Research, Applications, and Challenges with using the Noah-MP LSM in the NASA Land Information System

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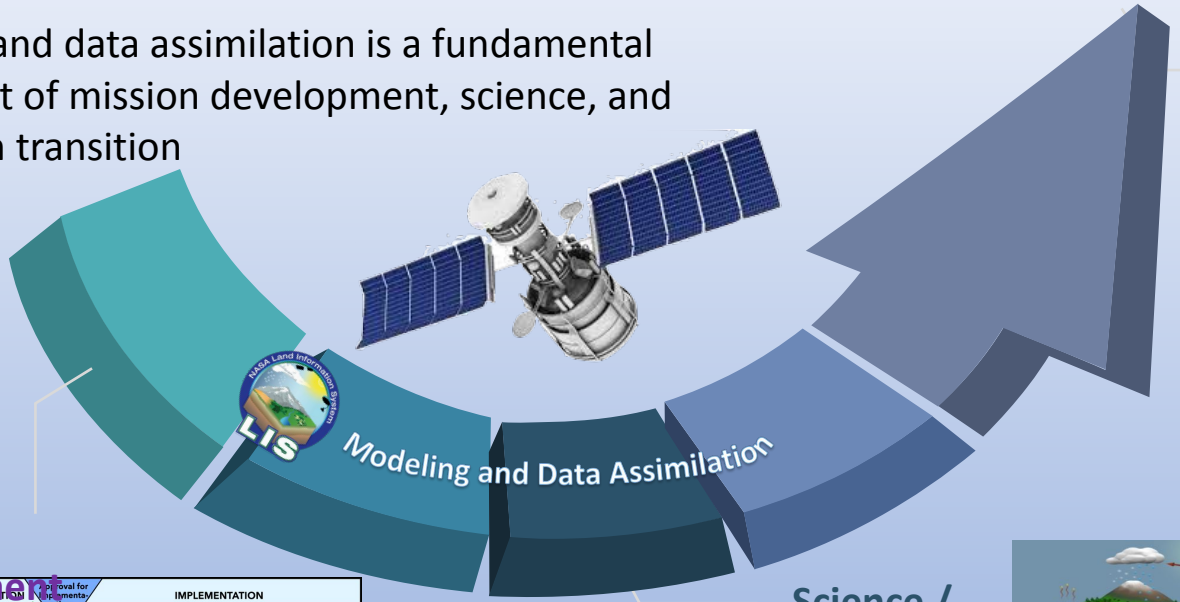
The Land Information System (LIS)

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



Terrestrial hydrology applications


NWP

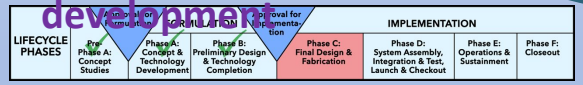

Availability


Quality

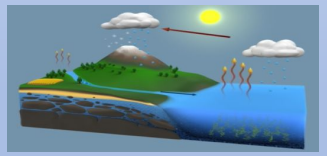

Food security


Extremes

Mission development



Science / research



Improved quantification of terrestrial water budget components and their variability

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

LIS (https://lis.gsfc.nasa.gov/)

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

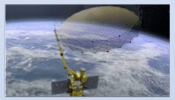
2010

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)

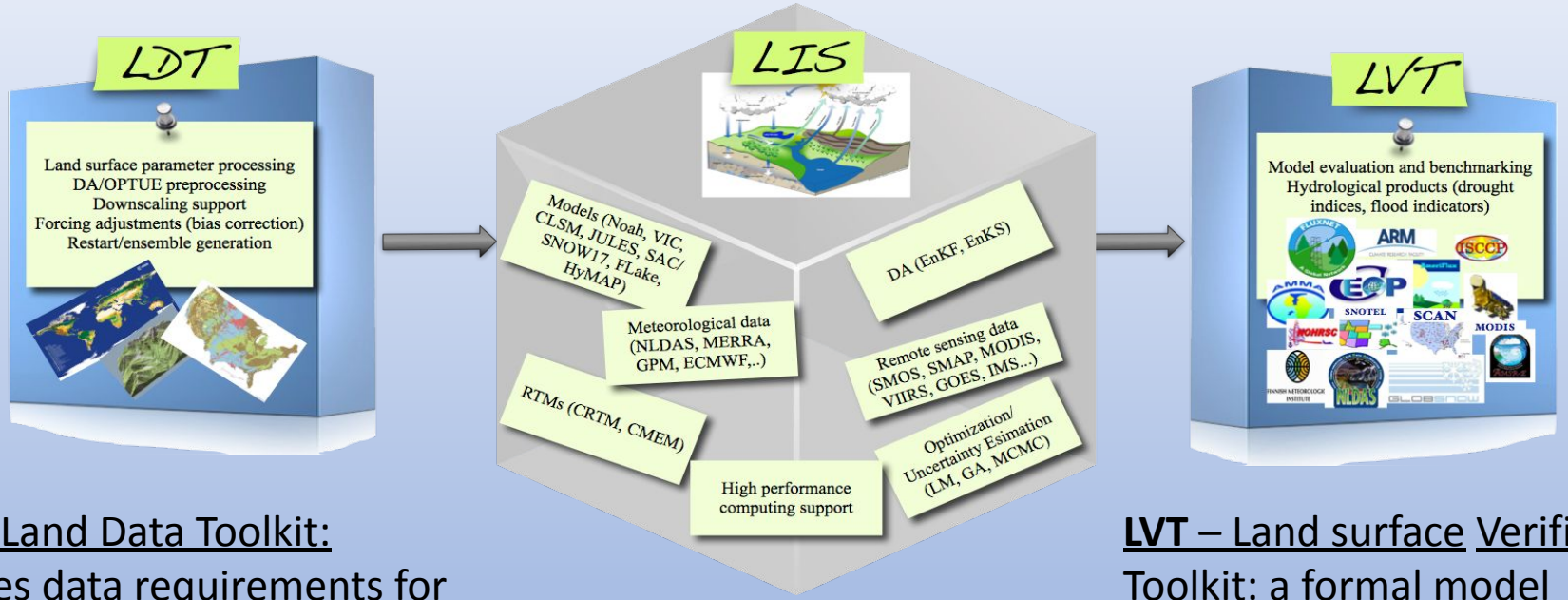
2022

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 – and supports Land Data Assimilation (LDAS) efforts around the world including NLDAS, GLDAS, FLDAS, and NCA-LDAS

