Overview of LIS and Noah-MP efforts and NCAR-NASA/GSFC strategic partnership

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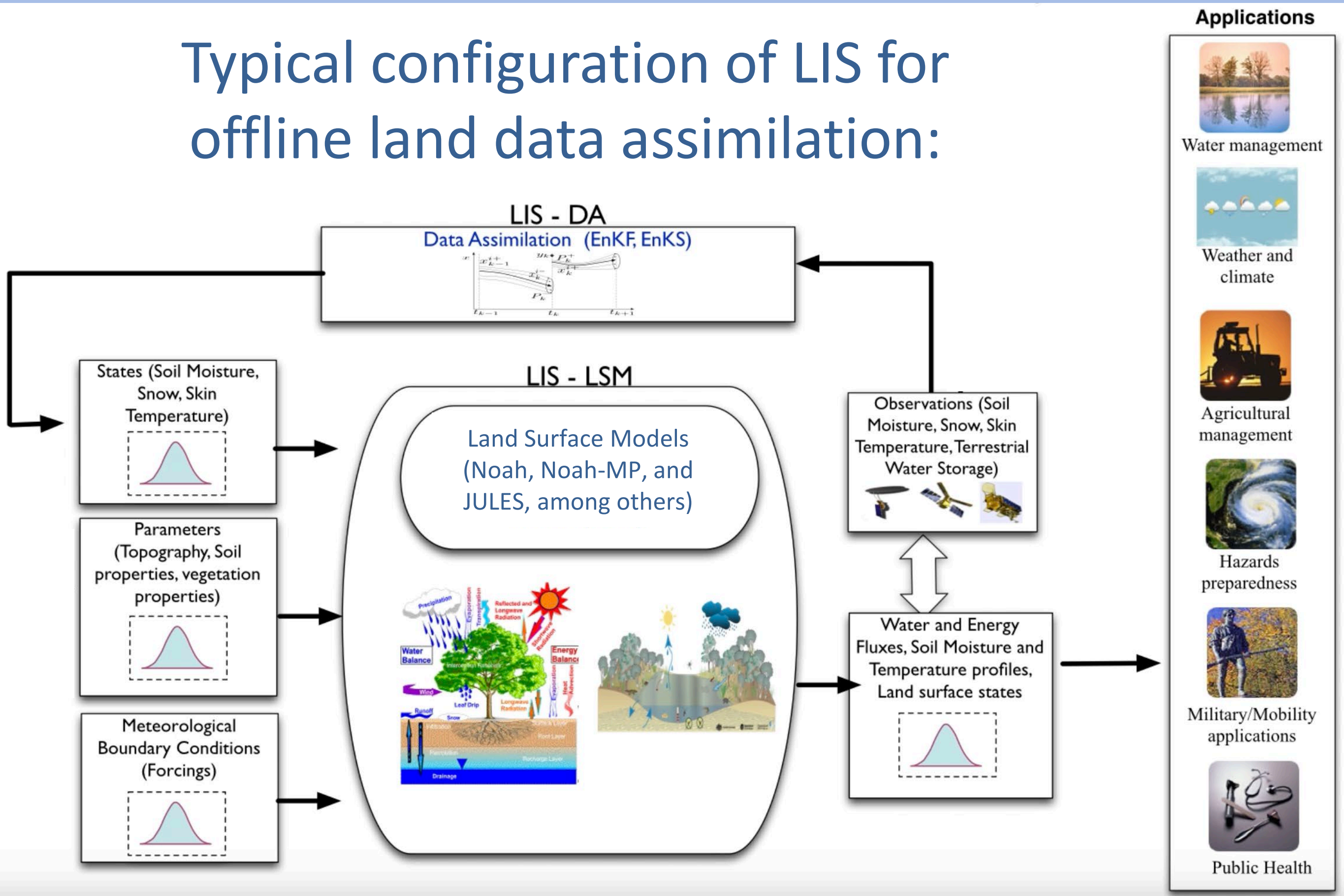
5. Science Data Processing Branch, NASA Goddard S.F.C., Greenbelt, MD

The LIS software suite

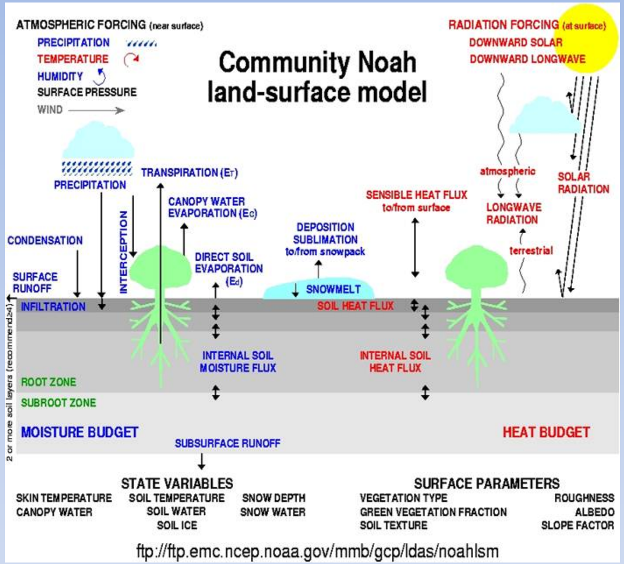
Typical configuration of LIS for offline land data assimilation:

