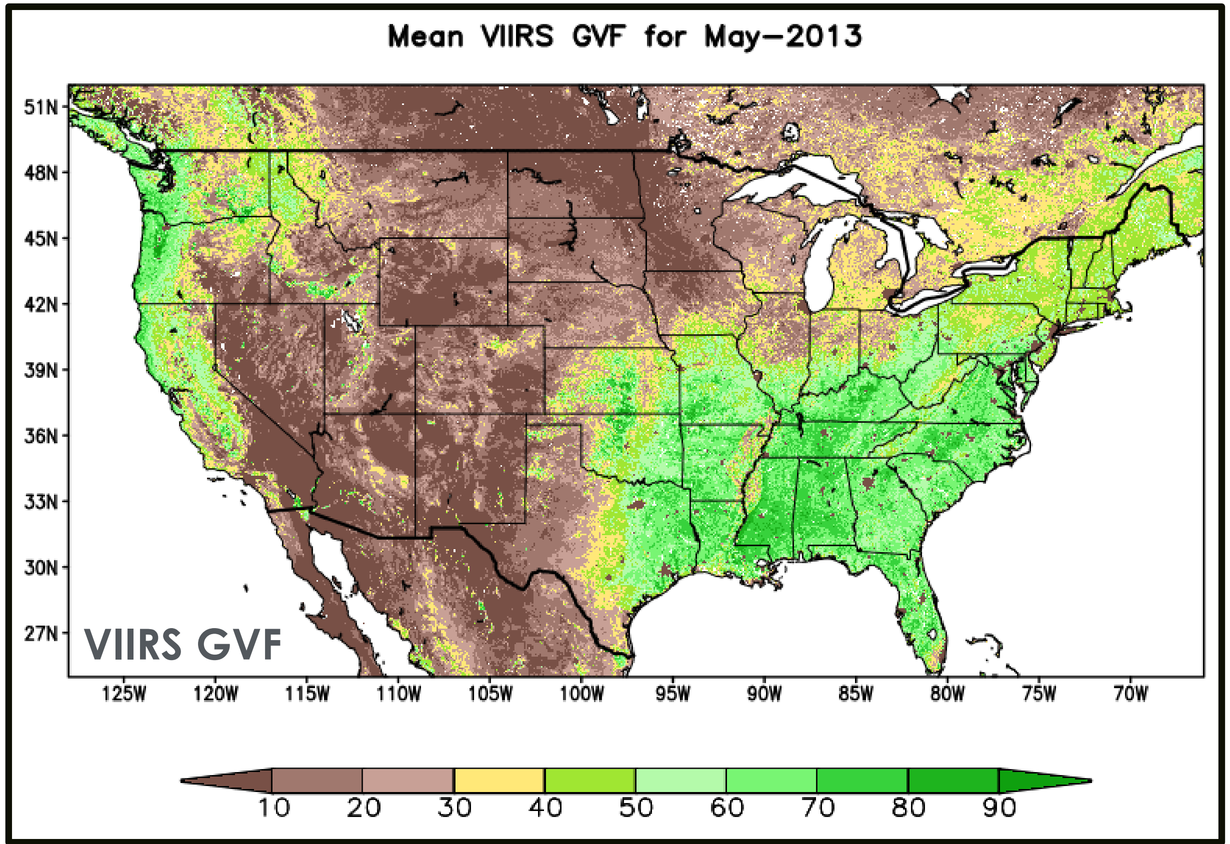

- Mean Monthly VIIRS GVF for May 2013

Vargas, M., et al., 2015: *20th Conf. Sat. Met.*, P210, https://ams.confex.com/ams/95Annual/webprogram/Paper259494.html

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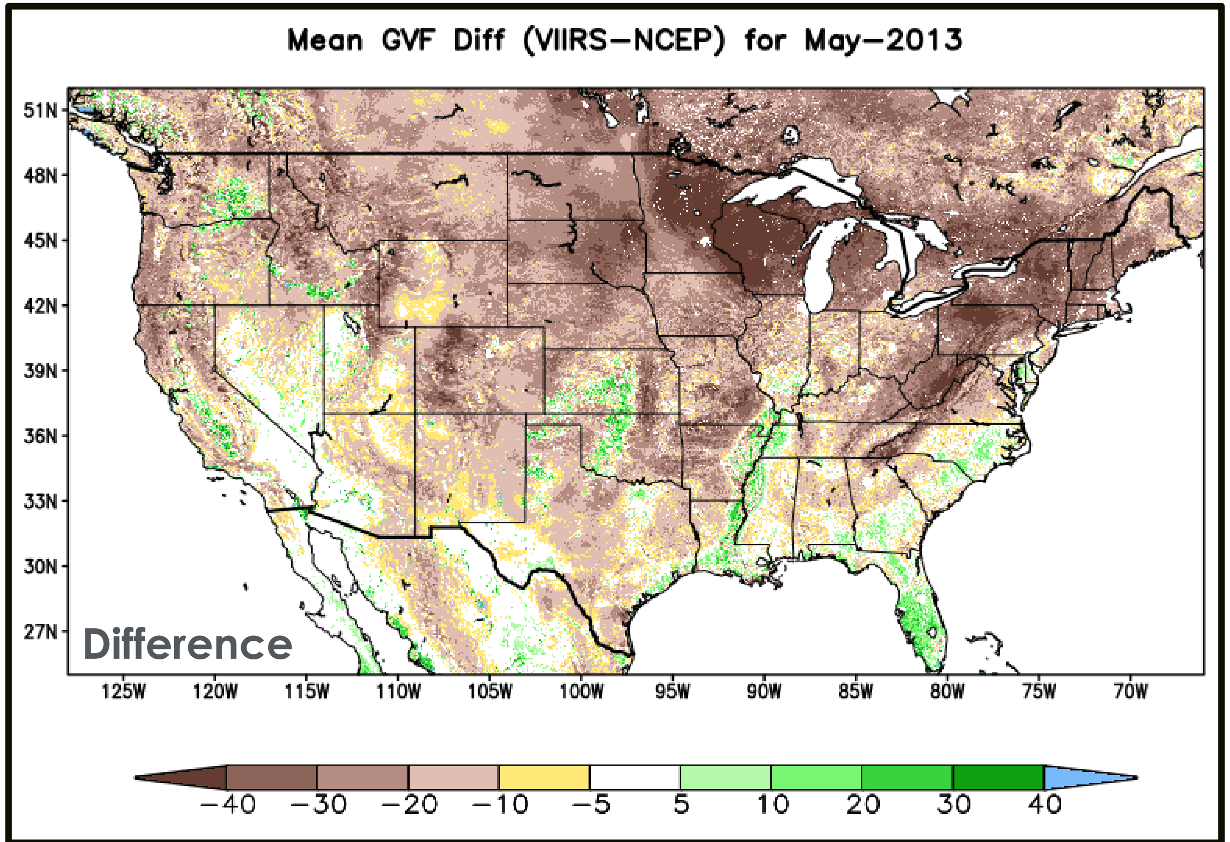

- **Difference (VIIRS GVF – Climo GVF)**
- **Large region of lower GVF, esp. in Midwest and Appalachians, due to anomalously cool temperatures during Spring 2013**

Vargas, M., et al., 2015: *20th Conf. Sat. Met.*, P210, https://ams.confex.com/ams/95Annual/webprogram/Paper259494.html

Time-Varying Inputs – Green Vegetation Fraction (GVF)

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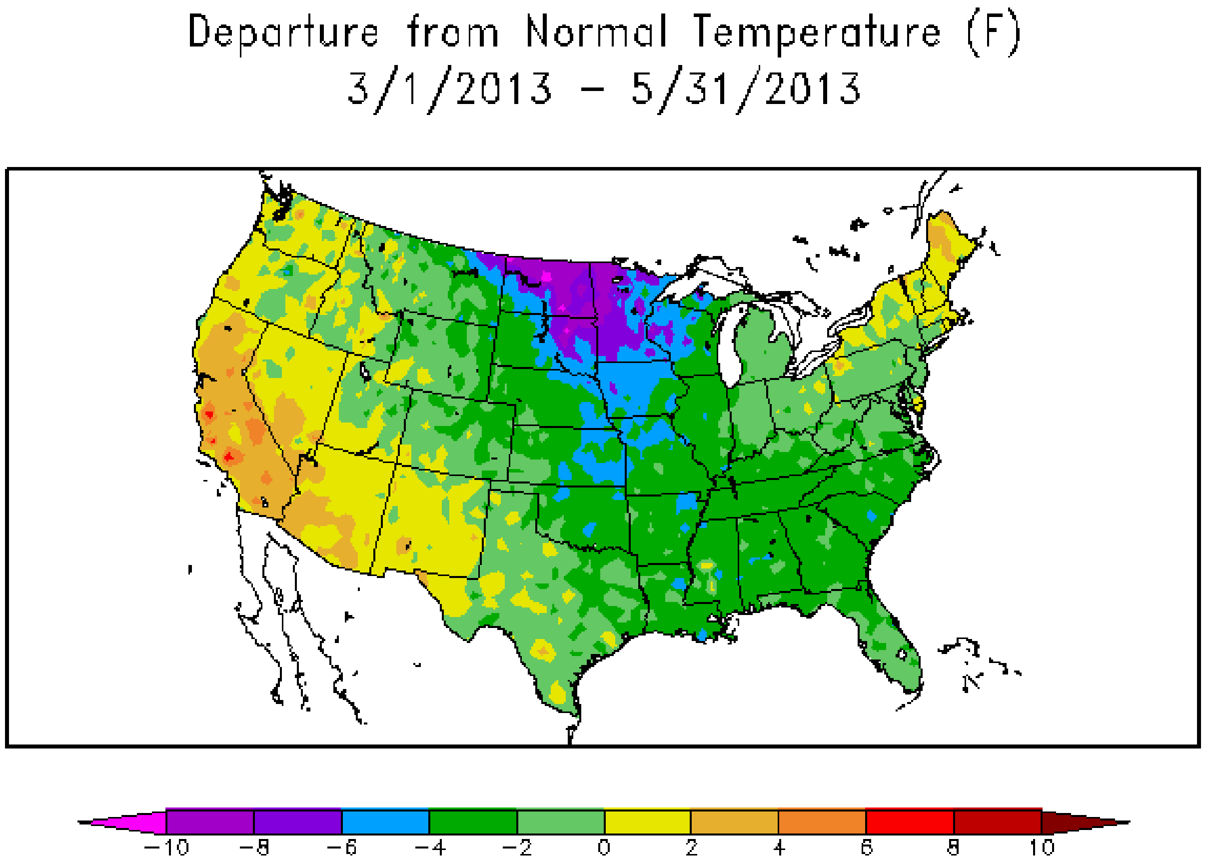


- **Departure from normal temperatures for March to May 2013**
- **Large region of lower GVF, esp. in Midwest and Appalachians, due to anomalously cool temperatures during Spring 2013**

Vargas, M., et al., 2015: *20th Conf. Sat. Met.*, P210, https://ams.confex.com/ams/95Annual/webprogram/Paper259494.html

Timeline Overview

SPoRT-LIS Spin-up, Climatology, and Real-Time Run Descriptions

- **Spin-Up:** Ran Noah LSM for long time (1979-2010), so soils converge to equilibrium state
- **Climatology:** Re-run spin-up period, outputting Noah LSM solution daily from 1981 to 2013
- **Real-Time/Forecasts:** Extend climatology run to real-time and cycle every 6 hours

Climatology Run – Atmospheric Inputs (Forcings)

North American Land Data Assimilation System – Phase 2 (NLDAS-2; Xia et al. 2012a, b)

- Hourly Analyses ~14 km res
- Run at Environmental Modeling Center (EMC)
- Incorporates GOES Shortwave Radiation
- Daily rain gauge data, temporally disaggregated by radar data into hourly precipitation analyses

Xia, Y., et al., 2012a: *J. Geophys. Res.*, **117**, doi:10.1029/2011JD016048.
Xia, Y., et al. 2012b: *J. Geophys. Res.*, **117**, doi:10.1029/2011JD016051.

Real-Time Run – Atmospheric Inputs (Forcings)

Global Data Assimilation System (GDAS; Wang et al. 2013)

- Data assimilation front-end for the Global [Ensemble] Forecast System
- Analyses/short-term forecasts 0-9 hours
- Bridges **4-day latency gap in NLDAS-2**

Wang, X., et al., 2013: *Mon. Wea. Rev.*, **141**, 4098- 4117, doi:10.1175/MWR-D-12-00141.1.

Real-time Run – Atmospheric Inputs (Forcings), cont.

Multi-Radar Multi-Sensor (MRMS) precipitation estimation (Zhang et al. 2016)

- **Radar + rain gauge hourly estimates** over Contiguous United States and other domains
- Resolution ~1 km grid spacing

Zhang, J., et al., 2016: *Bull. Amer. Meteor. Soc.*, **97**, 621-637, doi:10.1175/BAMS-D-14-00174.1.