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

The LIS software suite

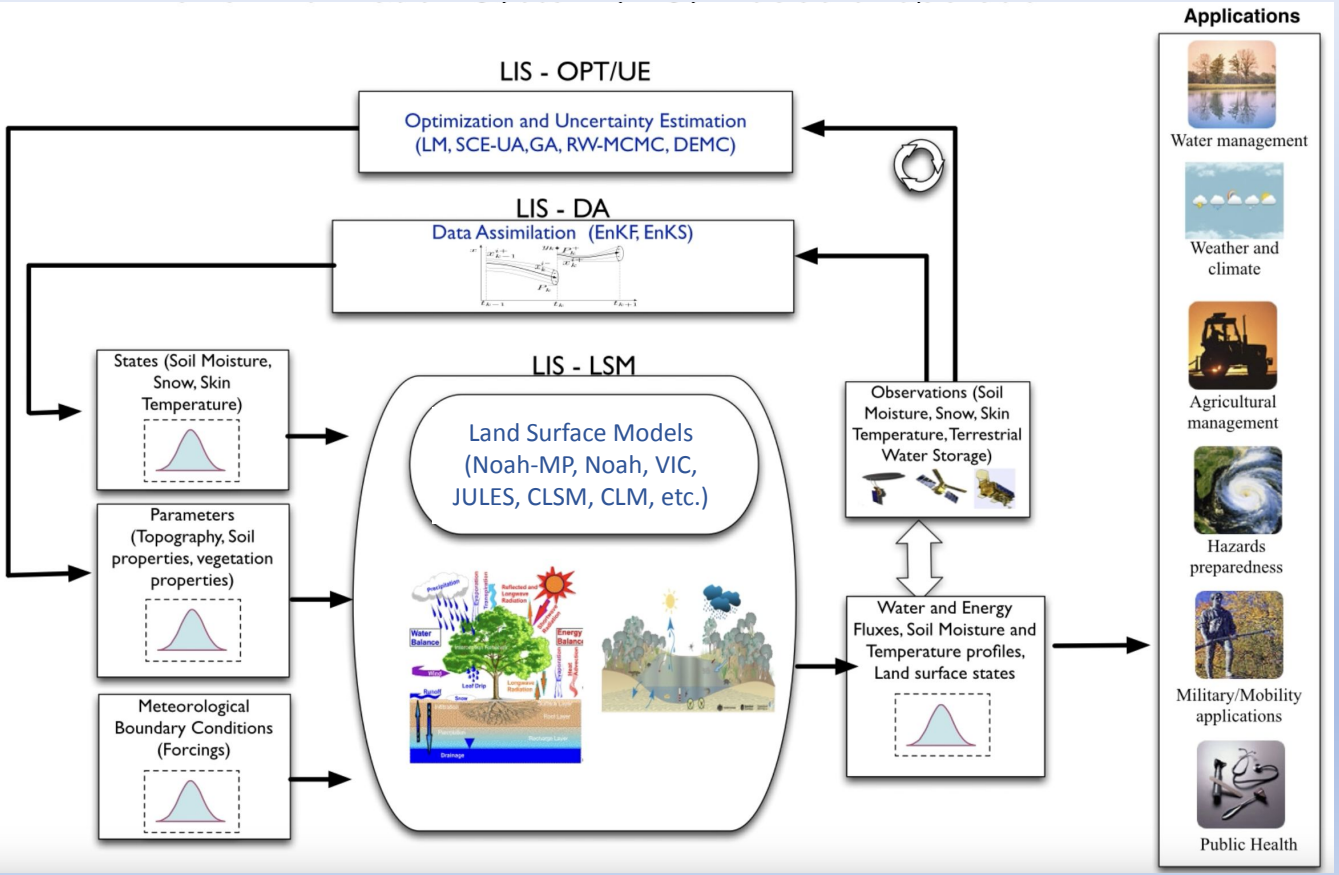


LDT – Land Data Toolkit: handles data requirements for LIS, including land-surface parameter processing and data assimilation pre-processing

LIS – Land Information System: high-performance modeling system with physical models, data assimilation, and OPT/UE

LVT – Land surface Verification Toolkit: a formal model verification and benchmarking environment that compares against a wide range of observations/reference data

LIS modes of operation



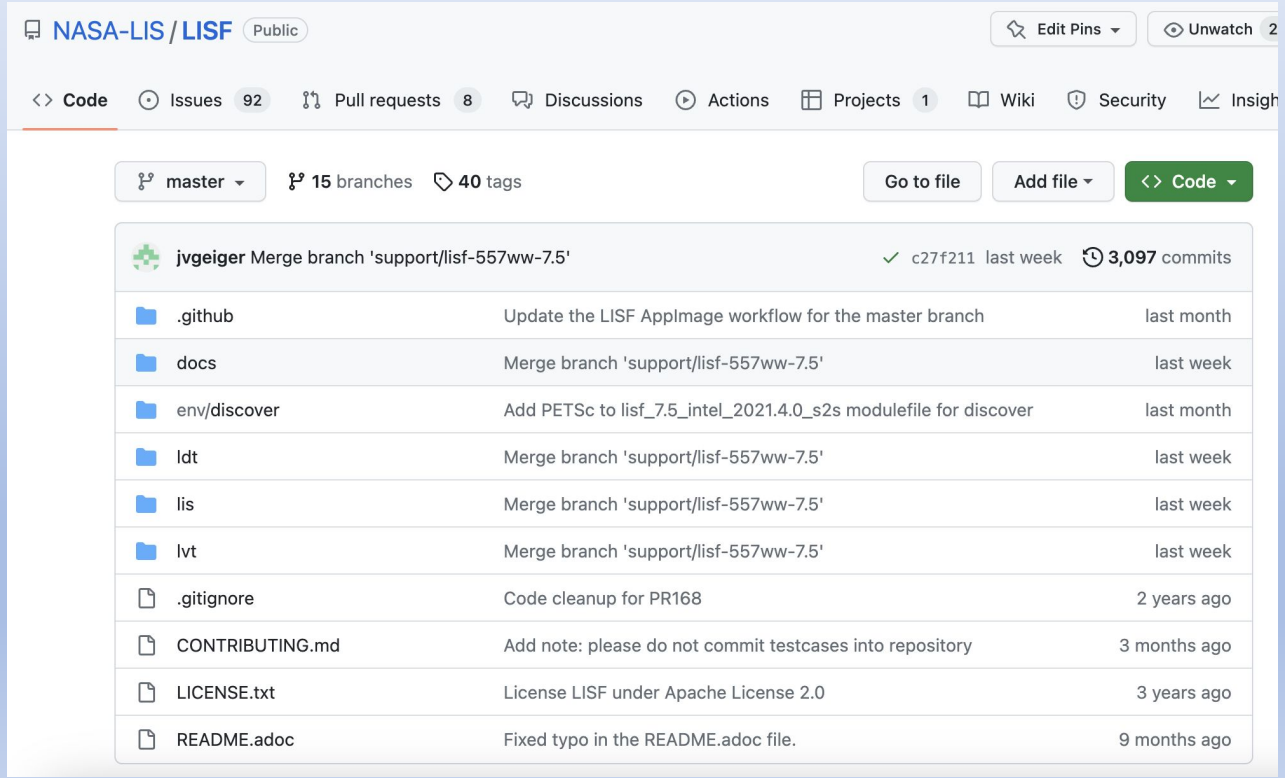
LIS supports a wide array of land-surface models, meteorological forcing datasets, and remotely-sensed observations for data assimiliation.