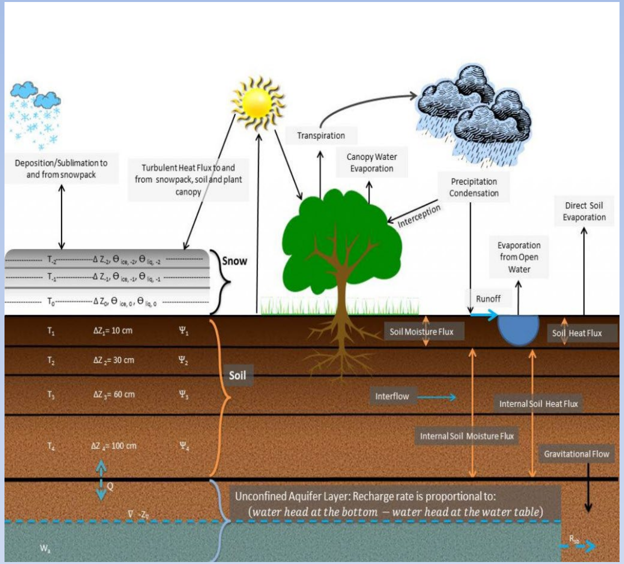


<u>Land Information System</u>

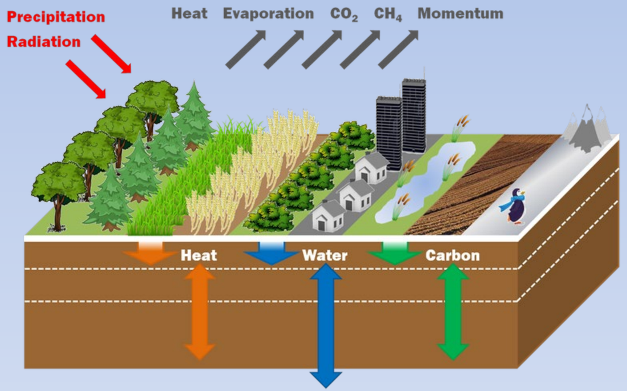
a high-performance software framework and modeling system with physical land-surface models (LSMs) and data assimilation of remotely-sensed land observations including soil moisture and snow.

LIS can run multiple LSMs, including:





JULES
Joint UK Land Environment Simulator



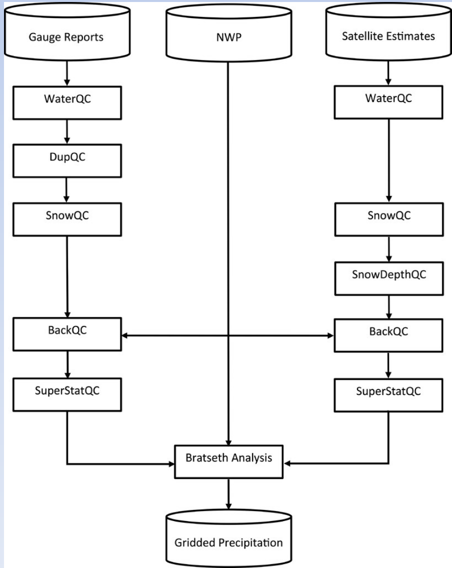
Noah-3.9 is maintained by NCAR; this version was taken from the WRF-3.9 release. Noah has 1 snow layer physics.

Noah-MP-4.0.1 is maintained by NCAR; includes numerous physics options, including for groundwater. Noah-MP has 3 snow layer physics.

JULES-5.0 is maintained by UKMO; PS41 (Parallel Suite 41) configuration was used, which also uses 3 snow layer physics.