Forecast SPoRT-LIS – Atmospheric Inputs (Forcings)

Global Forecast System numerical weather prediction model (GFS; Zhou et al. 2019)

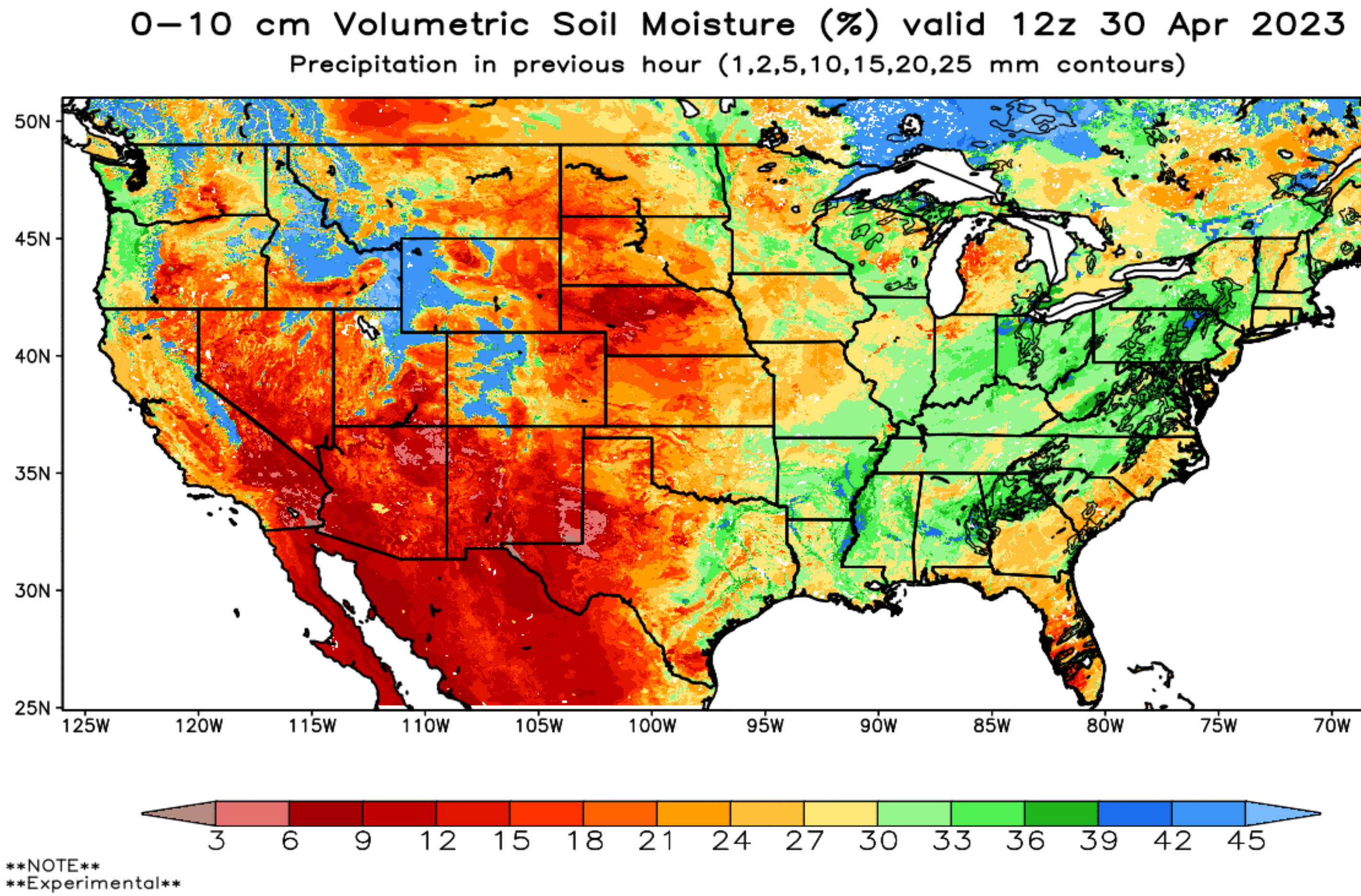
- NCEP/EMC's global prediction model
- Surface flux files provide **forecast forcings out 2 weeks**, updated every 6-hourly cycle of the GFS

Zhou, L., et al., 2019: *Bull. Amer. Meteor. Soc.*, **100**, 1225-1243, doi:10.1175/BAMS-D-17-0246.1.

Sample Output Fields: Volumetric Soil Moisture

Volumetric Soil Moisture (VSM, $m^3\ m^{-3}$)

- **Definition:** Fraction of water volume per total soil volume
- Theoretical max ~0.45 (45%); lower for coarse soils like sand
- (Right) 0-10 cm VSM x 100%
- MRMS precipitation contours

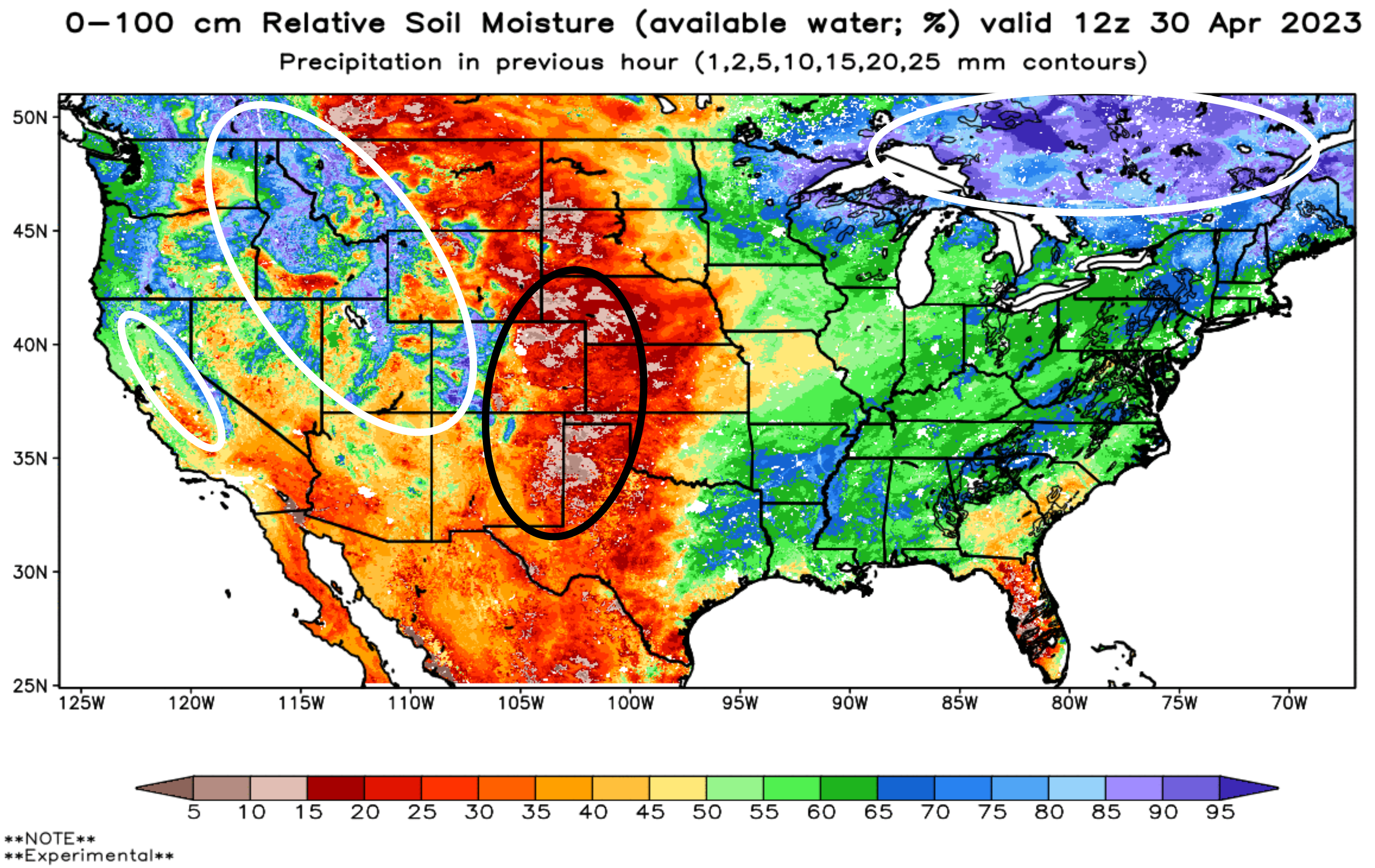


Sample Output Fields: Relative Soil Moisture (RSM)

Relative Soil Moisture (RSM)

- **Definition:** Ratio of VSM between wilting (plants cannot extract water) and saturation (soil cannot hold more water)
- Urban corridors masked due to Noah LSM setting narrow dynamic range
- (Right) 0-100 cm RSM shows dry soils < 20% saturation over High Plains (black oval)
- Near-saturated soils in California Sierras, Rockies, and SE Canada (white ovals)

$$RSM = \left(\frac{\theta - \theta_{wilt}}{\theta_{sat} - \theta_{wilt}}\right) x\ 100\%$$



Relative Soil Moisture Response by Layer (31 March to 2 April 2023)