Different data assimilation techniques are supported, as well as parameter optimization and uncertainty estimation (OPT/UE).

All supported via plugins.

LIS is available at GitHub

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



LIS is available from GitHub via the Apache-2.0 license.

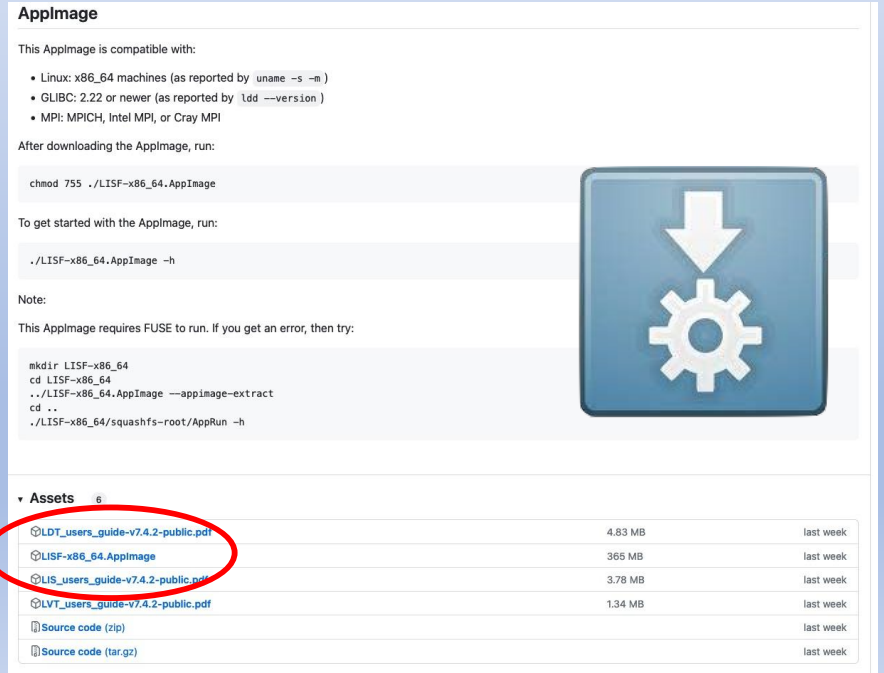
Detailed documentation (including Users' Guides) and a Discussion page for help are available.

Formal code releases with version numbers are also made available.

We encourage contributions of code via pull requests that are reviewed before merging.

LIS now available as a container

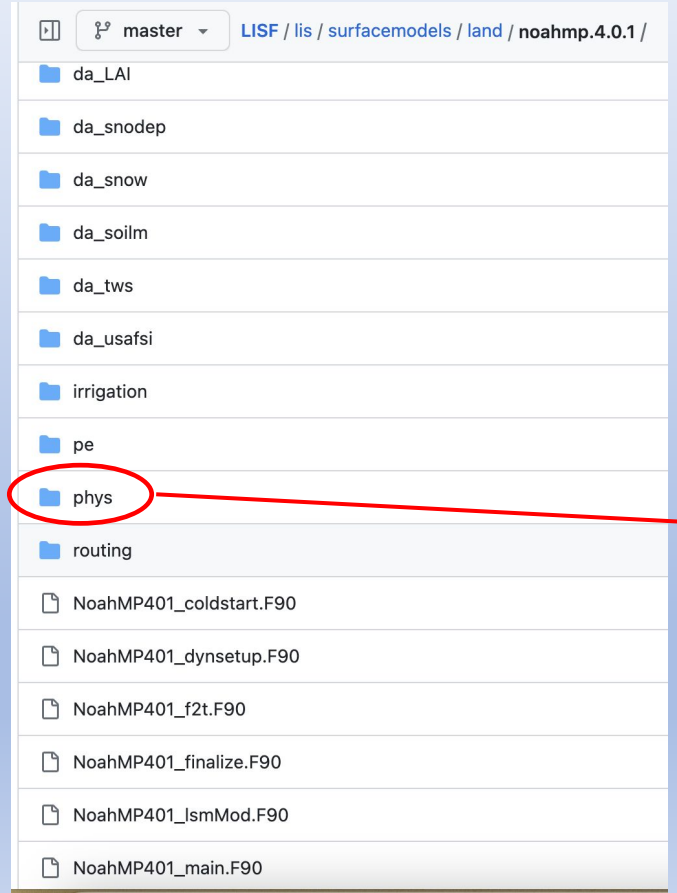
- Porting the LIS code, particularly the libraries, has been a major bottleneck for users
- Packing LIS and its dependencies into a ready-to-run file, b.k.a. an image/container, eliminates this barrier to entry to using LIS.