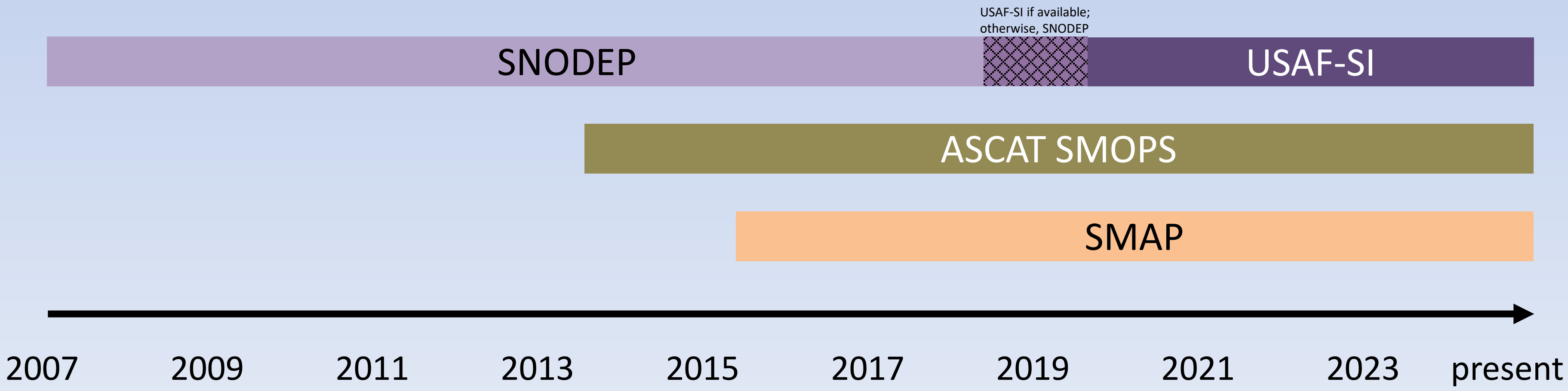
Global model configuration and forcing

- 3 LSMs (Noah-3.9, Noah-MP-4.0.1, and JULES-5.0) are each run on a global lat-lon grid at **~10-km grid spacing** (2560 x 1920 grid points), including glacial points.
- The surface meteorological forcing used as forcing is a combination of **NAFPA** (NASA – Air Force Precipitation Analysis) precipitation, meteorology from NWP and surface observations, and WWMCA (World Wide Merged Cloud Analysis).
- **NAFPA** (Kemp et al., 2022) uses a Bratseth analysis to combine precipitation from NWP as background with gauge reports and satellite estimates to produce a high-quality real-time analysis.
- NWP used until ~mid-2017 is from the **GFS**; after, **GALWEM** (USAF Global Air–Land Weather Exploitation Model) is used.
- Data archives go back to **Nov 2007**. LSM soil state spin-ups were done by looping through the forcing several times.

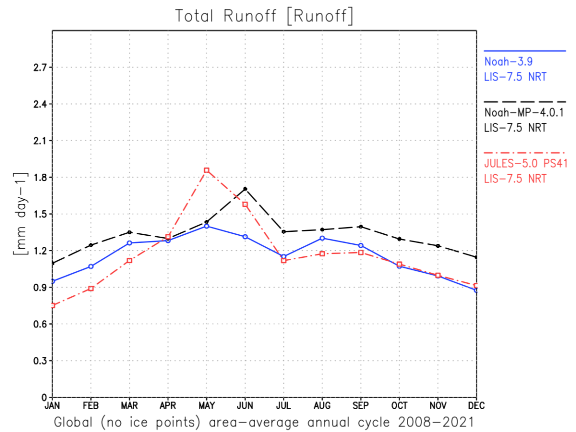


Products assimilated (timeline)

- Snow products from **USAF-SI** (USAF Snow and Ice Analysis; Yoon et al., 2022) and from **SNODEP** (USAF's Snow Depth Analysis Model) are assimilated.
- Soil moisture products from **ASCAT SMOPS** and from **SMAP** are assimilated using CDF matching, with the observations scaled into the LSM's climatology.
- Two simulations were performed for each LSM: One with data assimilation (DA) of the above products, and one with no data assimilation (Open Loop = OL).

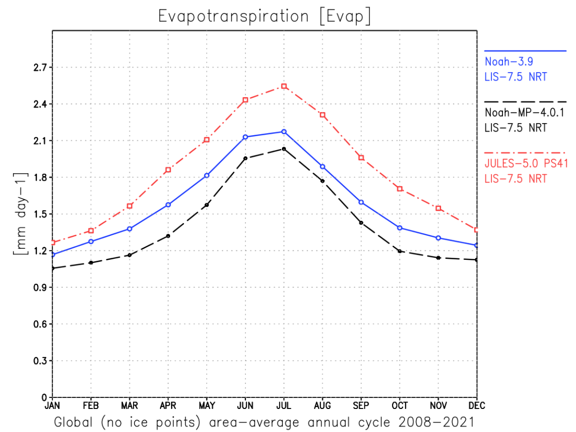


Annual cycle with data assimilation (DA)



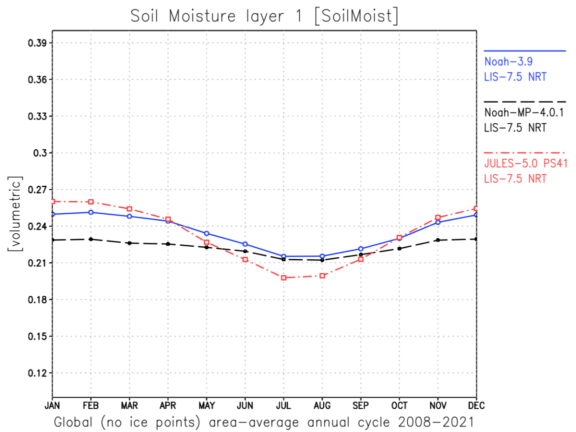
Total Runoff

Noah-MP generally higher than Noah. JULES has a high runoff peak in May, likely from higher NH winter SWE.



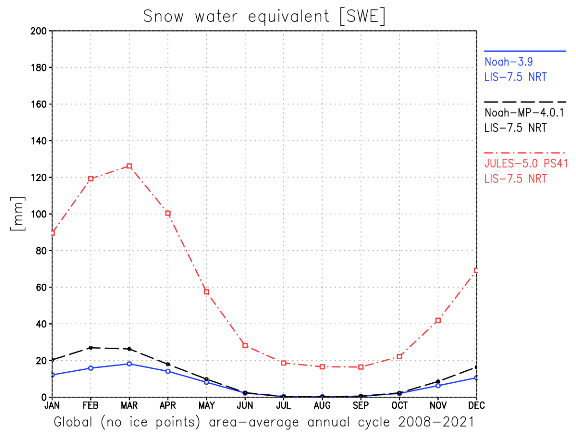
Evapotranspiration

JULES has the highest ET for all months, while Noah-MP has the lowest ET. All LSMs peak ET in July.