0-10 cm quickly moistens

- Hours

10-40 cm lags slightly

- Hours to days

40-100 cm slower response

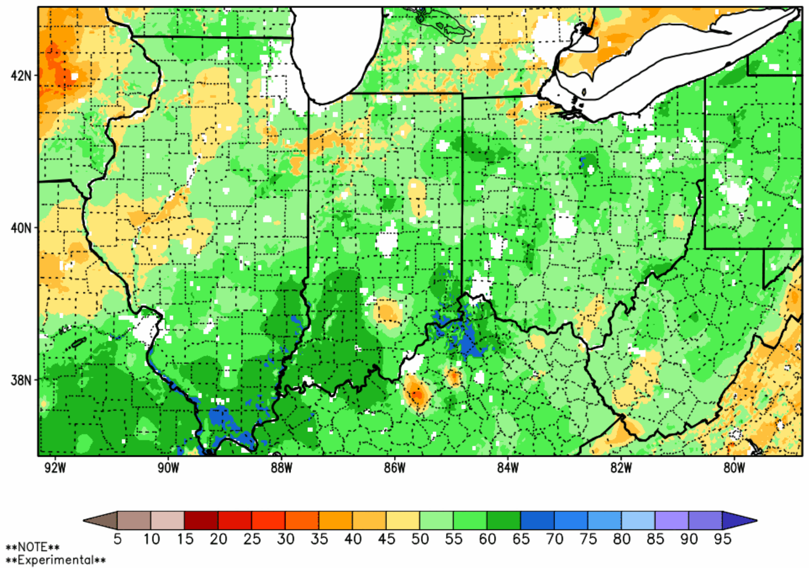
- Days to weeks/months

100-200 cm slow to adjust

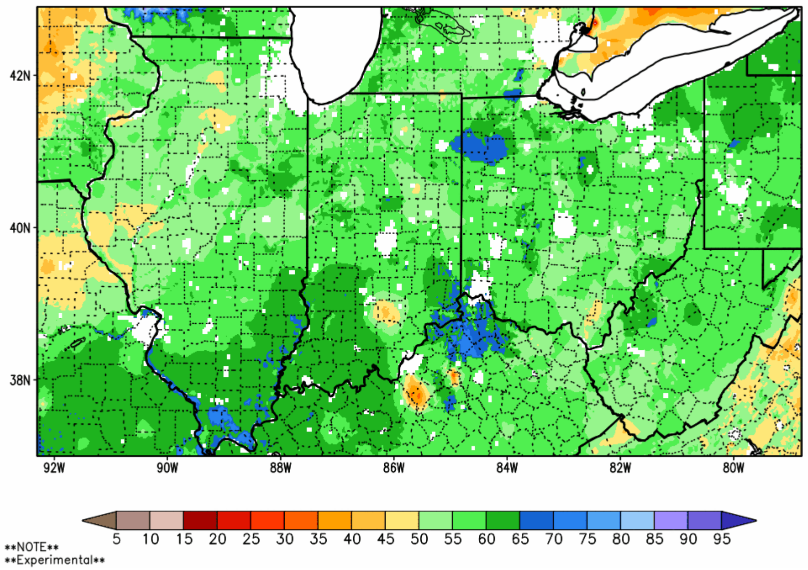
- Months to years

– Drying periods take longest to adjust

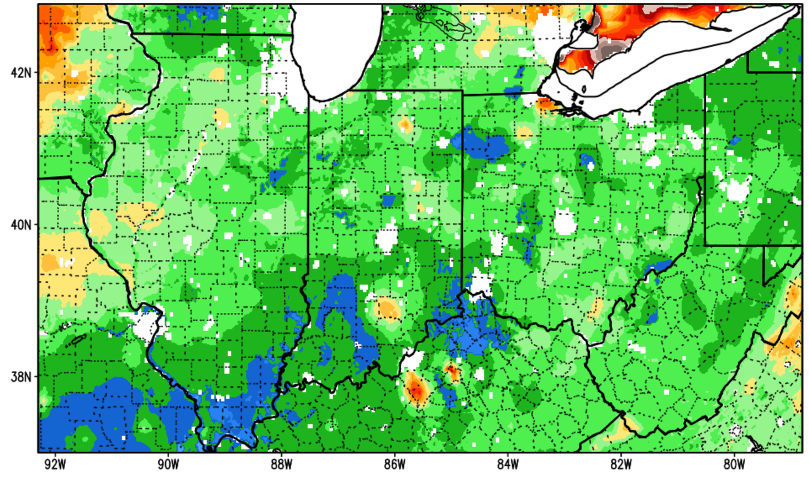
Hourly 0-10 cm RSM



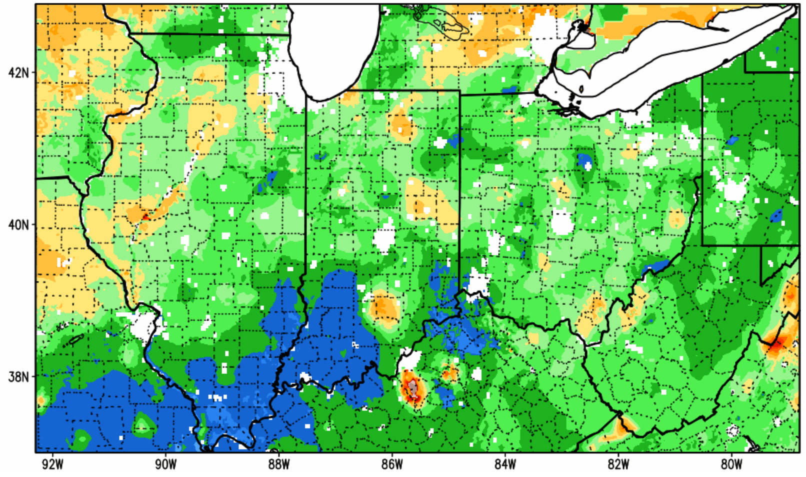
Hourly 10-40 cm RSM



Hourly 40-100 cm RSM

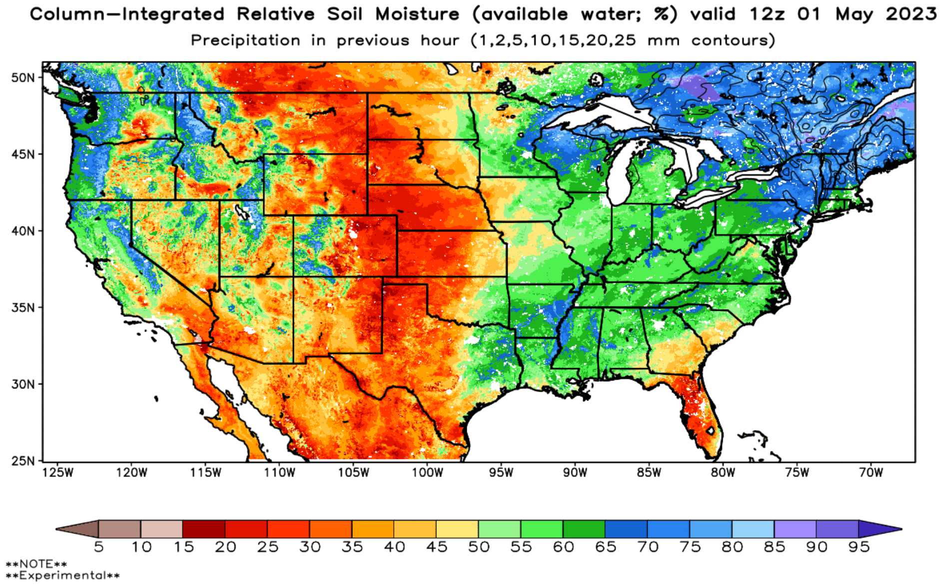


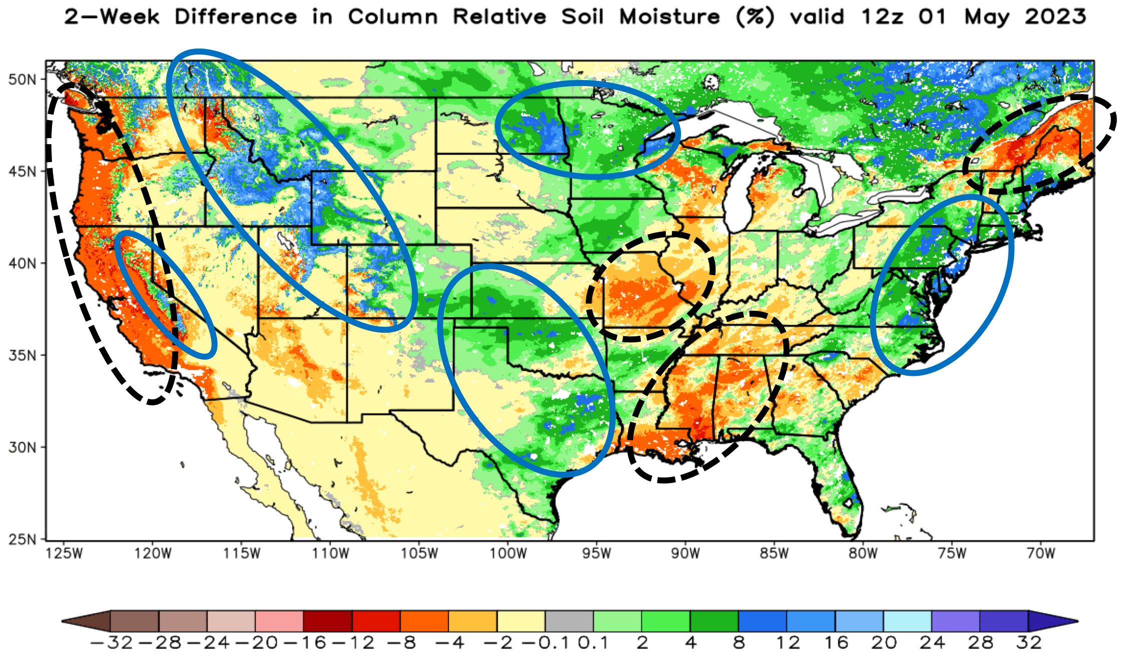
Hourly 100-200 cm RSM



Time Changes in Total Column Relative Soil Moisture: 1-week, 2-week, 1-month, 3-months, 6-months, and 1-year

- **1-week/2-week: U.S. Drought Monitor update frequency/short-term soil moisture changes**
- 2-week to 1-month: Targets flash drought onset/relief
- 3-month to 6-month: Seasonal changes and impact
- 1-year: Compare current soil states to a year ago





2-Week Change Ending 12z 1 May 2023:

- Drying along West Coast; parts of Midwest, South, and Northeast
- Moistening due to snow melt in California Sierras, Rockies, and Northern Plains
- Recent rains in Mid-Atlantic Region and Southern Plains

Time Changes in Total Column Relative Soil Moisture: 1-week, 2-week, 1-month, 3-months, 6-months, and 1-year

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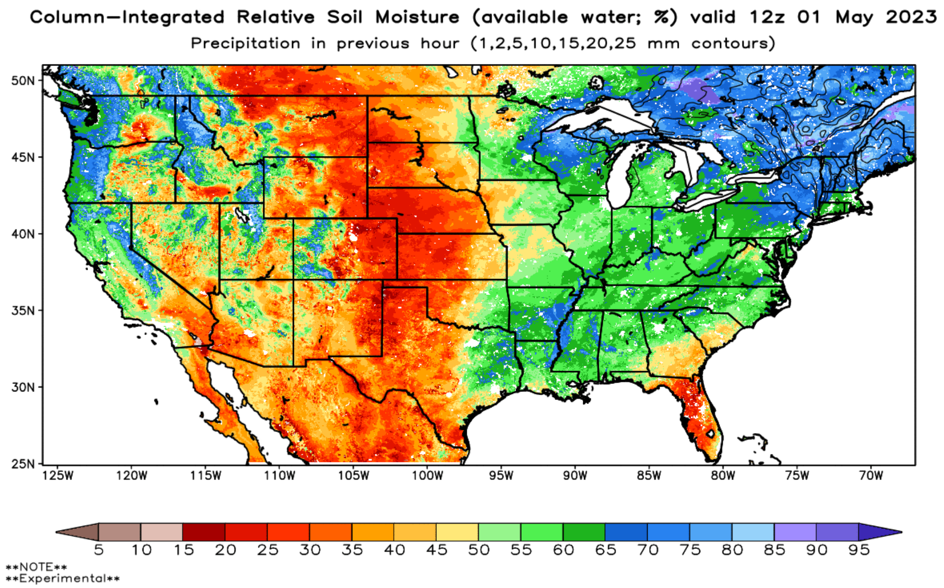

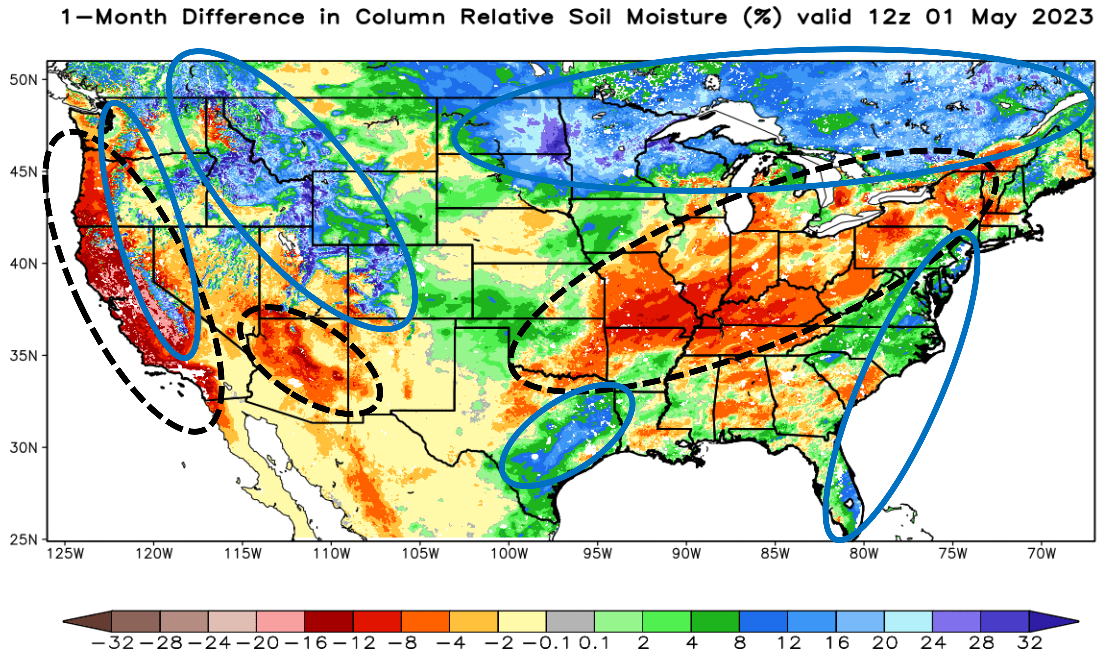

1-Month Change Ending 12z 1 May 2023:

- Drying along West Coast, Arizona, and from Oklahoma to New York
- Moistening in SE Texas, East Florida, and Mid-Atlantic Region
- Snowmelt signal even stronger in CA Sierras, Cascades, Rockies, and from Northern Plains to Southeast Canada

Time Changes in Total Column Relative Soil Moisture: 1-week, 2-week, 1-month, 3-months, 6-months, and 1-year

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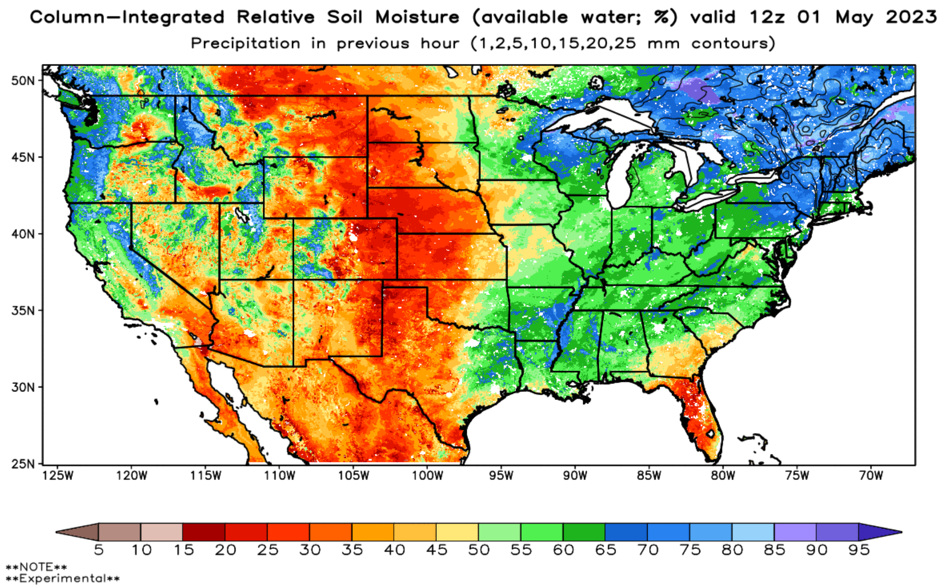
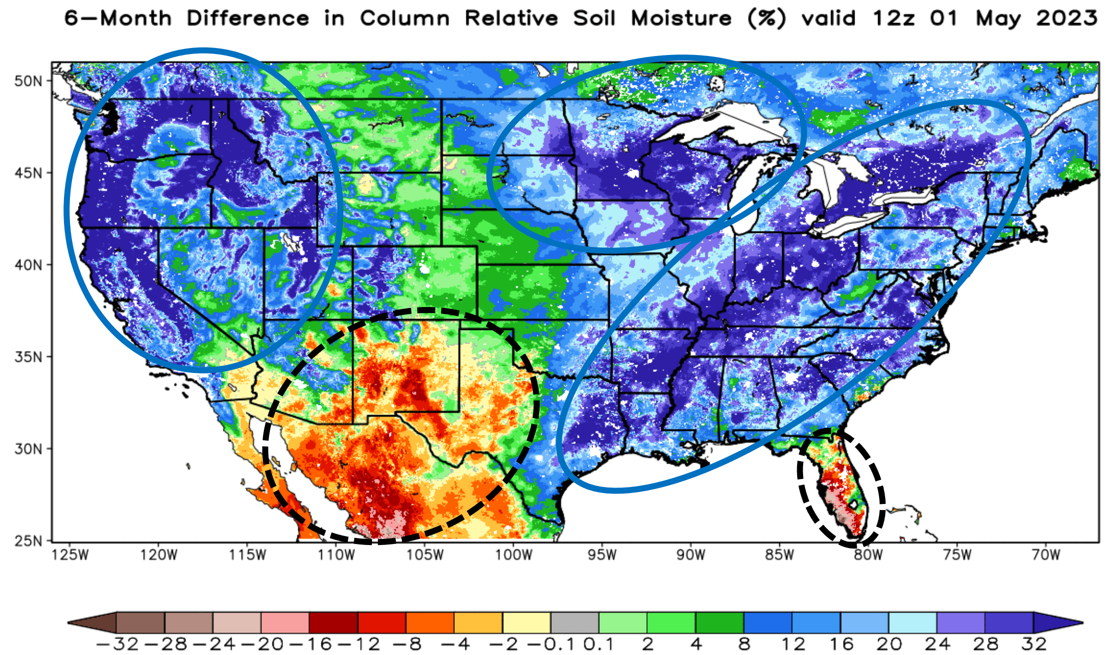


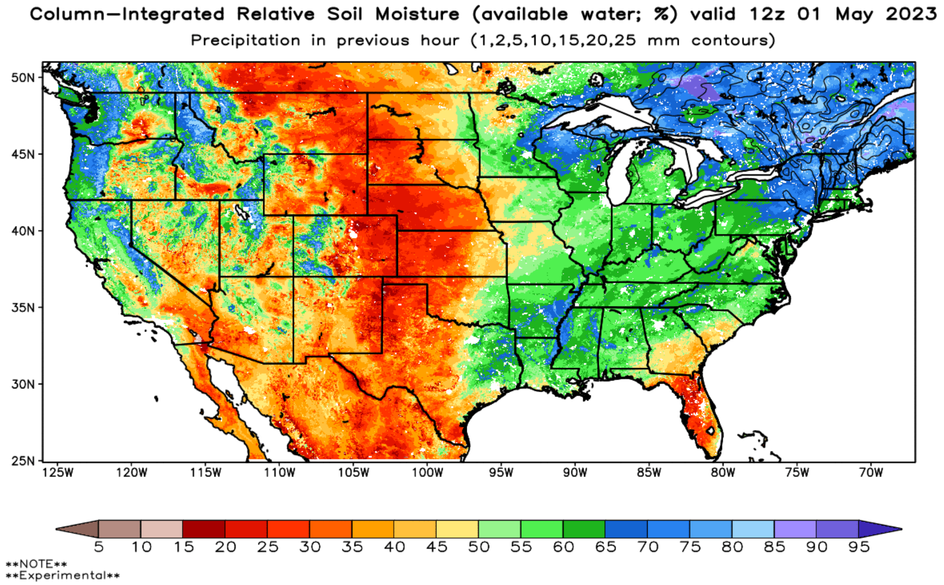


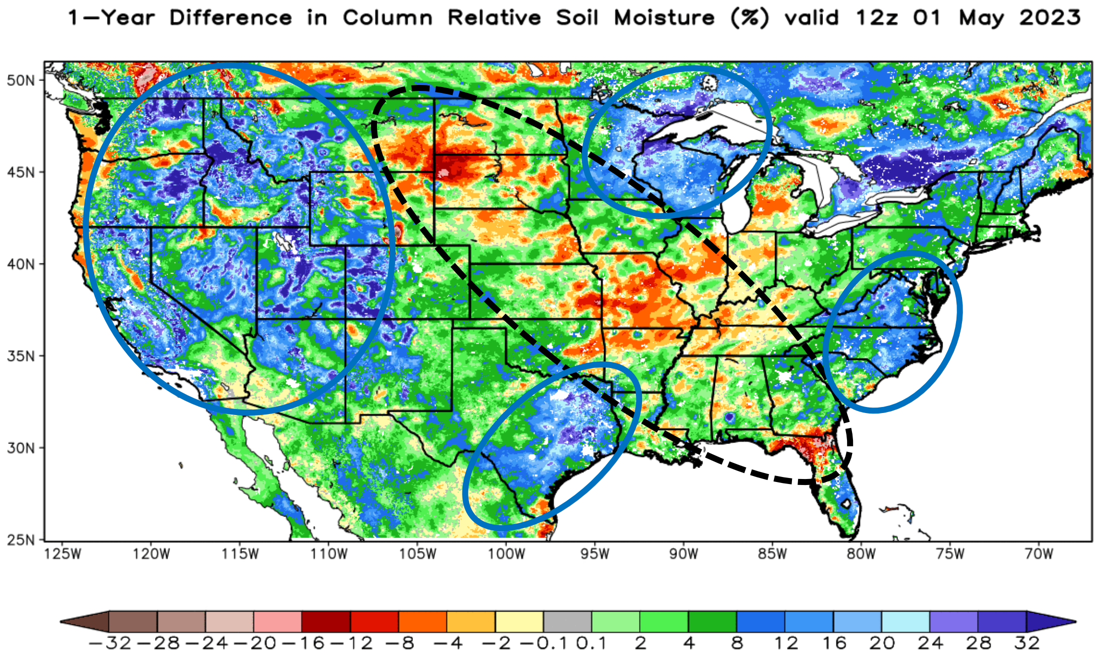
6-Month Change Ending 12z 1 May 2023:

- Drying confined to Southwest and Florida
- Winter season produced substantial moistening in the West, Upper Midwest, and from east Texas to Southeast Canada

Time Changes in Total Column Relative Soil Moisture: 1-week, 2-week, 1-month, 3-months, 6-months, and 1-year

- 1-week/2-week: U.S. Drought Monitor update frequency/short-term soil moisture changes
- 2-week to 1-month: Targets flash drought onset/relief
- 3-month to 6-month: Seasonal changes and impact
- **1-year: Compare current soil states to a year ago**

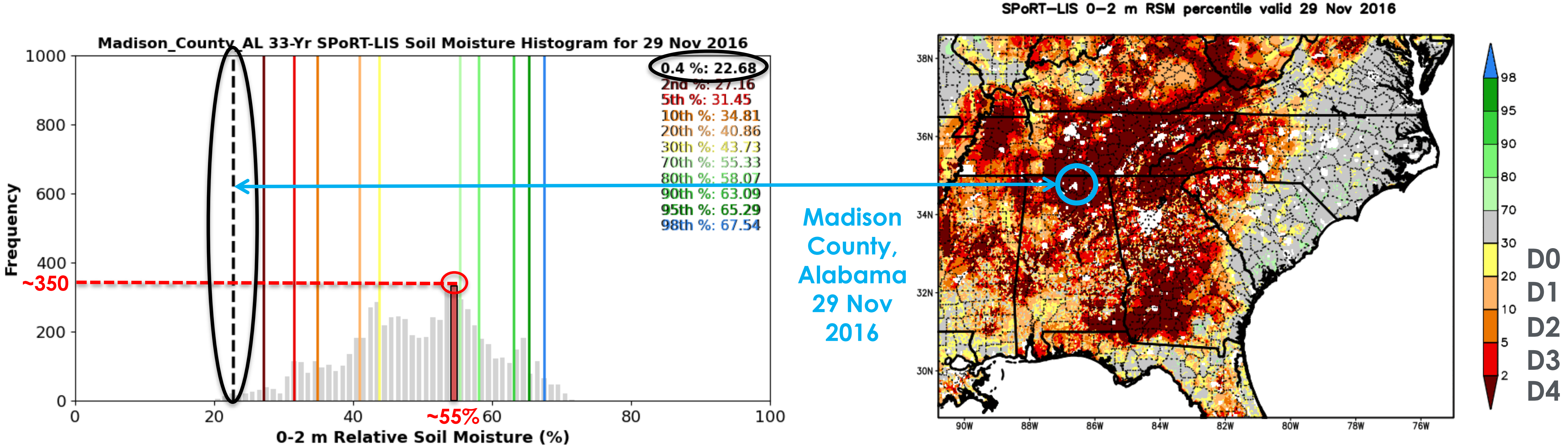




Annual Change Ending 12z 1 May 2023:

- Corridor of drying from northern High Plains to northwest Florida
- More moist areas this year on May 1st include much of the West, Eastern Texas, Upper Midwest, and Mid-Atlantic

Daily Soil Moisture Percentile by County: 1200z Daily

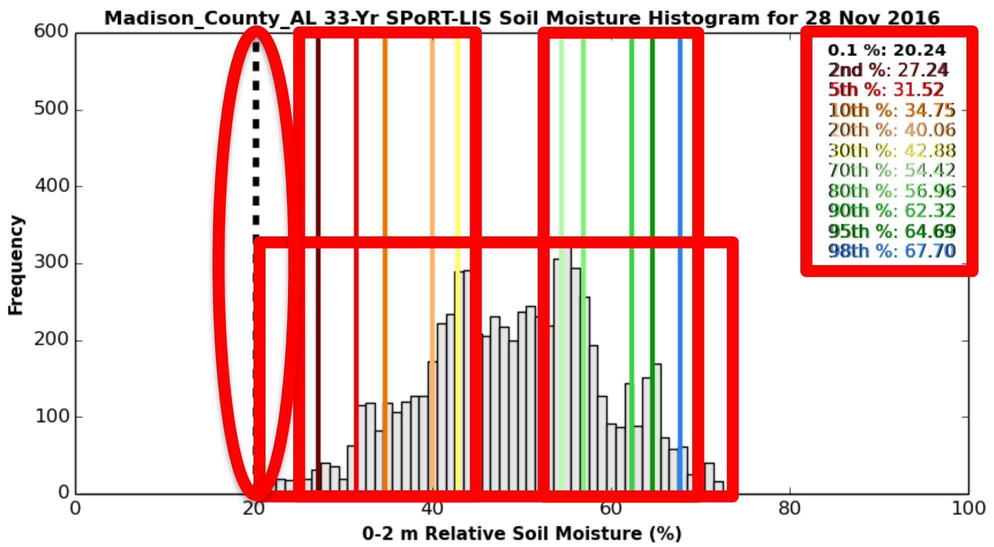


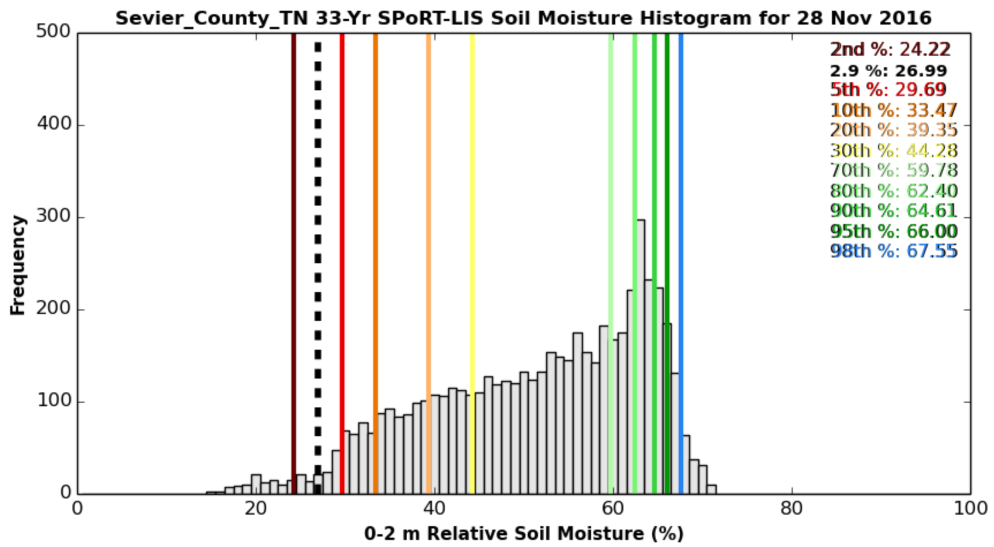
Proxy Drought Categories: D4 ≤ 2% D3 ≤ 5% D2 ≤ 10% D1 ≤ 20% D0 ≤ 30%

- **Rank all 1981-2013 0-200 cm RSM values within county for each day of year**
- **Frequency ranking used to compute percentile maps and histograms visuals**
- **Proxy percentiles of U.S. Drought Monitor categories (D0 through D4)**
  - ✓ Proxy drought categories given by percentile thresholds, as defined in Xia et al. (2014; *JGR Atmos.*)

Xia, Y., et al., 2014: *J. Geophys. Res. Atmos.*, **119**, 2947-2965, doi:10.1002/2013JD020994.

Daily Soil Moisture Percentile by County:
Histogram Analysis and Flash Drought Episode

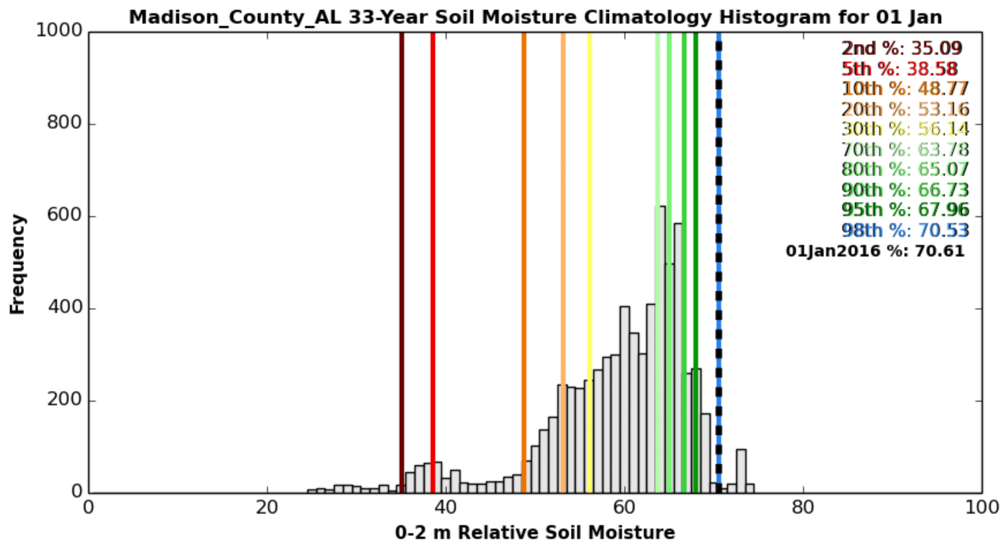


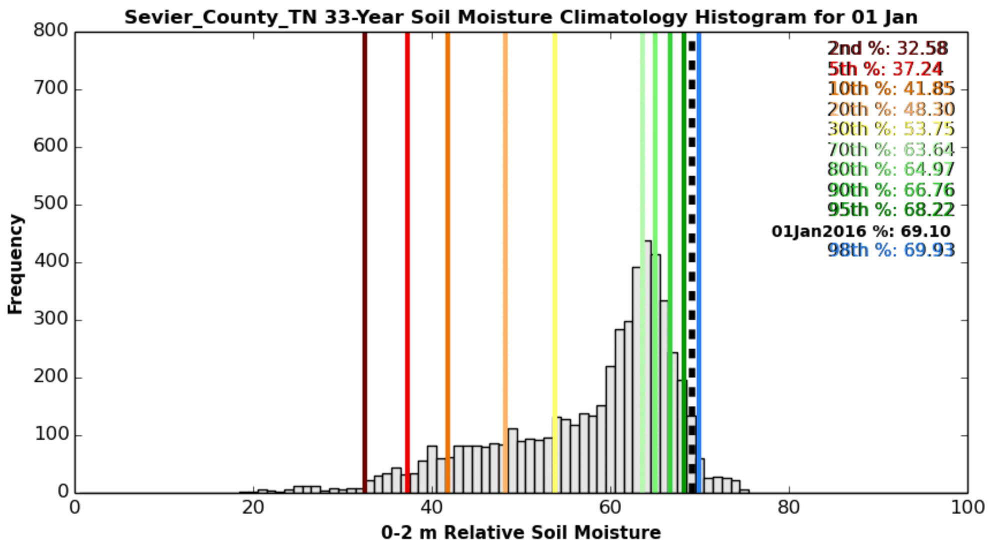


- **Gray Bars: 1981-2013 Climatology Daily "Normals"**
- **Vertical Colored Lines: Reference Percentile Thresholds**
- **Vertical Dashed Line: Current-Day Average 0-200 cm RSM over County**
- **Table: 0-200 cm RSM Values for Current-Day and Reference Percentiles**
- **Daily animations during 2016 "flash drought" in SE U.S.**
  - Unusually wet start to year in Madison County, AL and Sevier County, TN
  - Transition to exceptional drought during Autumn months, which culminated in Gatlinburg, TN deadly firestorm on 28-29 November 2016 (Case and Zavodsky 2018)

Case and Zavodsky, 2018: *Res. Physics*, **8**, 654-656, doi:10.1016/j.rinp.2017.12.029.