LIS was built into an AppImage image and runs on AWS, NCCS Discover, Navy Narwhal, ORNL HPC-11, Colorado Climate Center (CCC). Lightweight system for bundling an executable and its dependencies. Runs like a native executable; no special software required on the host computer.

The AppImages are available for download from the NASA LIS GitHub site.

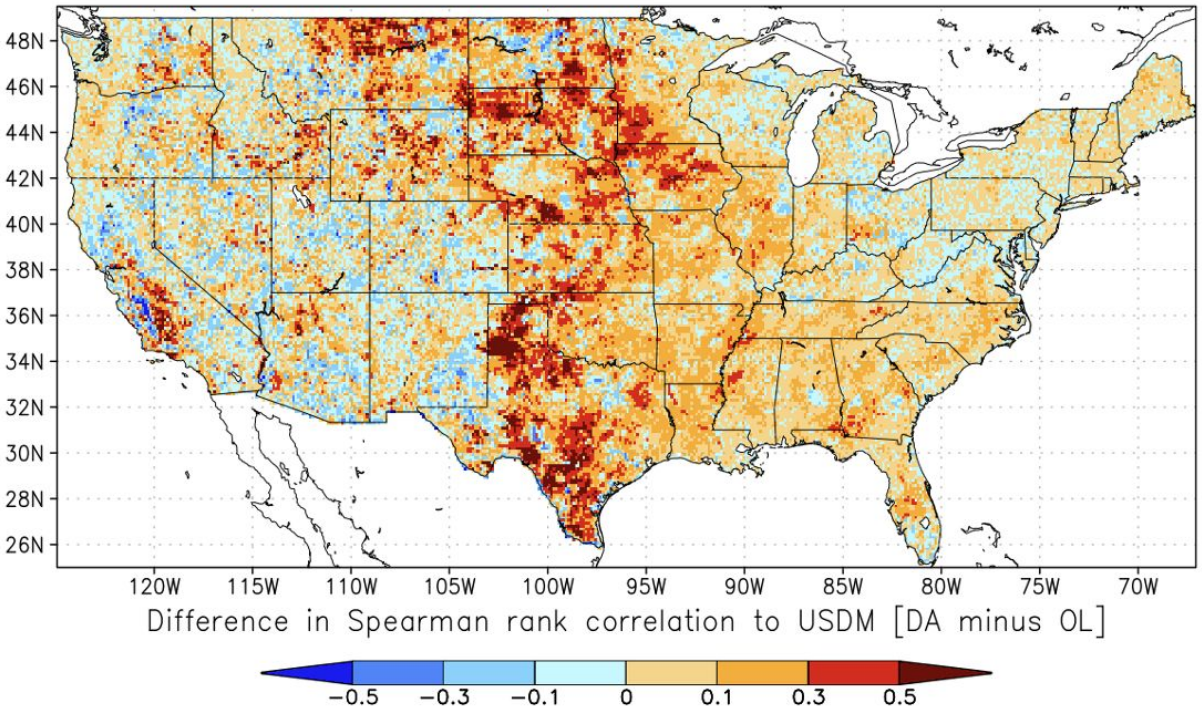
Noah-MP LSM integrated into LIS



- In the directory for the Noah-MP-4.0.1 version of the code, there are sub-directories with plugins for:
  - LAI data assimilation
  - Snow data assimilation (several products)
  - Soil moisture data assimilation
  - Terrestrial Water Storage data assimilation (GRACE)
  - Irrigation
  - Parameter estimation
  - Routing
- The “phys” directory contains the original model physics code as released by NCAR (with VERY minimal changes)
- Then there are ~a dozen LIS routines that handle the input and output to interact with the Noah-MP model physics, which is run as a single point for single timestep

LAI DA improves states/droughts

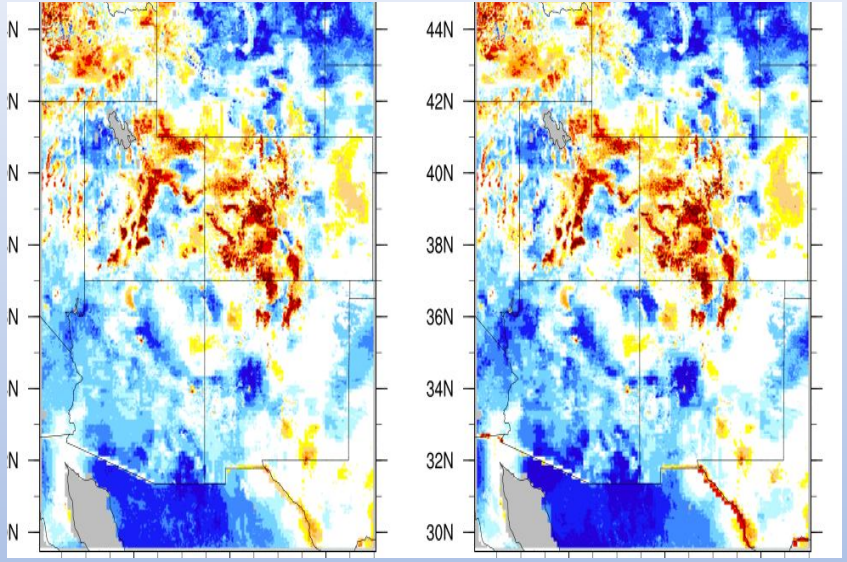
- GLASS LAI (Leaf Area Index) was assimilated into Noah-MP (with dynamic vegetation) using LIS for 1981-2017
- LAI DA improved water and carbon states and fluxes vs. observations and improved the depiction of drought
- Soil moisture simulations were improved, particularly during drought & in areas w/ human-managed water use
- Mocko et al., 2021: JHM, DOI:10.1175/JHM-D-20-0065.1



Improvement in the correlation of drought intensity estimates from soil moisture percentiles due to LAI data assimilation, as compared to the U.S. Drought Monitor.