0-10cm soil moist.

JULES tends to be wetter in NH winter and drier in NH summer. Noah is wetter on surface than Noah-MP, but drier in root zone (not shown).



SWE (Snow water equivalent)

JULES has a much higher SWE in NH winter. Noah-MP has slightly more SWE than Noah.

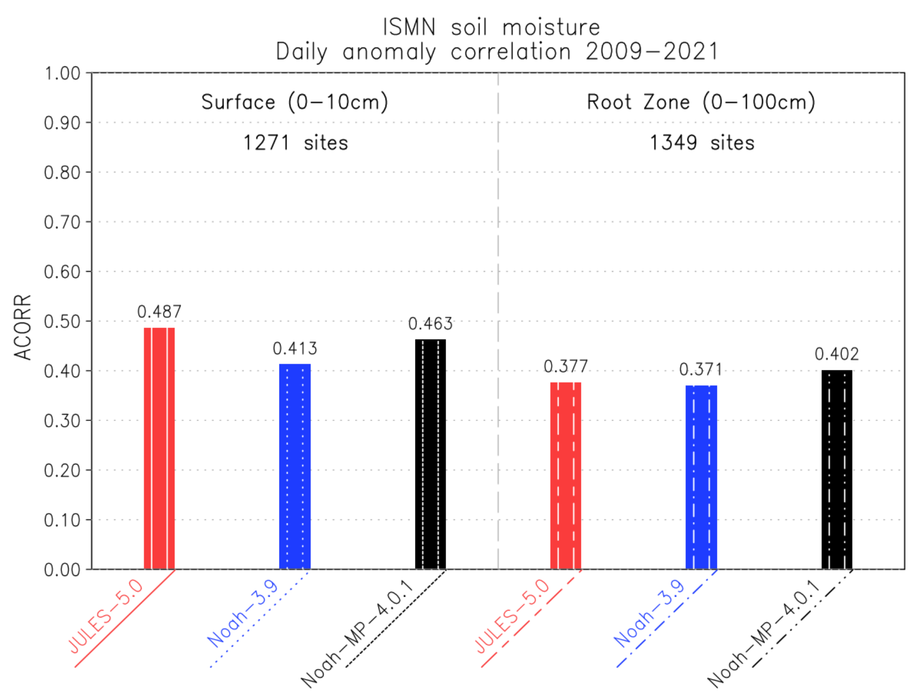
LVT and evaluation datasets

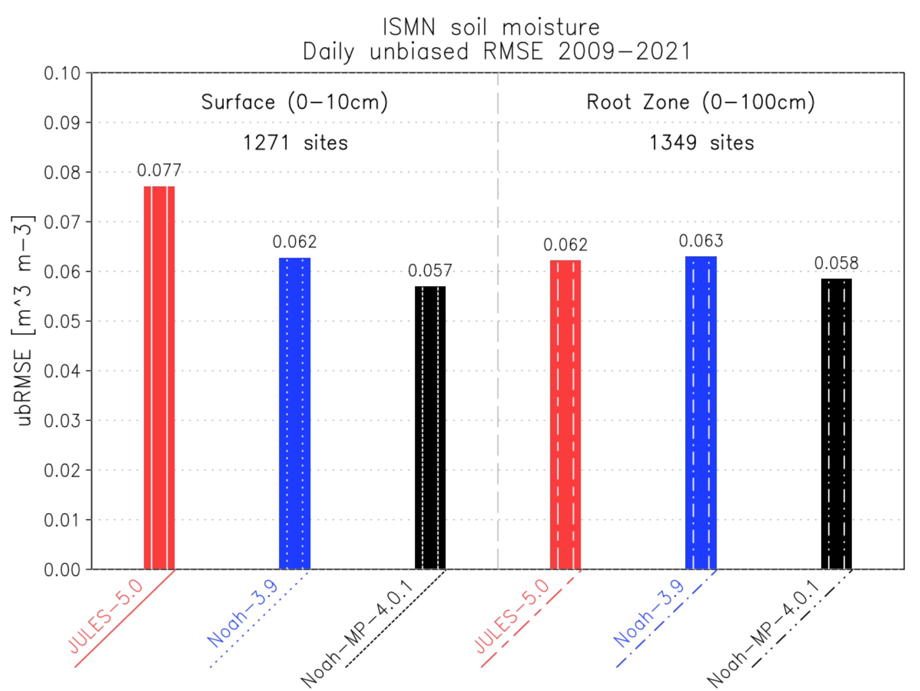
The Land surface Verification Toolkit is a component of the LIS software framework for model verification, evaluation, and benchmarking. (Kumar et al., 2012)

We used LVT to compare both DA and OL simulated output against these evaluation datasets:

- ISMN – International Soil Moisture Network (https://ismn.earth/en/)
- UASNOW – Univ. of Arizona 4-km gridded SWE and Snow Depth over CONUS (doi:10.5067/0GGPB220EX6A)
- GLEAM – Global Land Evaporation Amsterdam Model 0.25-deg. gridded evaporation (https://www.gleam.eu/)