Daily Soil Moisture Percentile by County:
Histogram Analysis and Flash Drought Episode





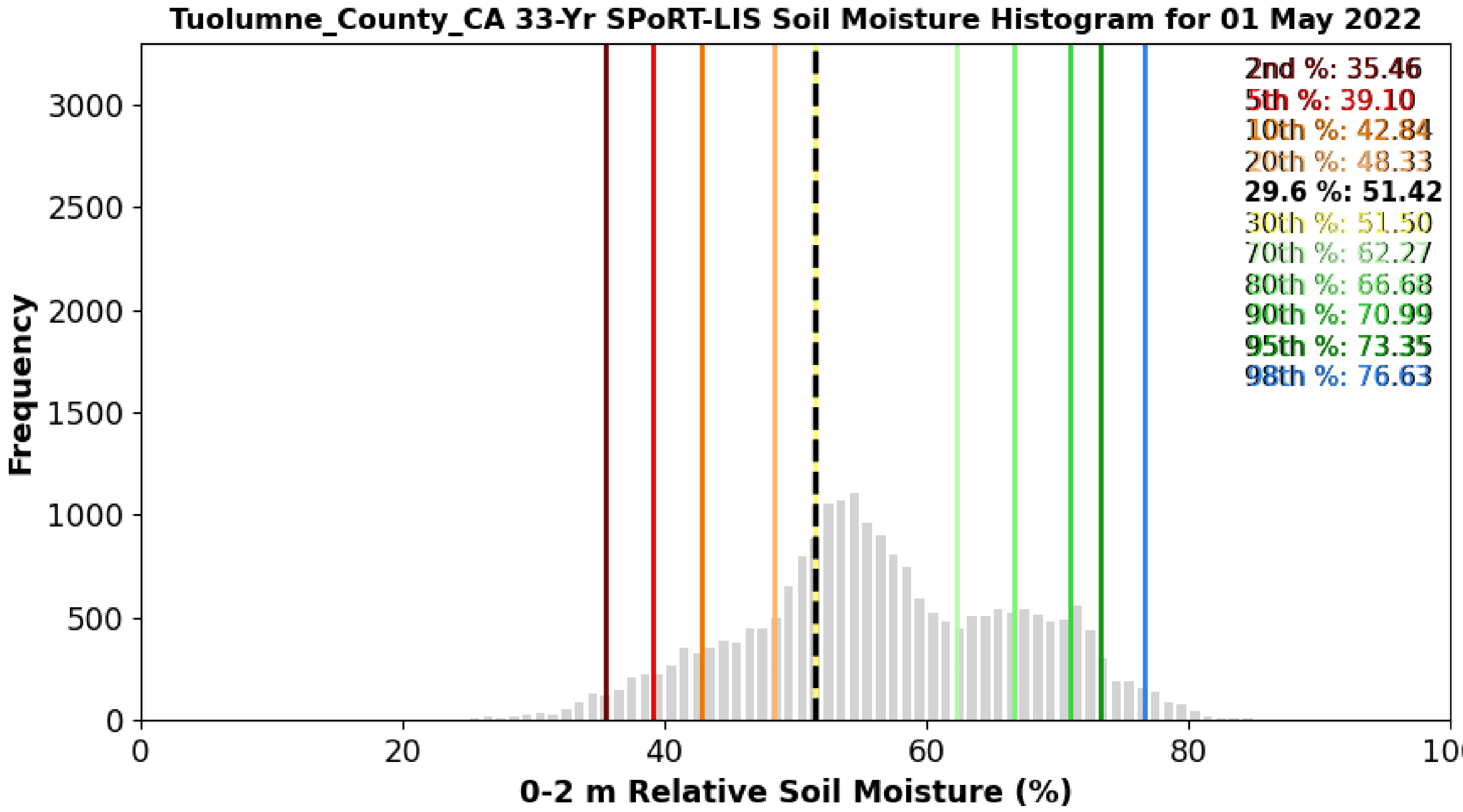
- **Gray Bars: 1981-2013 Climatology Daily “Normals”**
- **Vertical Colored Lines: Reference Percentile Thresholds**
- **Vertical Dashed Line: Current-Day Average 0-200 cm RSM over County**
- **Table: 0-200 cm RSM Values for Current-Day and Reference Percentiles**
- **Daily animations during 2016 “flash drought” in SE U.S.**
  - Unusually wet start to year in Madison County, AL and Sevier County, TN
  - Transition to exceptional drought during Autumn months, which culminated in Gatlinburg, TN deadly firestorm on 28-29 November 2016 (Case and Zavodsky 2018)

Case and Zavodsky, 2018: *Res. Physics*, **8,** 654-656, doi:10.1016/j.rinp.2017.12.029.

Soil Moisture Percentile by County:
Inferring Weather and Climate Regimes and Seasonality

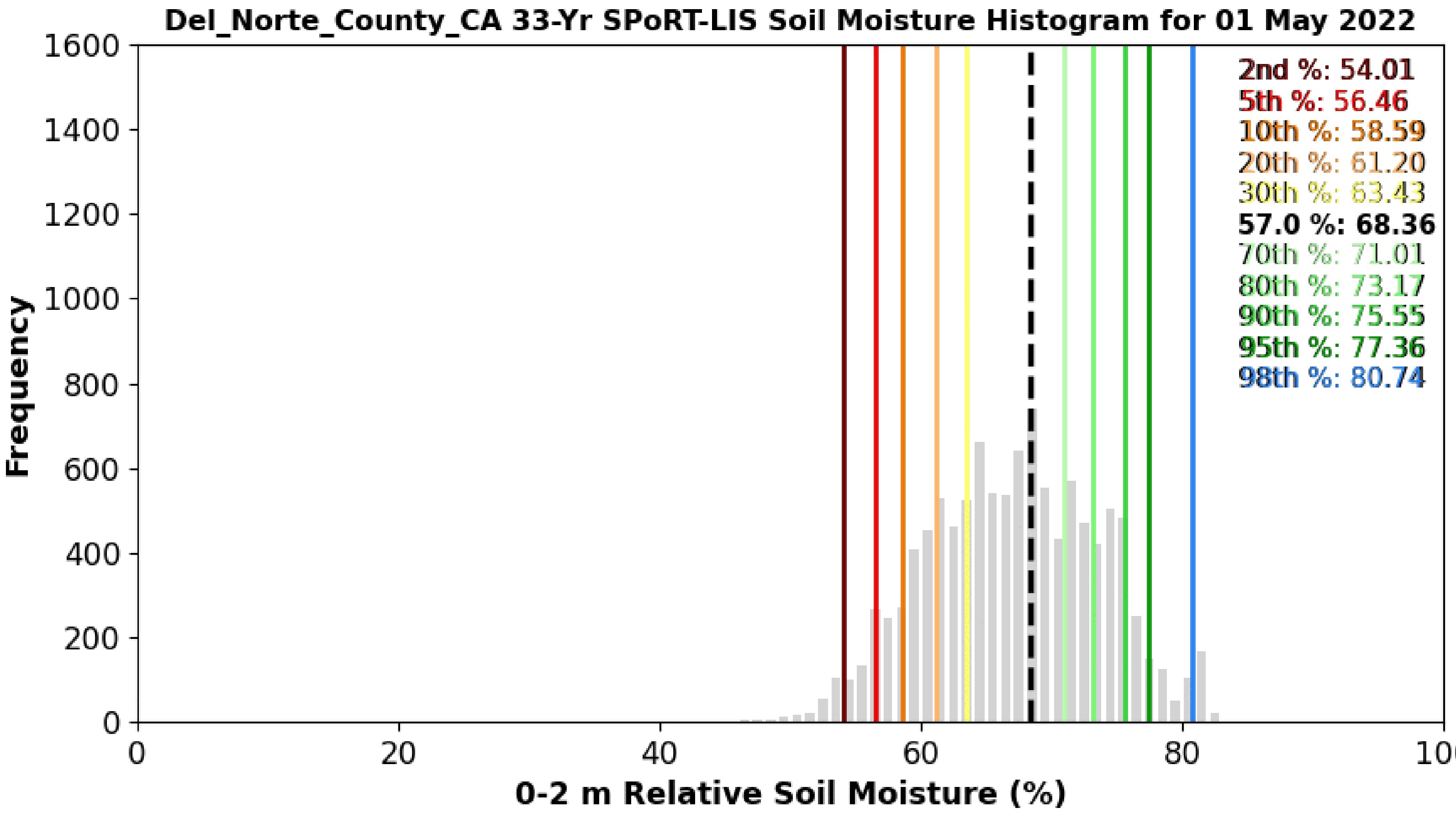
- Tuolumne County, CA (Yosemite National Park)
- Monthly Histograms on 1st of Each Month: May 2022 to Apr 2023
- Strong drying trend from May to Oct; moistening from Nov to Apr
- Wide distribution suggests both drought and wet years are common

Big jump in county mean percentile by 1 Jan 2023!



Soil Moisture Percentile by County:
Inferring Weather and Climate Regimes and Seasonality

- Del Norte County, CA (cooler, moist coastal regime)
- Monthly Histograms on 1st of Each Month; May 2022 to Apr 2023
- Very strong drying trend from May to Oct; rapid moistening from Nov to Jan
- Tight distributions from Jan–Sep suggest consistent climate compared to Tuolumne County

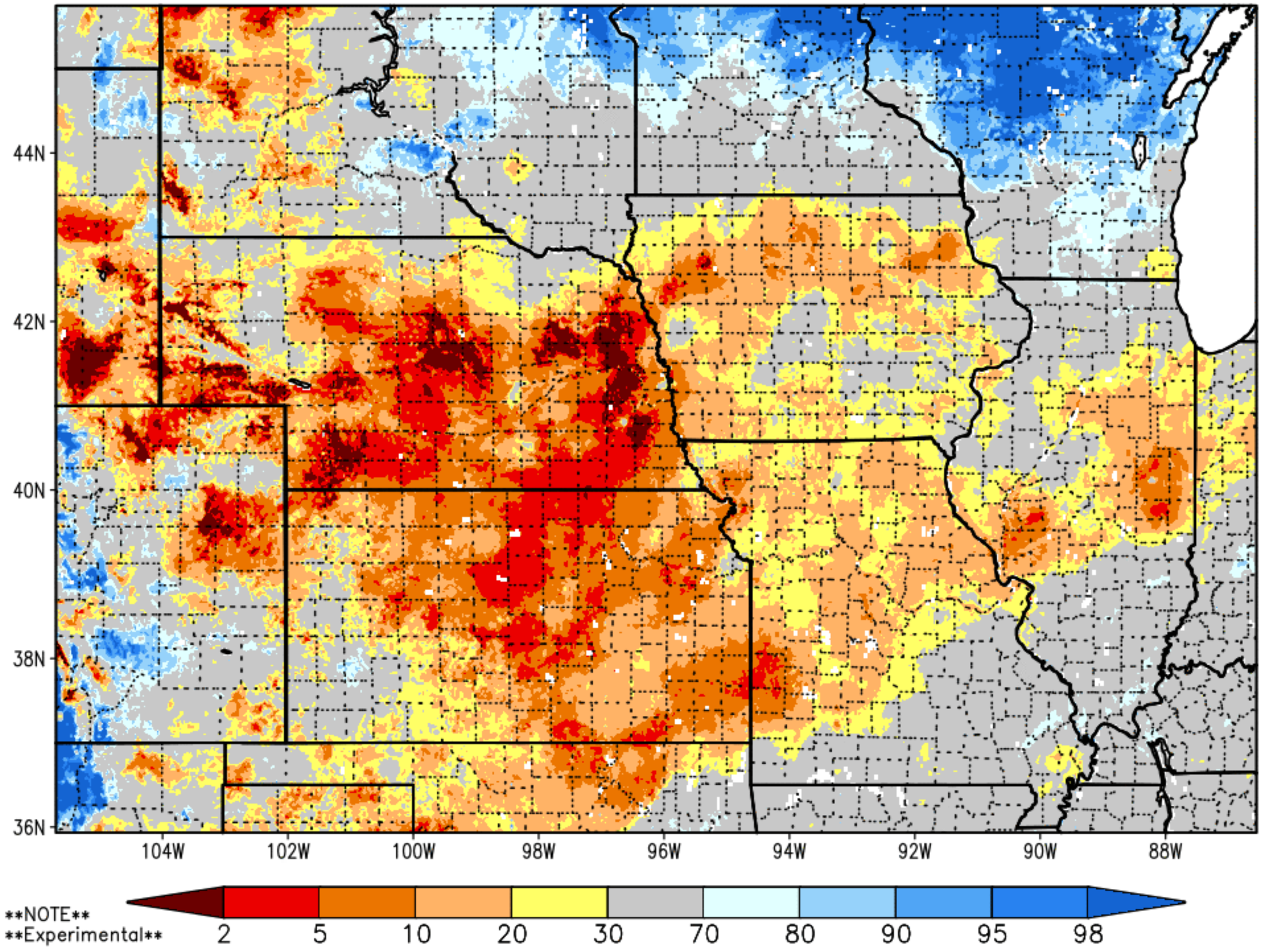


Daily Soil Moisture Percentile by Grid Point: 0000z Daily

Daily 1981-2013 Soil Moisture Climatologies

- VSM cumulative layers at all grid points
  - 0-10 cm, 0-40 cm, 0-100 cm, 0-200 cm
  - One-week centered window: 231 samples per grid point (33 years x 7 days)