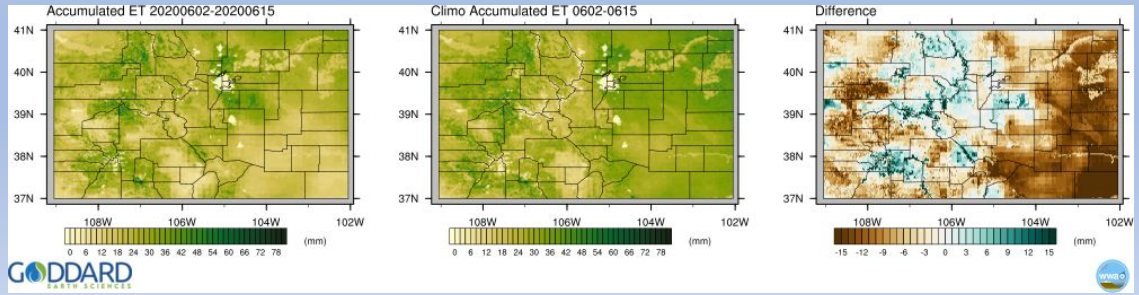
WLDAS Drought Monitoring at the Colorado Climate Center

- 1-km, daily land surface water and energy budgets from 1979-present
- Near real time runs every Monday to support the Colorado Climate Center's contributions to the United States Drought Monitor
- Data and images available at: https://portal.nccs.nasa.gov/datashare/WLDAS/



a) Surface soil moisture and b) root zone soil moisture percentiles for 2020.

Accumulated evapotranspiration (ET; left), climatological accumulated ET (center), and difference (right) for June 2-15, 2020. This hot and dry period occurred at a critical point in development of the winter wheat crop in eastern Colorado.



Slide credit: Jessica Erlingis Lamers

Noah-MP GRACE data assimilation

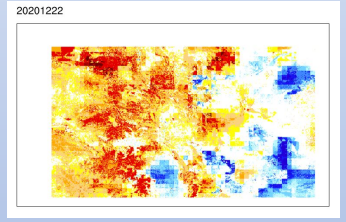
GRACE and GRACE-FO data assimilation into Noah-MP for drought monitoring in Colorado

- Data assimilation at 1 km
- Supported from NASA WWAO Office
- DA Capability will be running at the Colorado Climate Center
- Noah-MP simulated little groundwater dynamics in eastern CO which causes some problems for drought monitoring

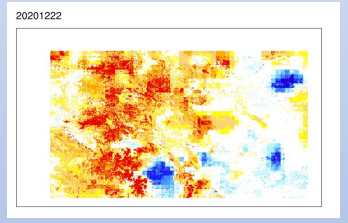
Contact bailing.li@nasa.gov for more information

Slide credit: Bailing Li

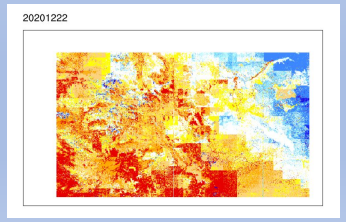
Surface SMC



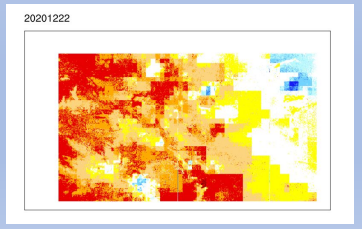
Root zone SMC



GWS



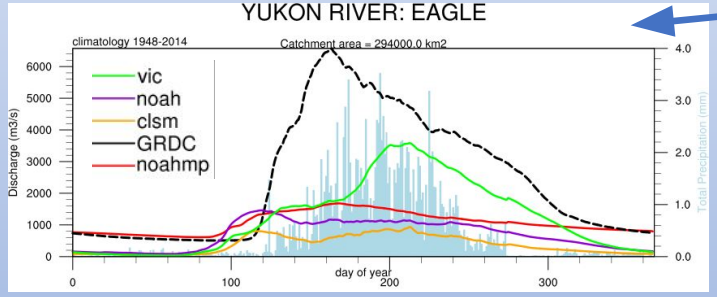
TWS

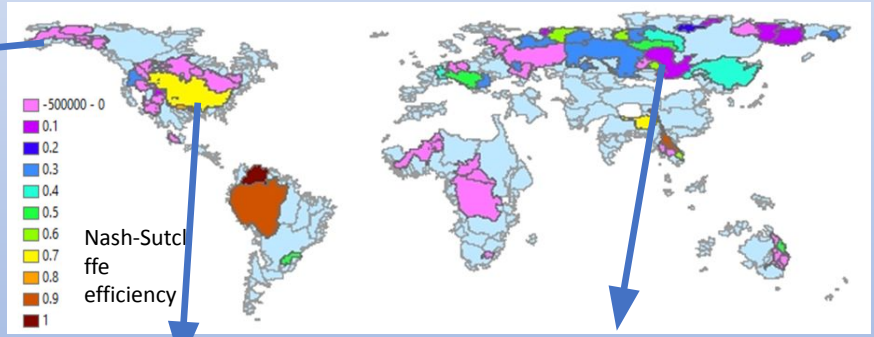


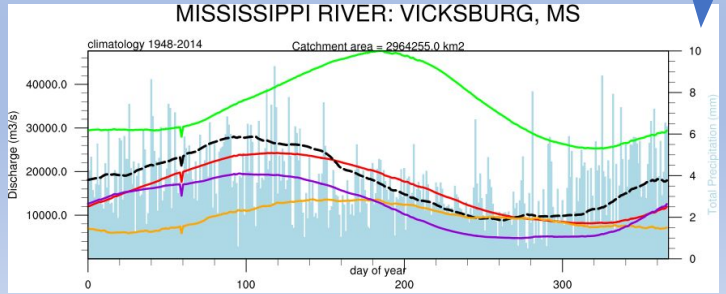
GRACE-based drought percentile maps on Dec. 22, 2020

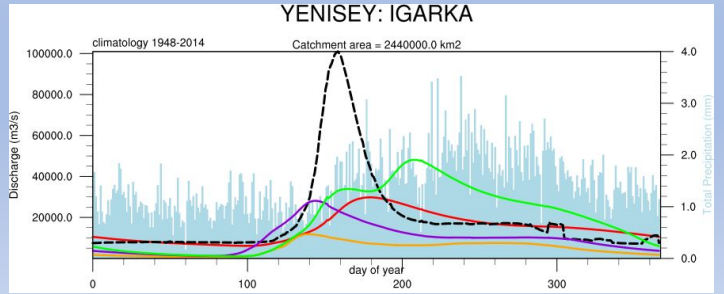
GLDAS-2.0 Noah-MP with HYMAP2

- Global Land Data Assimilation System (GLDAS) land surface model simulations are coupled to Hydrological Modeling and Analysis Platform (HYMAP) routing model (Getirana et al., 2012, JHM), producing streamflow and surface water related outputs. Noah-MP 4.0.1 will be added to the suite of GLDAS products--Noah3.6, Catchment, and VIC 4.1.2 Land Surface Models.
- Discharge estimates are generated from runoff estimates of Noah-MP 4.0.1 using Princeton meteorological forcing dataset from 1948-2014 at 1 degree. Preliminary comparison with 117 GRDC station data shows that NoahMP agrees better than other LSMs in general. All models are problematic in Africa (overestimation) and in high latitudes (underestimation) with snowmelt timing and peak amount in the spring-summer.