DA comparison to in situ ISMN soil moisture

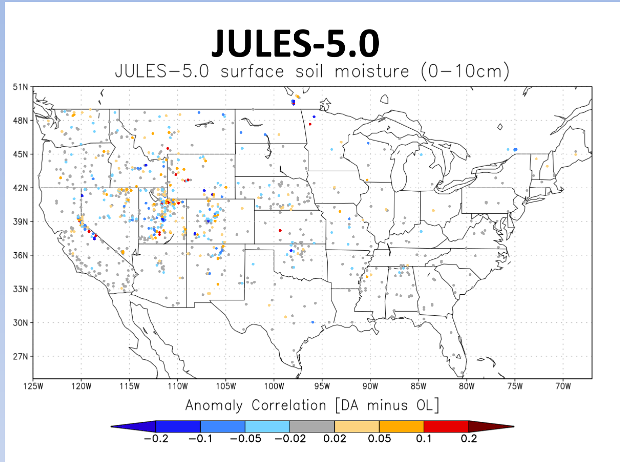


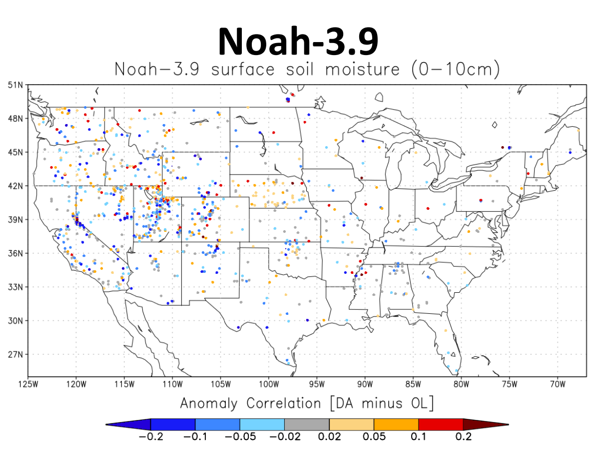


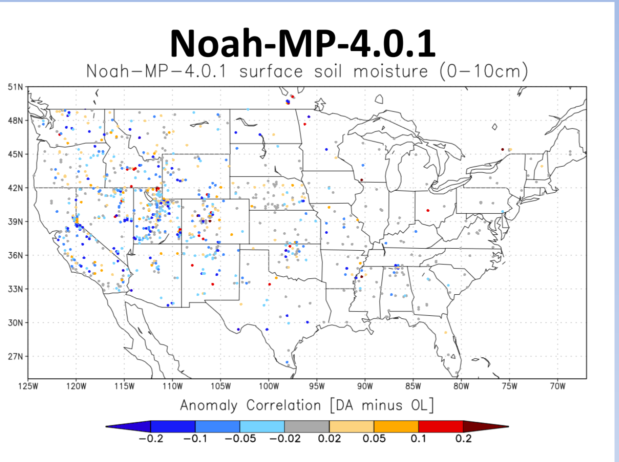
Noah-MP has the highest anomaly correlation (AC) for root zone and 2nd highest for surface SM. Noah has the lowest AC for both layers, while JULES has a higher AC for surface than it does for root zone.

Noah-MP has the lowest unbiased RMSE for both layers, while JULES has a high RMSE for surface. JULES tends to be “wetter when wet” and “drier when dry” as compared to Noah and Noah-MP.

ISMN AC difference (DA minus OL) – CONUS







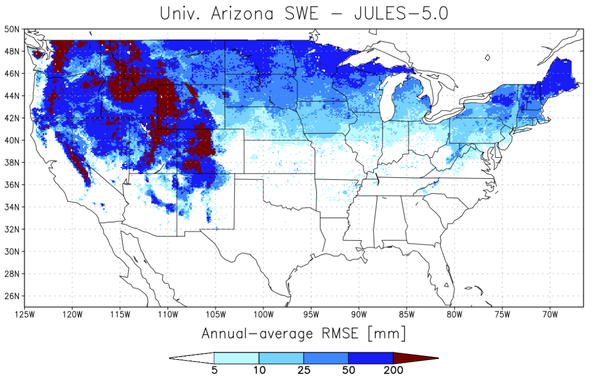
Difference in the anomaly correlation between the DA simulation and OL simulation (both as compared to ISMN for 2009-2021).

Warm colors (from orange to red) show areas where there is improved correlation to ISMN observations from data assimilation.

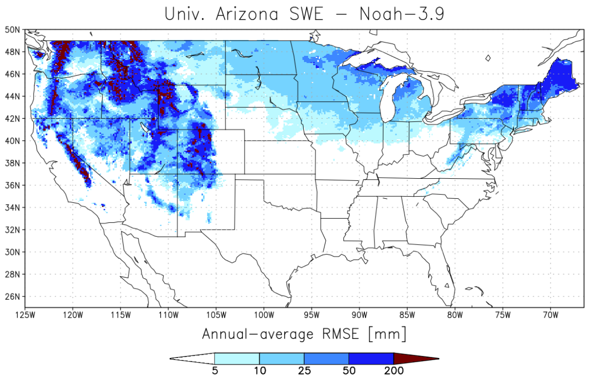
Cool colors (from light blue to dark blue) show areas where the correlation is degraded from data assimilation.