Grid Point-Based 0-200 cm Percentile: Valid 1 May 2023

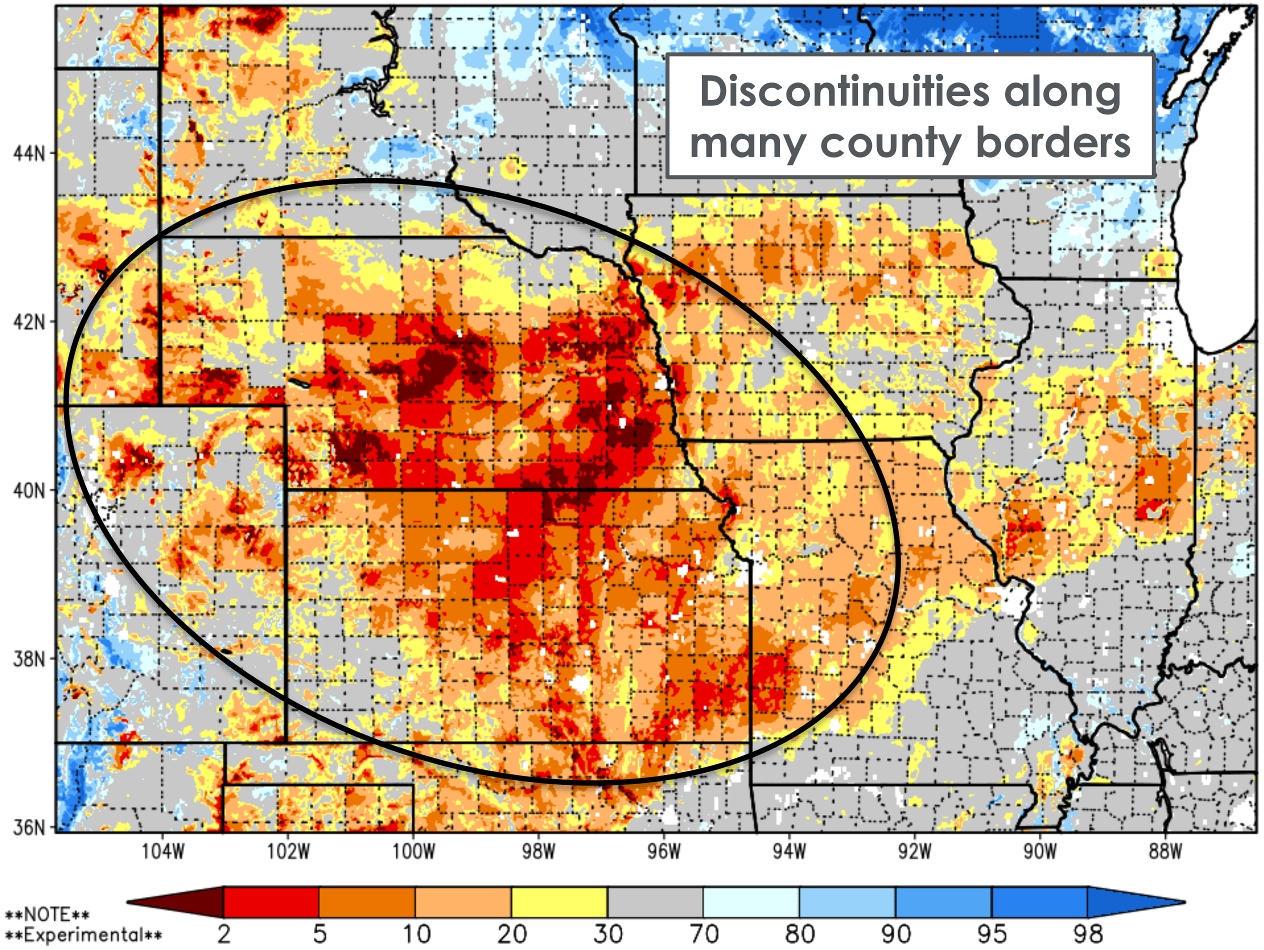


Daily Soil Moisture Percentile by Grid Point: 0000z Daily

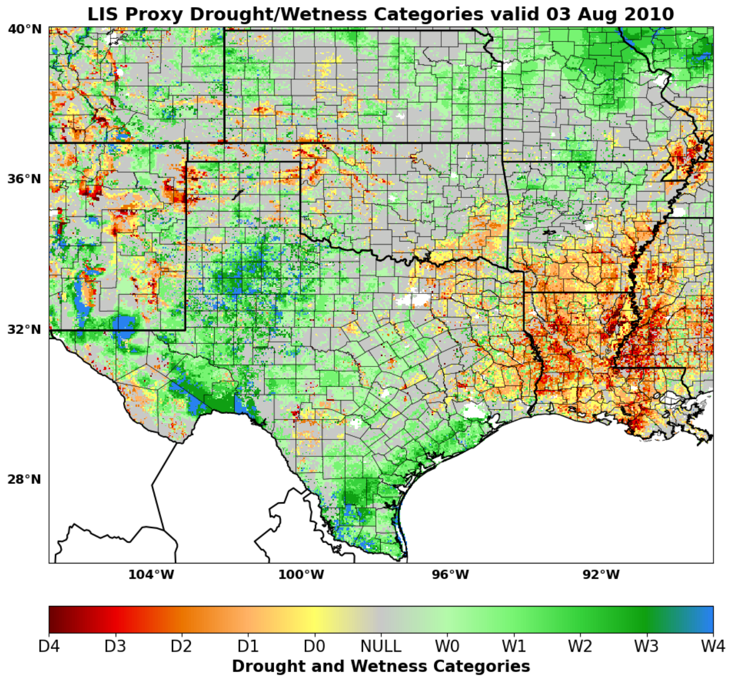
Daily 1981-2013 Soil Moisture Climatologies

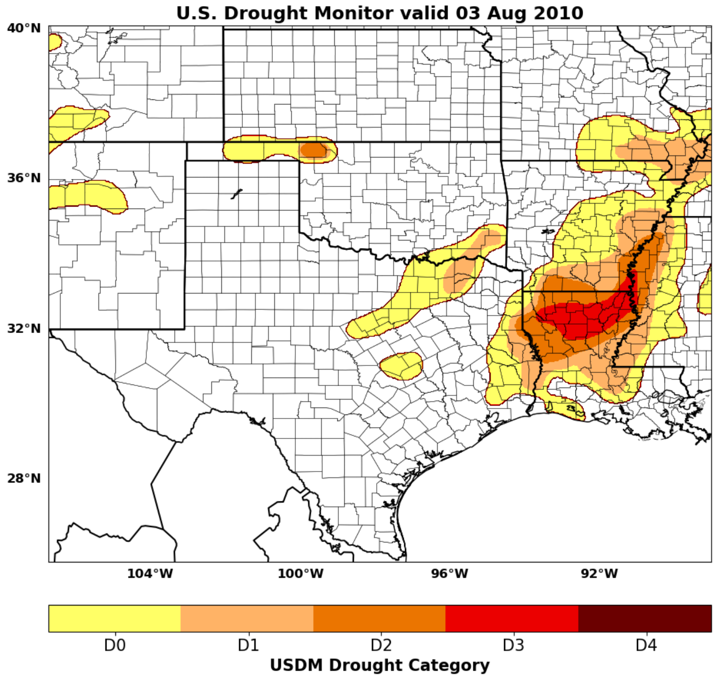
- VSM Cumulative Layers at All Grid Points:
  - 0-10 cm, 0-40 cm, 0-100 cm, 0-200 cm
  - One-week centered window: 231 samples per grid point (33 years x 7 days)
- Benefits over County-Based Method:
  - Fixed sample size compared to county
  - Improved spatial continuity: "County edges" disappear
  - No masking of urban corridors
  - Full domain coverage; county-based percentiles only over CONUS

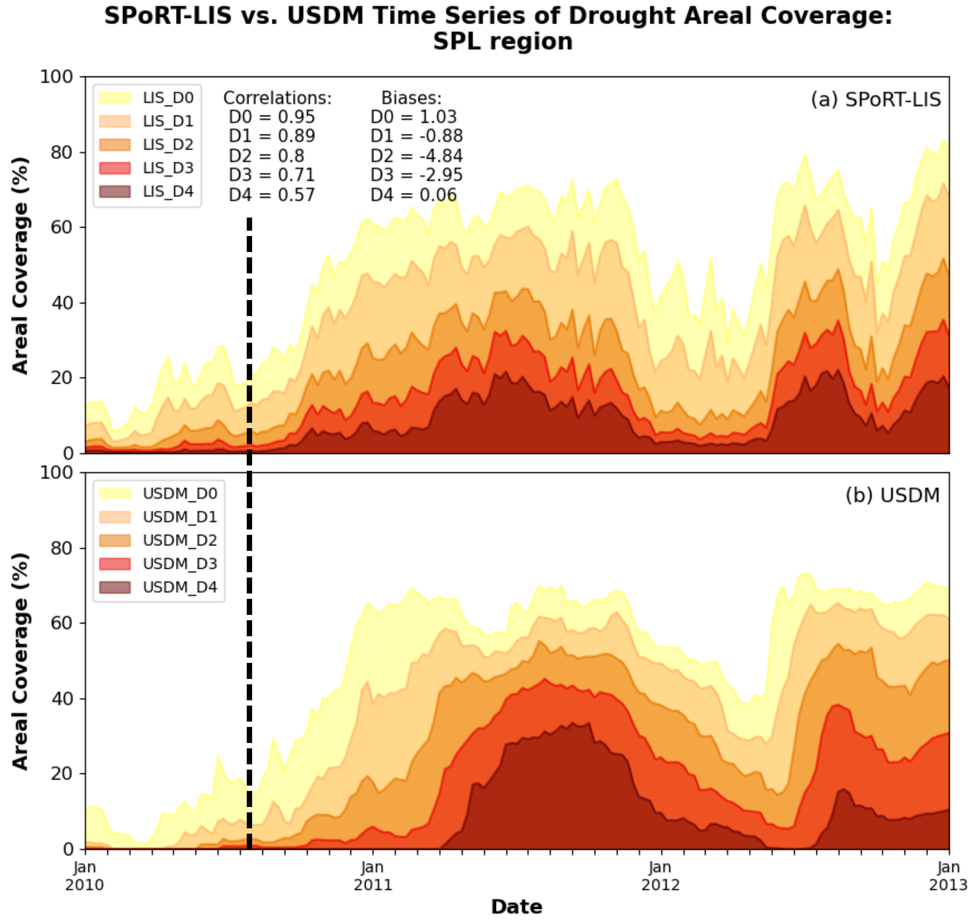
County-Based 0-200 cm Percentile: Valid 1 May 2023



Comparing 0-200 cm RSM Percentile to U.S. Drought Monitor:
2011-2012 Southern Plains Exceptional Droughts



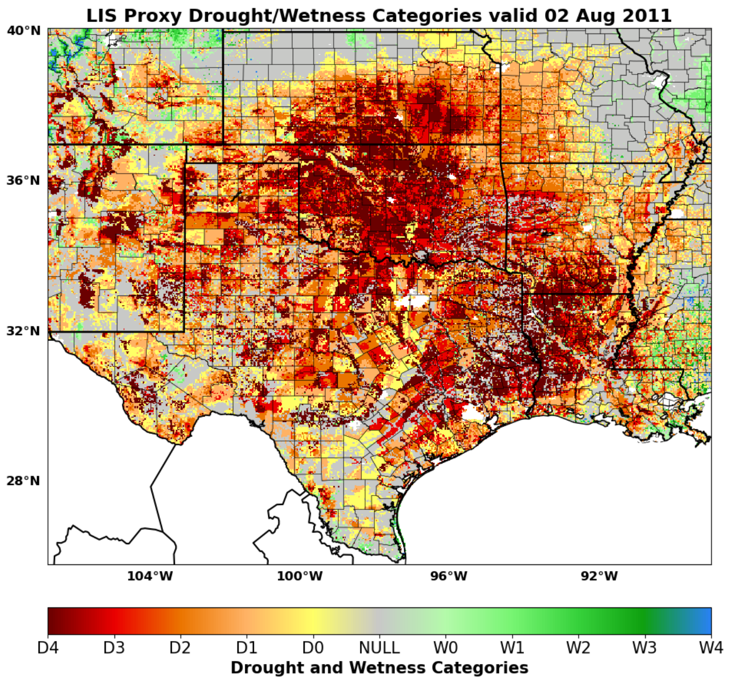


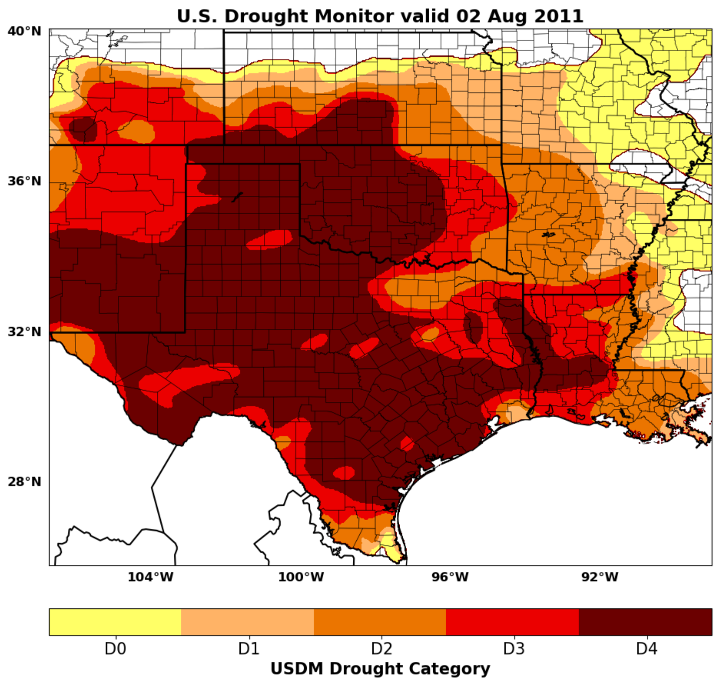


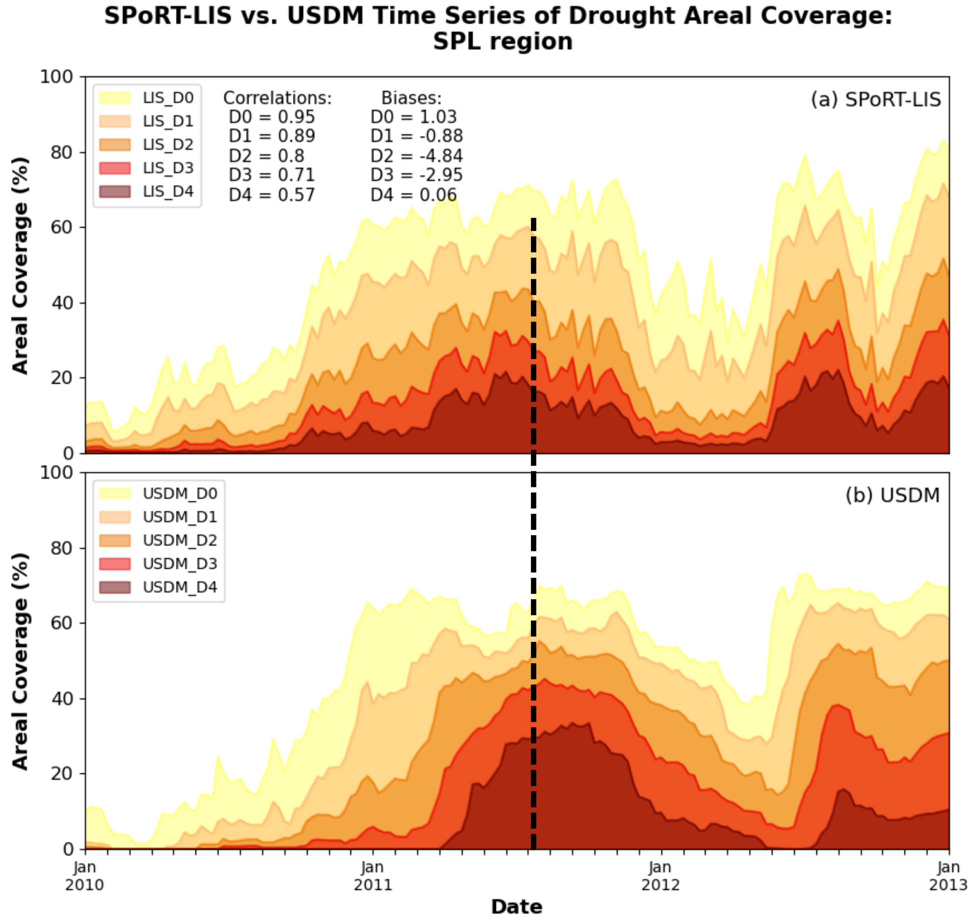
Time series of SPoRT-LIS 0-200 cm RSM drought categories areal coverage [top row] versus USDM areal coverage of drought categories from 2010-2012.