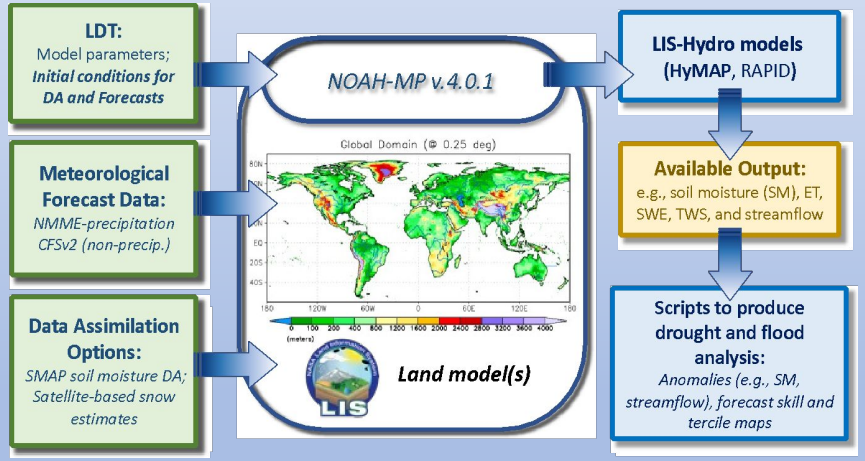


Slide credit:
Hiroko Kato
Beaudoing

Subseasonal-to-Seasonal Forecasts

Using Noah-MP in LIS for subseasonal-to-seasonal (S2S) forecasts around the globe.

S2S system components (*with LIS*)

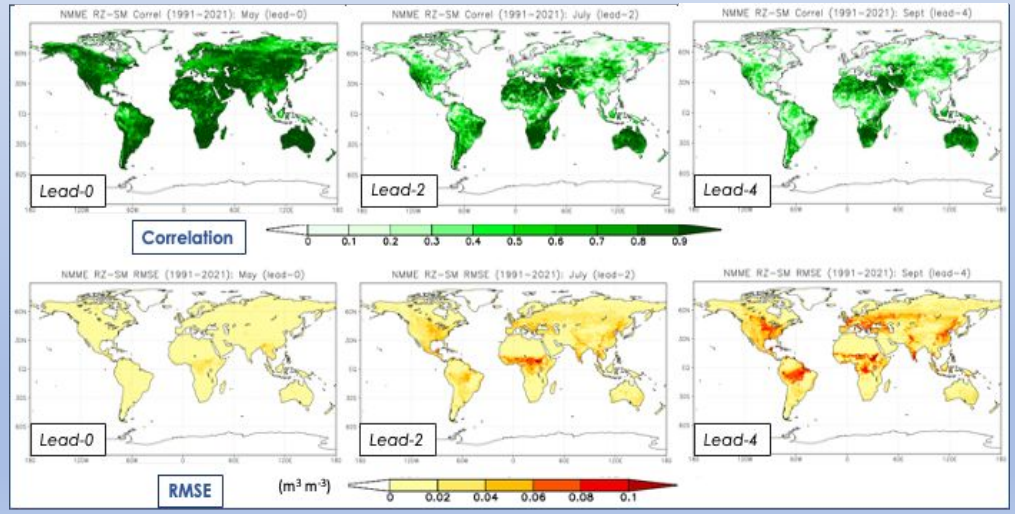


Noah-MP version 4.0.1 (*Niu et al., 2011; Yang et al., 2011)*

- Used for a LIS data-assimilation run for hydrological initial conditions, globally at 0.25° resolution.
- Forecasts – uses LIS+NoahMP401 with NMME and CFSv2 forcing inputs.

Root-Zone Soil Moisture (RZ-SM) Skill for May-1 Hindcasts

(Period: *1991-2021*; Reference: *Retrospective NoahMP401 run*)



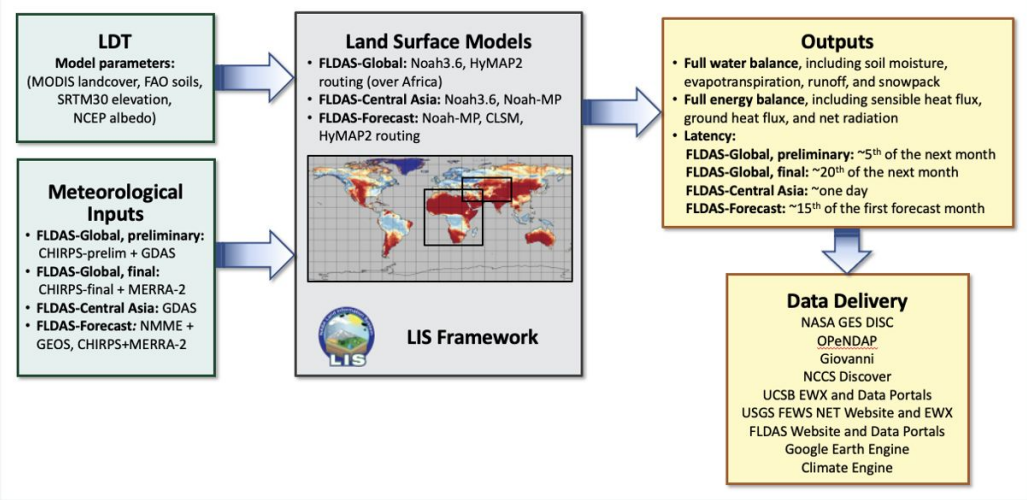
(K. Arsenault, R. Zamora, S. Mahanama, J. Wegiel, S. Kumar, and LIS team members)