Comparison to SWE from UASNOW

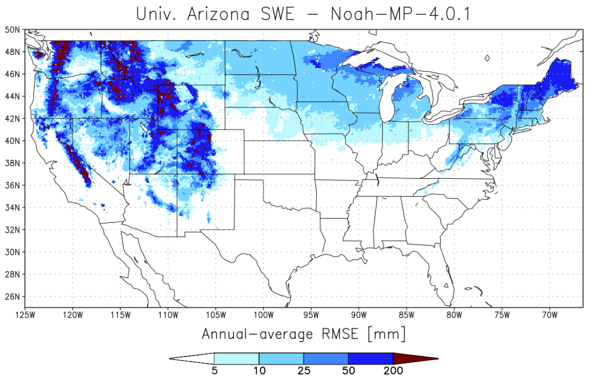
JULES-5.0



Noah-3.9



Noah-MP-4.0.1

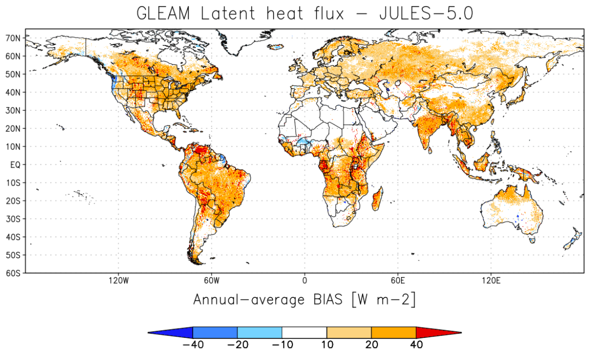


Comparison to the Univ. of Arizona snow analysis for WY2008-WY2020 over CONUS. Noah and Noah-MP have generally similar RMSE patterns, while JULES has higher RMSE of SWE over the intermountain west and over the northern plains.

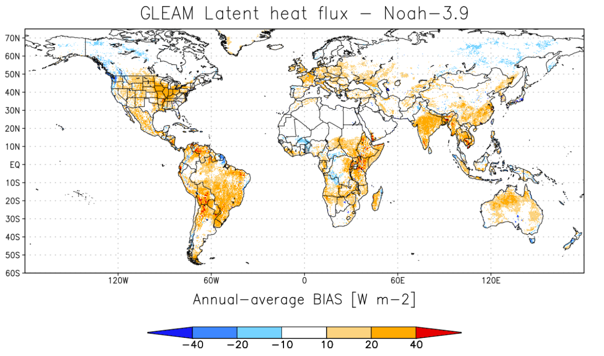
Metric	JULES-5.0	Noah-3.9	Noah-MP-4.0.1
RMSE	46.8 mm	20.1 mm	20.8 mm
Bias	9.1 mm	–7.0 mm	–6.9 mm

Comparison to latent heat flux from GLEAM

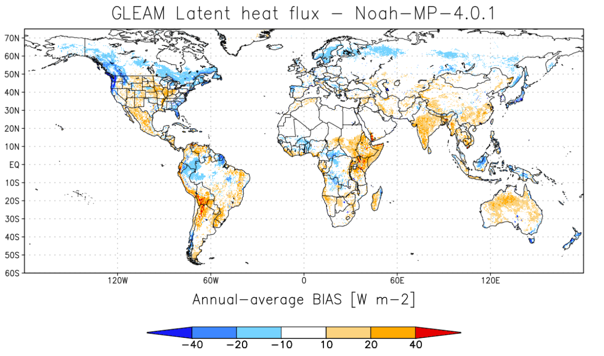
JULES-5.0



Noah-3.9



Noah-MP-4.0.1



Comparison to the GLEAM latent heat flux (LE) for 2009-2021. JULES has higher LE than GLEAM for most areas and has only a few areas where its LE is less than GLEAM. Noah-MP is generally closest to GLEAM LE, while Noah has somewhat higher LE.

Metric	JULES-5.0	Noah-3.9	Noah-MP-4.0.1
RMSE	24.7 W m^{-2}	18.6 W m^{-2}	19.2 W m^{-2}
Bias	8.5 W m^{-2}	4.0 W m^{-2}	1.5 W m^{-2}

Noah-MP-5.0 code integration

- NCAR has released version 5.0 of Noah-MP, with the code completely re-factored (modernized) including detailed in-line and pdf documentation
- NASA/GSFC entered into a strategic partnership with NCAR to integrate this version of Noah-MP into the LIS framework through linking of our Github repositories. This will allow smoother/quicker integration of bug fixes and future Noah-MP versions going forward.
- Other major deliverables of this work (to be completed by 30 June 2024):
  - Benchmarking/testing LIS-Noah-MP results against Noah-MP outside of LIS
  - Evaluate LIS-Noah-MP in global 557 WW domain as well as a regional domain against observations (and Noah-MP-4.0.1) using the Land surface Verification Toolkit (LVT)
  - Investigate/fix cold surface temperature biases in Noah-MP under snow cover