Comparing 0-200 cm RSM Percentile to U.S. Drought Monitor:

2011-2012 Southern Plains Exceptional Droughts







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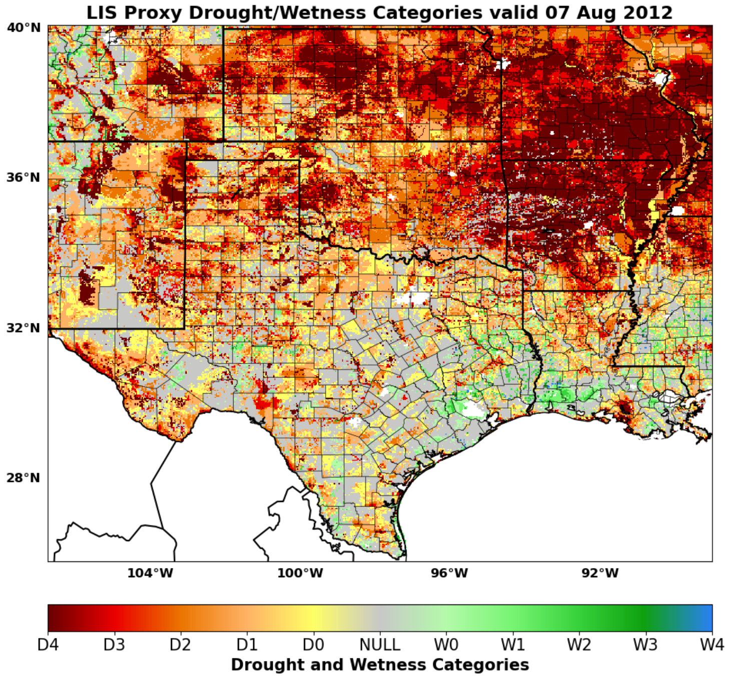
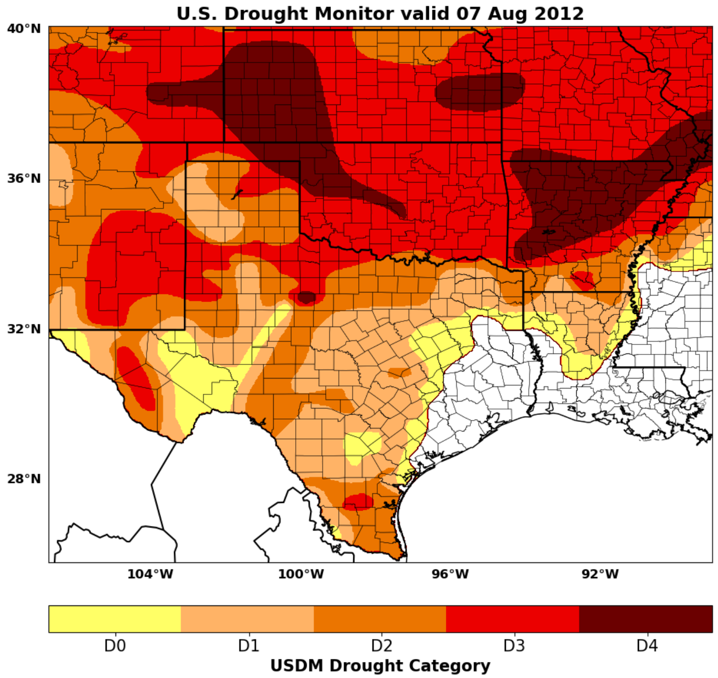
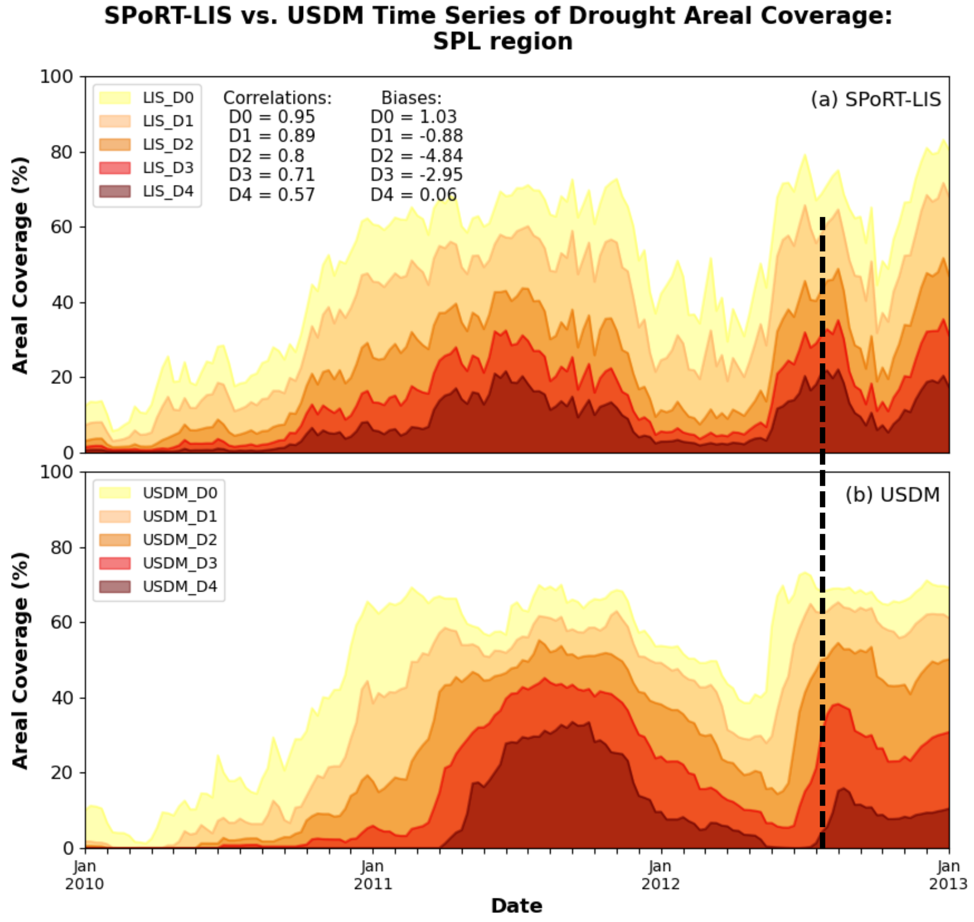
2011-2012 Southern Plains Exceptional Droughts



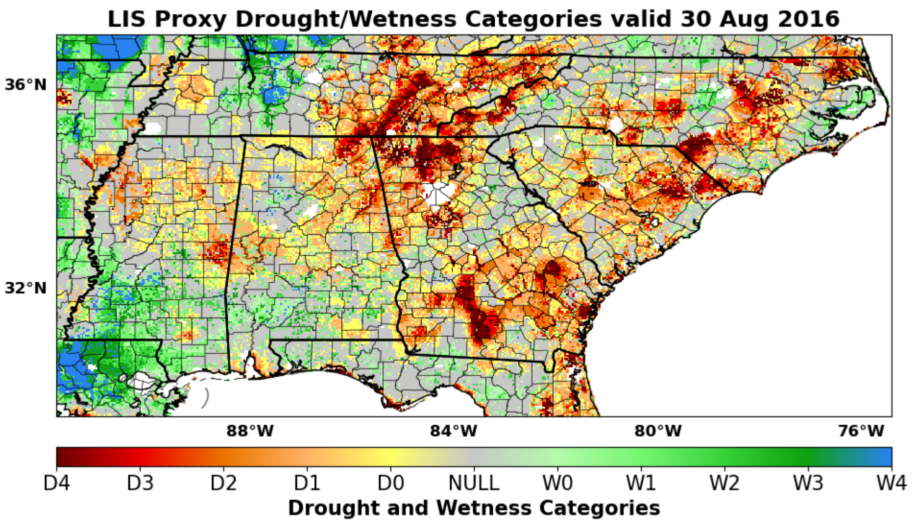


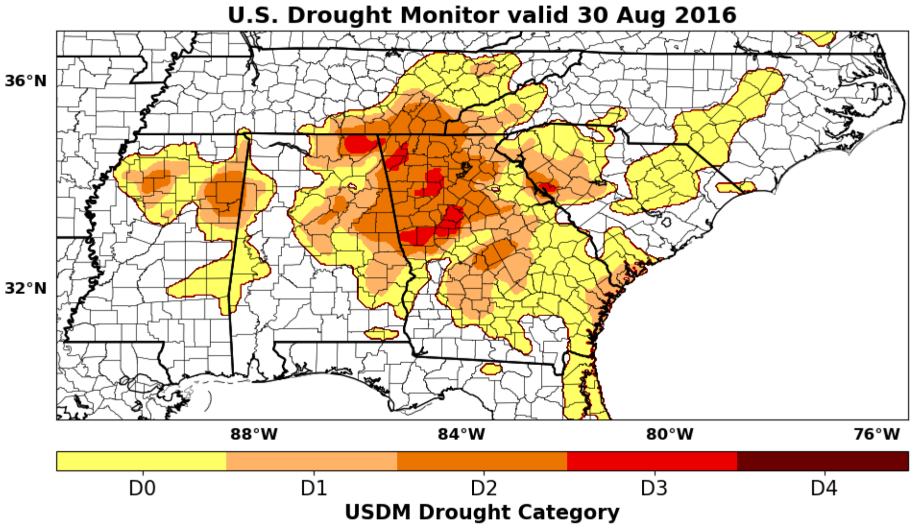


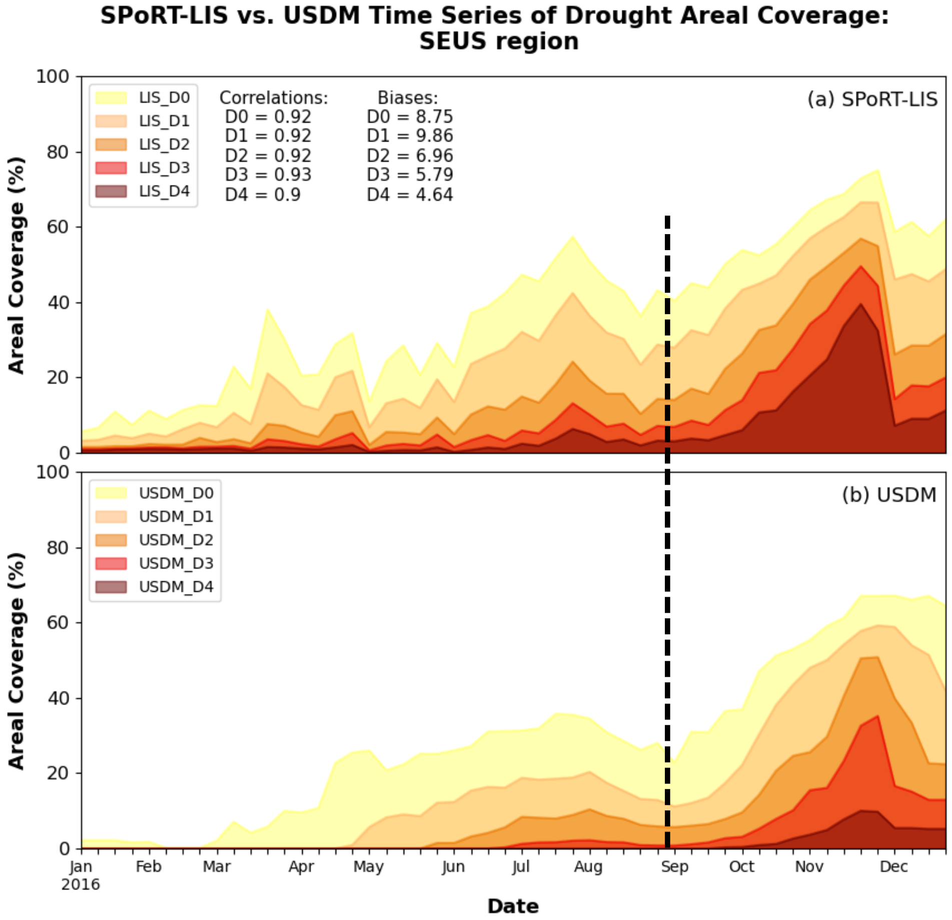
Time series of SPoRT-LIS 0-200 cm RSM drought categories areal coverage [top row] versus USDM areal coverage of drought categories from 2010-2012.

Comparing 0-200 cm RSM Percentile to U.S. Drought Monitor:

Autumn 2016 Southeast U.S. Flash Drought/Gatlinburg Wildfire

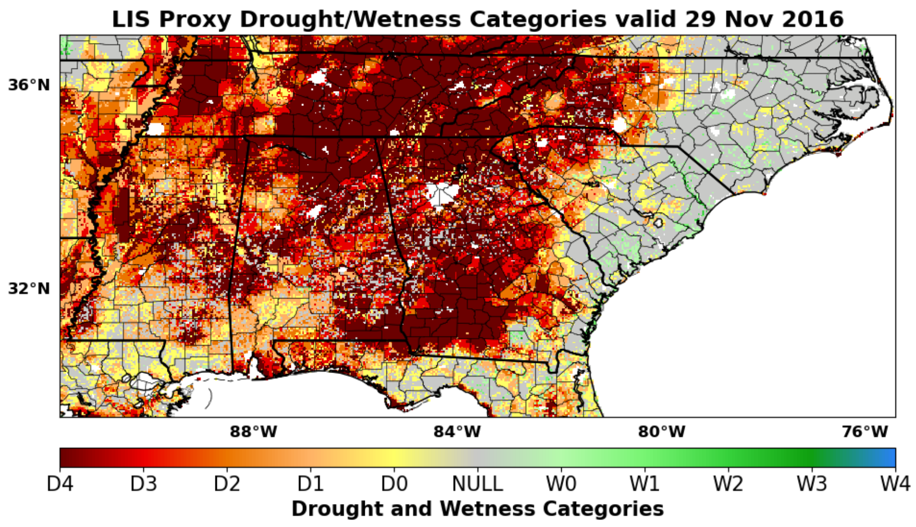


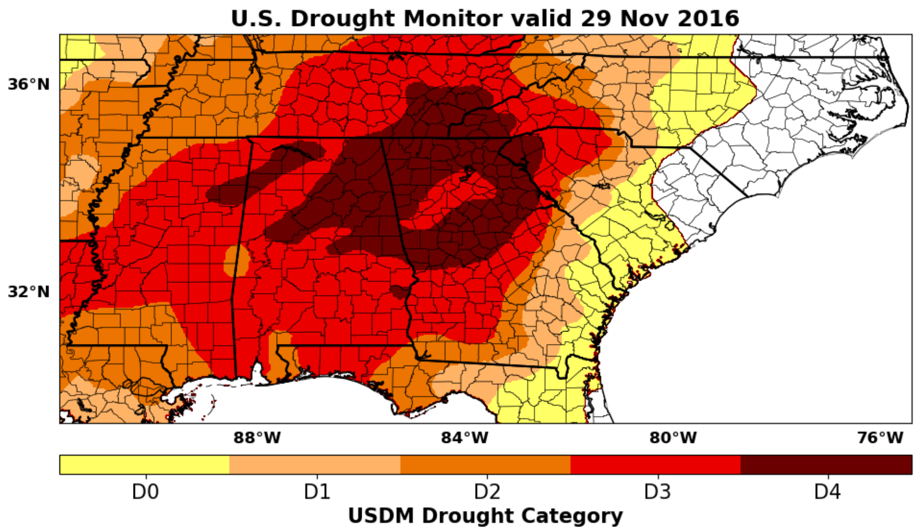


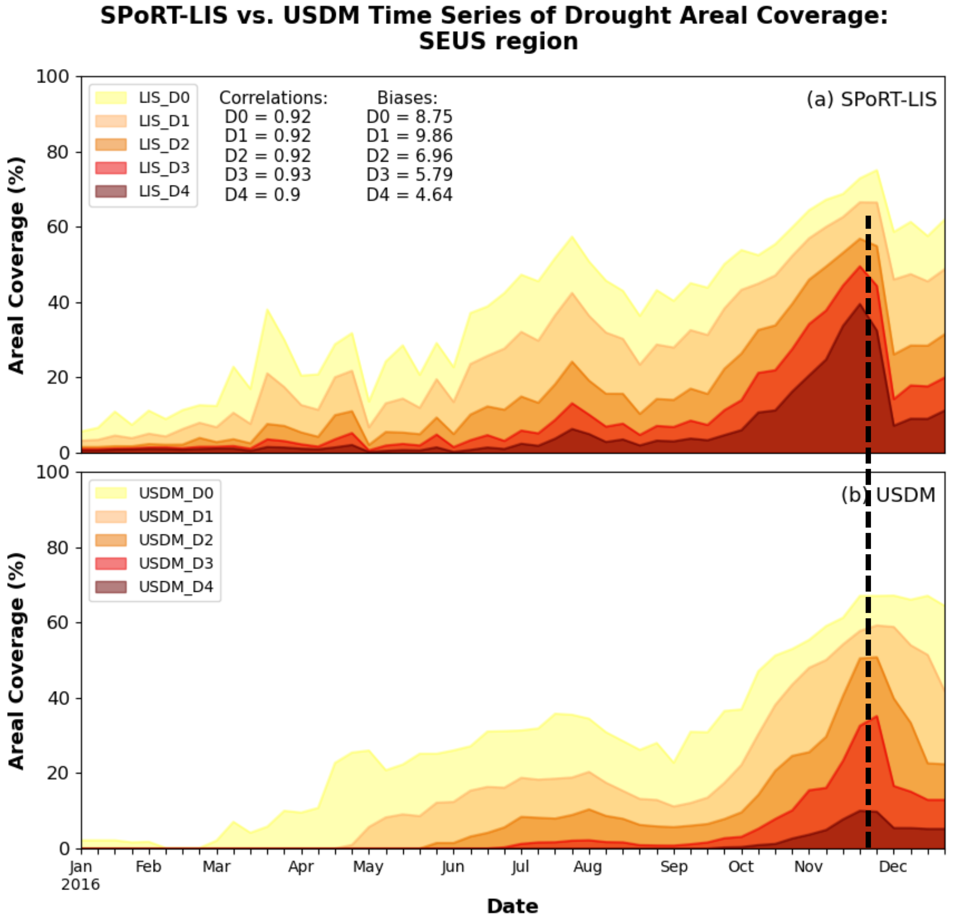


Time series of SPoRT-LIS 0-200 cm RSM drought categories areal coverage [top row] versus USDM areal coverage of drought categories during 2016.

Comparing 0-200 cm RSM Percentile to U.S. Drought Monitor:
Autumn 2016 Southeast U.S. Flash Drought/Gatlinburg Wildfire

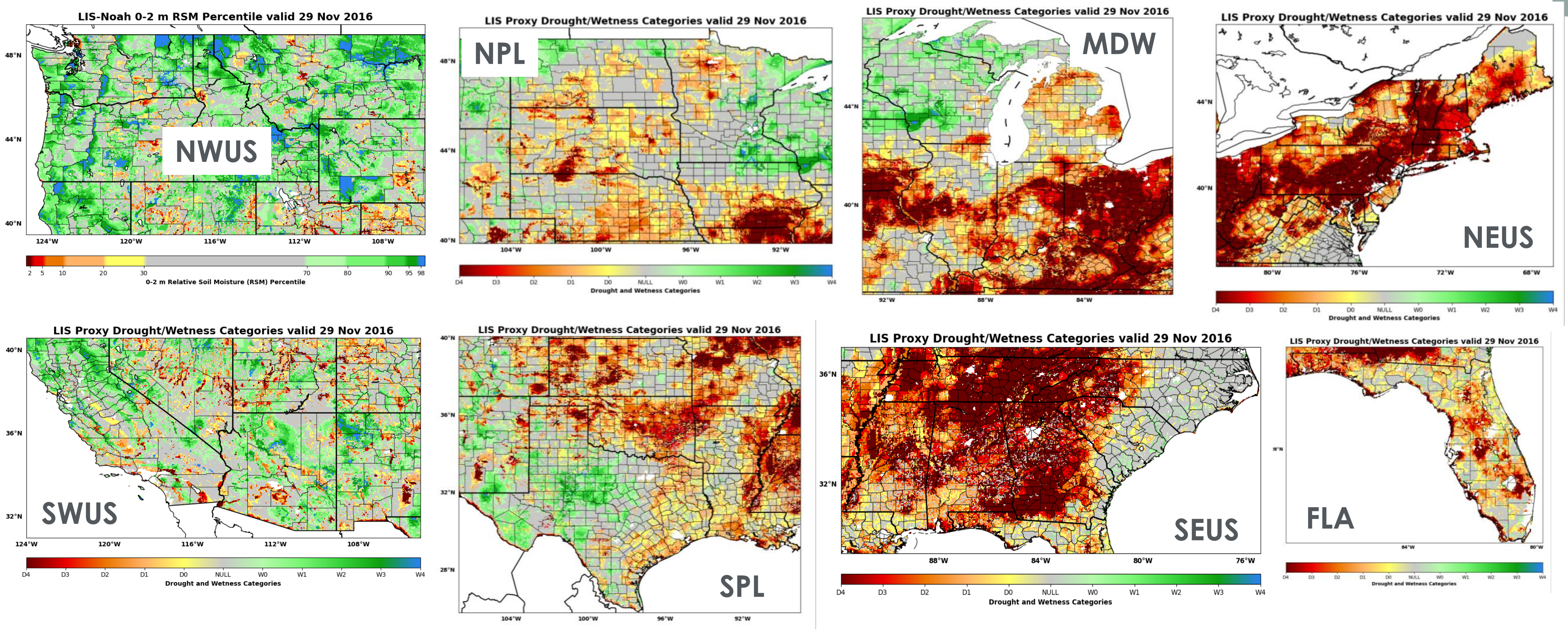






Time series of SPoRT-LIS 0-200 cm RSM drought categories areal coverage [top row] versus USDM areal coverage of drought categories during 2016.

Validation of 0-200 cm RSM Drought Categories



Evaluated 0-200 cm RSM, county-based drought categories from 2000-2022 over the regions above

SPoRT-LIS Proxy Drought Validation:
Areal Coverage of Exceeding Drought Categories

Diff in Mean Area (SPoRT-LIS minus USDM)

Bias	D0	D1	D2	D3	D4
FLA	25.9	20.6	12.2	8.0	5.0
SEUS	5.9	8.6	5.5	4.3	3.2
NEUS	25.5	21.6	13.3	8.4	5.0
MDW	19.3	19.9	13.4	8.7	5.0
SPL	-1.7	1.3	-0.0	1.5	2.4
NPL	-3.5	2.7	2.1	3.5	3.4
SWUS	-20.6	-17.1	-13.3	-5.1	0.4
NWUS	8.3	7.5	3.6	3.4	3.1

Best

Best

Correlation	D0	D1	D2	D3	D4
FLA	0.85	0.79	0.71	0.63	0.46
SEUS	0.89	0.85	0.81	0.76	0.71
NEUS	0.80	0.69	0.57	0.44	0.07
MDW	0.72	0.63	0.53	0.40	0.34
SPL	0.90	0.87	0.81	0.69	0.52
NPL	0.82	0.77	0.71	0.61	0.60
SWUS	0.46	0.48	0.48	0.37	0.27
NWUS	0.64	0.60	0.54	0.40	0.23

SPoRT-LIS 0-200 cm county soil moisture percentile drought category verification; Bias (left) and Pearson Correlation (right) statistics from 2000-2022.

SPoRT-LIS Proxy Drought Validation:
Areal Coverage of Exceeding Drought Categories

Diff in Mean Area (SPoRT-LIS minus USDM)

Bias	D0	D1	D2	D3	D4
FLA	25.9	20.6	12.2	8.0	5.0
Over-representing drought coverage				4.3	3.2
NEUS	25.5	21.6	13.3	8.4	5.0
MDW	19.3	19.9	13.4	8.7	5.0
SPL	-1.7	1.3	-0.0	1.5	2.4
NPL	-3.5	2.7	2.1	3.5	3.4
SWUS	-20.6	-17.1	-13.3	-5.1	0.4
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Correlation	D0	D1	D2	D3	D4
FLA	0.85	0.79	0.71	0.63	0.46
SEUS	0.89	0.85	0.81	0.76	0.71
NEUS	0.80	0.69	0.57	0.44	0.07
MDW	0.72	0.63	0.53	0.40	0.34
SPL	0.90	0.87	0.81	0.69	0.52
NPL	0.82	0.77	0.71	0.61	0.60
SWUS	0.46	0.48	0.48	0.37	0.27
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SPoRT-LIS 0-200 cm county soil moisture percentile drought category verification; Bias (left) and Pearson Correlation (right) statistics from 2000-2022.

SPoRT-LIS Proxy Drought Validation:
Areal Coverage of Exceeding Drought Categories

Diff in Mean Area (SPoRT-LIS minus USDM)

Bias	D0	D1	D2	D3	D4
FLA	25.9	20.6	12.2	8.0	5.0
SEUS	5.9	8.6	5.5	4.3	3.2
NEUS	25.5	21.6	13.3	8.4	5.0
MDW	19.3	19.9	13.4	8.7	5.0
SPL	-1.7	1.3	-0.0	1.5	2.4
Under-representing drought coverage in SWUS					
SWUS	-20.6	-17.1	-13.3	-5.1	0.4
NWUS	8.3	7.5	3.6	3.4	3.1

Correlation	D0	D1	D2	D3	D4
FLA	0.85	0.79	0.71	0.63	0.46
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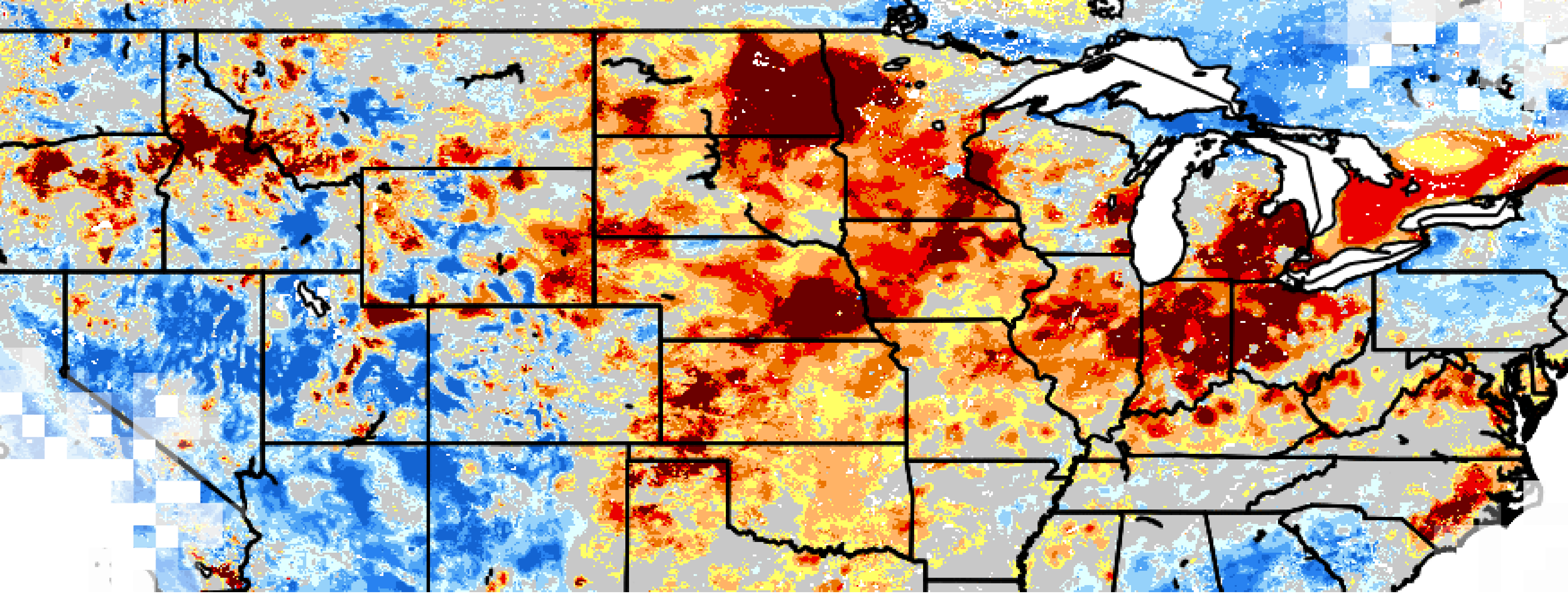
SPoRT-LIS 0-200 cm county soil moisture percentile drought category verification; Bias (left) and Pearson Correlation (right) statistics from 2000-2022.

Summary and thank you for listening!

- SPoRT-LIS provides real-time land surface fields and soil moisture percentiles for informed decisions on drought.
- Verifies best against U.S. Drought Monitor in Central and Eastern U.S.
- **Future:**
  - Expand SPoRT-LIS over full North American with follow-on NASA Unified LDAS development
  - Forecasts and ensemble probability of drought onset/intensification

NASA/SPoRT Web:
https://weather.msfc.nasa.gov/sport/
Twitter: @NASA_SPoRT
Facebook: NASA.SPoRT

Acknowledgements: *This research is funded by Dr. Tsengdar Lee of NASA HQ.*



Part 1
Summary

Summary

- The NASA Land Information System (LIS) provides a framework for the comprehensive characterization of the land surface and hydrological extremes such as drought.
- The capability of remote sensing data infusion through data assimilation enables the representation of land surface heterogeneity and human management impacts.
- SPoRT-LIS provides real-time surface fields and soil moisture percentiles for informed decisions on drought.

Looking Ahead

- In order to reinforce what we learned today, and to prepare you for part 2, we have a Microlesson which can be found on the training page.
- The Microlesson will allow you to independently practice the knowledge and skills from today's webinar.
- Part 2 will extend the concepts covered today to focus on early and established applications of LIS for drought analysis in operations.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 31 May, 2023
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 14 June, 2023**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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  - jonathan.case-1@nasa.gov

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Thank You!