Slide credit: Kristi Arsenault

FEWS NET LDAS (FLDAS)

FEWS NET Land Data Assimilation System (FLDAS)

Overview of the FLDAS Workflow



https://ldas.gsfc.nasa.gov/fldas

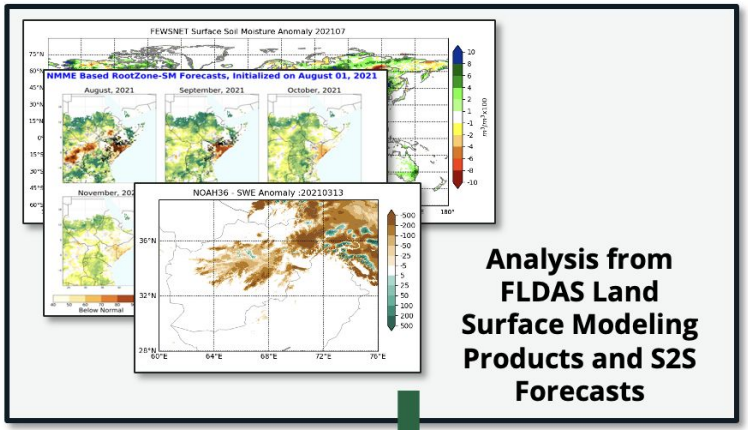
Additional Model Specifications

- **FLDAS-Global:** 0.1° grid, monthly outputs over quasi-global domain
- **FLDAS-Central Asia:** 0.01° grid, daily outputs over Central Asia
- **FLDAS-Forecast:** 0.25° grid, monthly subseasonal-to-seasonal forecasts out to 5 months over Africa and the Middle East

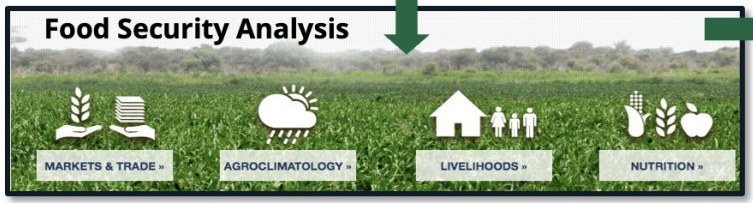
Slide credit: Kimberly Slinski

Food security with FLDAS

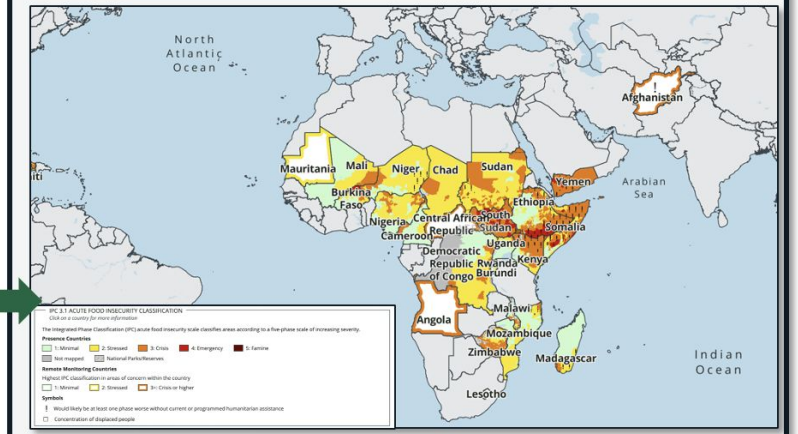
FEWS NET Land Data Assimilation System (FLDAS)



Analysis from FLDAS Land Surface Modeling Products and S2S Forecasts



FEWS NET Outlooks, Alerts, and IPC Acute Food Insecurity Phase Classification



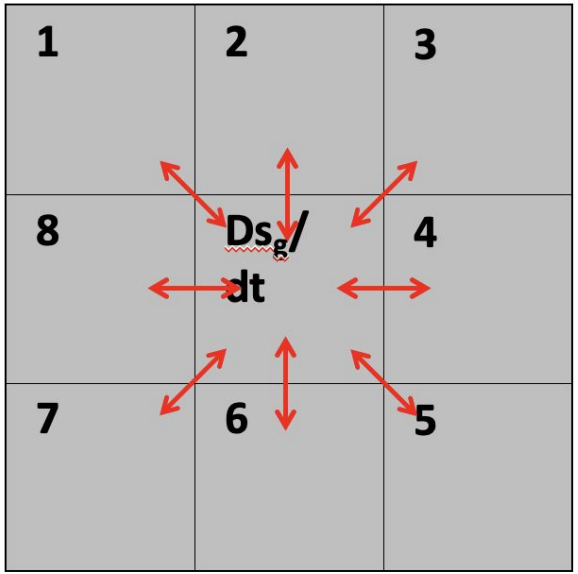
https://fews.net/

Slide credit: Kimberly Slinski

Miguez-Macho & Fan groundwater

About Miguez Macho and Fan et al. (2007) Scheme:

- Additional 2D Groundwater column exchange below Noah-MP LSM
- 2D Motion for a Gridpoint (see figure on right):
- $\frac{dS_g}{dt} = \Delta x \Delta y R + \sum_1^8 Q_n - Q_r$
- **Recharge + SUM(Lat. Flow - River Exchange)**
- River Exchange (Qr) parameterized with exponential function *(valid at resolutions up to 4-km)*



Use in Noah-MP LSM:

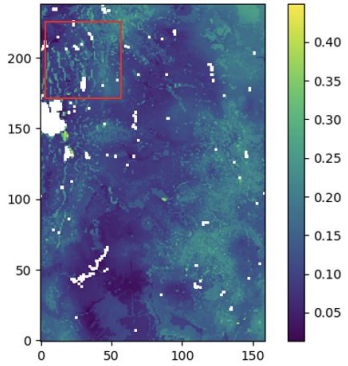
- Parallelized in WRF-ARW model
- Supported with HRLDAS in serial mode only
- **Ongoing work to develop parallel MMF scheme within NASA-LIS framework (consistent with HRLDAS)**
- Supported with resolutions up to 4-km
- Beta-Version Available on GitHub