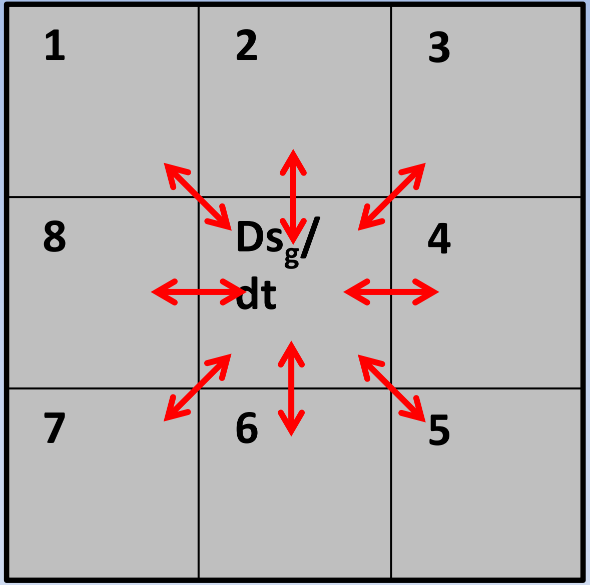
Miguez-Macho and Fan Scheme Overview

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 (Qrf) parameterized with exponential function (*valid at resolutions up to 4-km*)

Extension to Higher Resolutions (with physical channel parameters):

- Based on coupled River Conductivity (RCOND)
- RCOND = length * width * conductivity
- QRF = RCOND * (WTD – RIVERSURFACE) * (dt/area)
- Noah-MP LSM coupled to LIS Hydrological Modeling and Analysis Platform (HyMAP) routing model (Getirana et al. 2017).
- **Preliminary tests show need for new MMF LSM parameters**



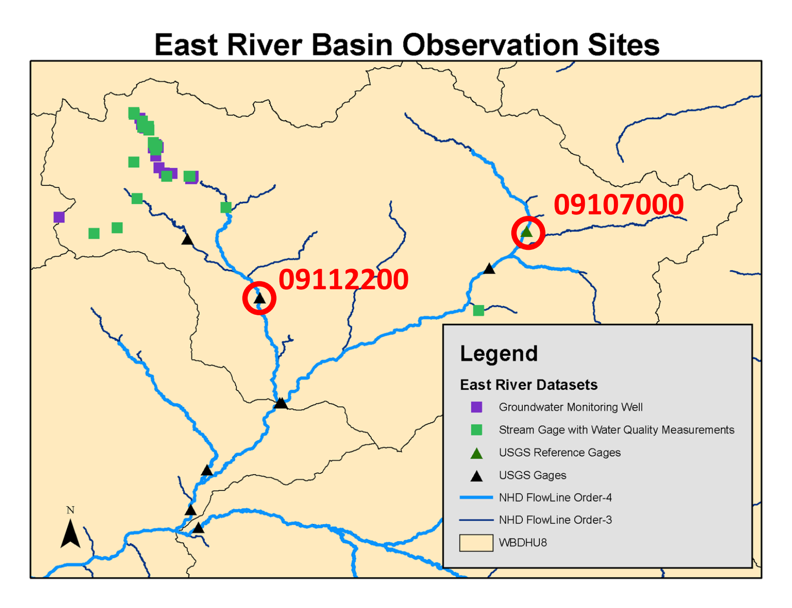
Study area and experimental design

Evaluate LIS Noah-MP v4.0.1 with four configurations:

- **Control:** Noah Original Surface and Sub-surface Shaake et al. (1996)
- **Noah-MP MMF:** Miguez-Macho and Fan et al. (2007) without modifications or additional coupling
- **Noah-MP MMF HyMAP:** Channel exfiltration from LIS-HyMAP (Getirana et al. 2017) parameters
- **LIS-MMF 2-Way Coupling:** Channel exfiltration/infiltration from LIS-HyMAP (Getirana et al. 2017) coupled to MMF groundwater

Model Spin-Up and Evaluation:

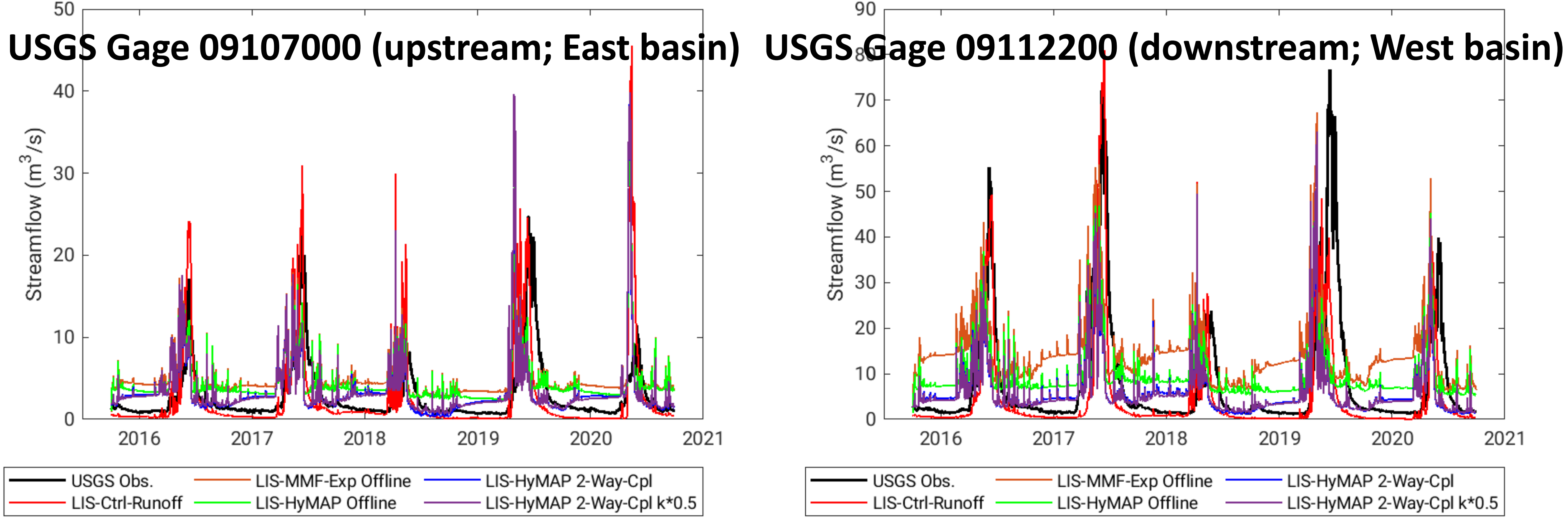
- **NLDAS-2 Atmospheric and Precipitation Forcing**
- Noah-MP LSM w/MMF spin-up with 30 iterations of WY2015 (control 10 iterations); WY2015 consistent with average conditions for East River (Maina et al. 2022)
- Streamflow and groundwater evaluated from WY2016-WY2021