Slide credit: Tim Lahmers

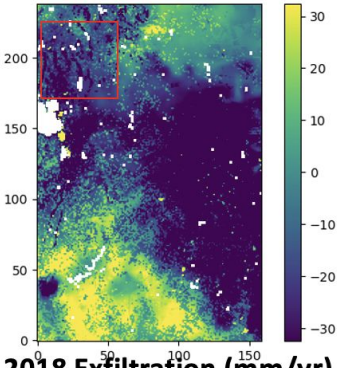
Miguez-Macho & Fan groundwater

LIS-MMF 4-km 1-year Demo (Upper CO River Basin)

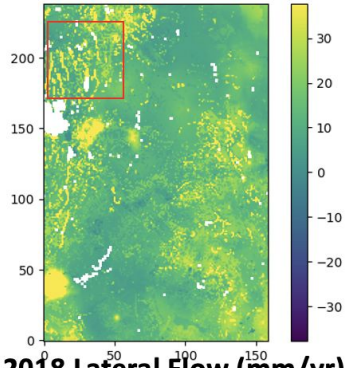
01-OCT-2018 0-10 cm SM



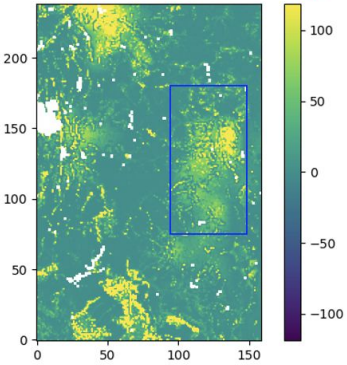
01-OCT-2018 Sensible Heat



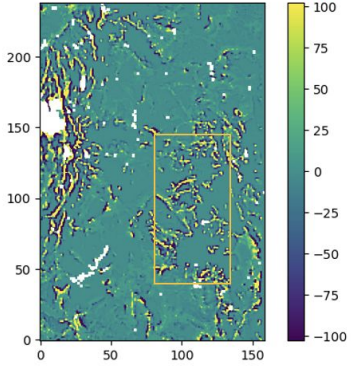
01-OCT-2018 Latent Heat



01-OCT-2018 Exfiltration (mm/yr)



01-OCT-2018 Lateral Flow (mm/yr)



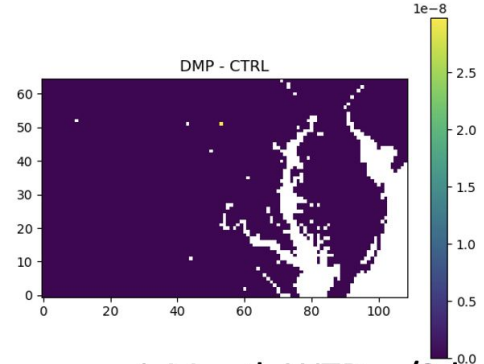
- MMF simulates lateral flow and vertical exchanges near rivers
  - Exfiltration
  - Lateral flow near water
- Surface variables reflect lateral fluxes
  - Increased SM and latent heat with decreased sensible heat

Slide credit: Tim Lahmers

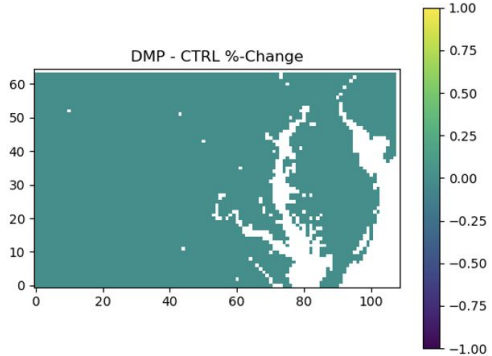
Miguez-Macho & Fan groundwater

LIS-MMF 4-km Domain w/Parallelization (Mid-Atlantic)

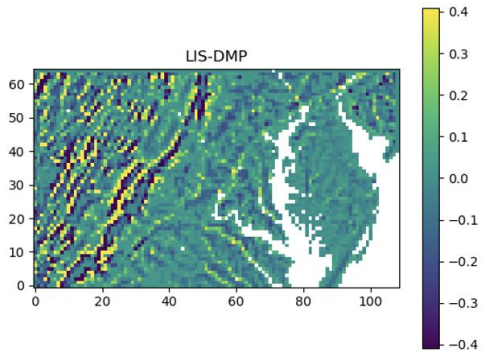
01-NOV-2017 QSLAT Error



01-NOV-2017 QSLAT %-Error

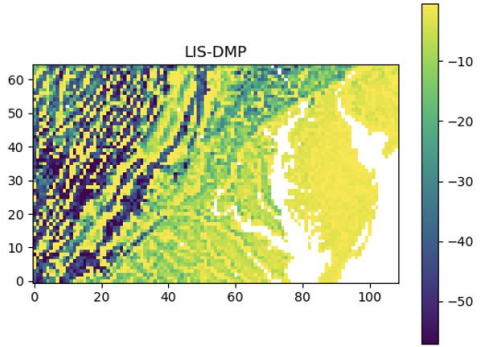


01-NOV-2017 QSLAT



- 1-Month WTD w/3dx Halos:
- Cold Initialization
  - Does not crash in domains with water
  - Errors are several orders of magnitude less than actual lateral flow (<< 1.0 %)
  - Realistic lateral flow and water table depth
- **Latest commit eliminates direct exchanges between processors (handled through overlapping halos)**
- **Update is technically valid and supports parallelization**
- **Next steps include fixing an initialization bug**

01-NOV-2017 WTD



Slide credit: Tim Lahmers

Other and on-going activities

- The re-factored Noah-MP-5.0 code is being integrated into LIS in a collaboration led by NCAR with assistance from the NASA LIS team
- Noah-MP has also been coupled to the Crocus snow model physics as well as to SnowModel physics via “subLSM” plugins
- Numerous efforts on improving soil moisture DA, including joint LAI and soil moisture data assimilation
- Coupled with NASA’s NU-WRF atmospheric model and with LIS/WRF-Hydro
- Irrigation studies (both uncoupled and coupled)
- Parameter estimation of Noah-MP with dynamic vegetation
- Being coupled to the Urban Canopy Model in LIS

https://lis.gsfc.nasa.gov/publications