Validation Datasets

- East River Domain
- 748 km^2 Drainage Area
- Tijerina-Kreuzer et al. (2023) study basin
- USGS Gages Available

Impacts of 2-way coupling on streamflow



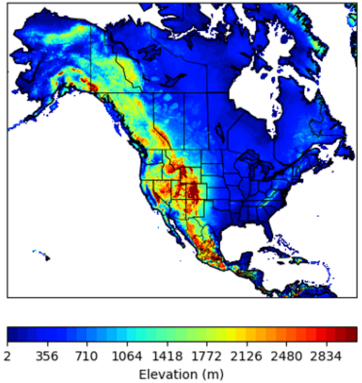
- LIS w/o MMF (red) underestimates baseflow (common Noah-MP issue)
- LIS-MMF original (orange) and LIS-MMF w/HyMAP channels (green) overestimate baseflow
- Baseflow is more realistic with full 2-way coupling (blue), but is still high late in season
- Reducing infiltration parameter (purple) somewhat reduces excess baseflow

NLDAS Phase 3

- NLDAS-3 will use only the Noah-MP-5.0 (or later) LSM with multi-variate land DA:

NLDAS-3 is a fine-scale North American surface meteorological and land-surface model dataset for retrospective and operational applications. NLDAS-3 is essential for drought monitoring, critical to the agricultural sector.

1. NLDAS-3 Domain



- NLDAS-3 covers all North America including Alaska, Hawaii, Puerto Rico and Central America
- NLDAS-3 has a spatial resolution of **1 km** and a temporal resolution of **an hour**

NLDAS-3 aims to accelerate the transition to operations and enhance user and stakeholder engagement

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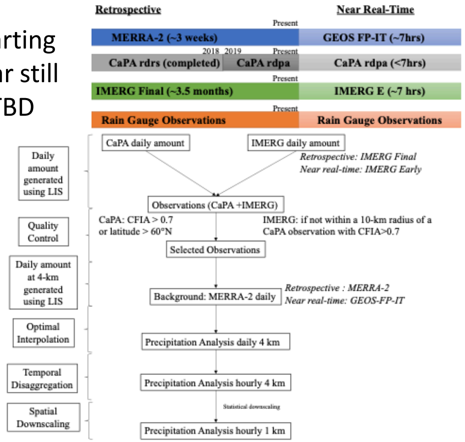
2. NLDAS-3 precipitation

What goes into NLDAS-3 precipitation?

Starting year still TBD



NLDAS-3 uses advanced optimal interpolation techniques to blend well-known and widely used meteorological forcing: **NASA's MERRA-2 and IMERG** and ECCC Canada's CaPA.

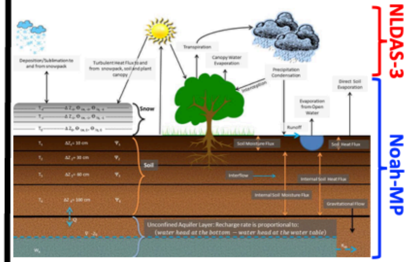
3. NLDAS-3 surface meteorology

MERRA-2 surface meteorology is downscaled to 1km

- Temperature adjustments are performed by using a dynamic lapse rate.
- Surface pressure and longwave down radiation are adjusted using a 1-km surface topography following the NLDAS-2 methodology.
- Shortwave down radiation is downscaled using data from CERES/POWER.
- Winds are adjusted using the MicroMet methodology, which uses values of topographic slope, slope azimuth, and curvature.

4. NLDAS-3 land surface processes

NLDAS-3 enables a high spatiotemporal resolution of land surface processes



Developed within the NASA Land Information System, NLDAS-3 will assimilate remotely-sensed datasets of soil moisture, snow, vegetation, water height, and terrestrial water storage (SMAP, GRACE, MODIS/VIIRS, SWOT) to better constraint land surface processes.

5. NLDAS-3

1. A multinational collaboration

NASA

Environment and Climate Change Canada
Environnement et Changement climatique Canada

2. A multicenter effort

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NASA MSFC Marshall Space Flight Center

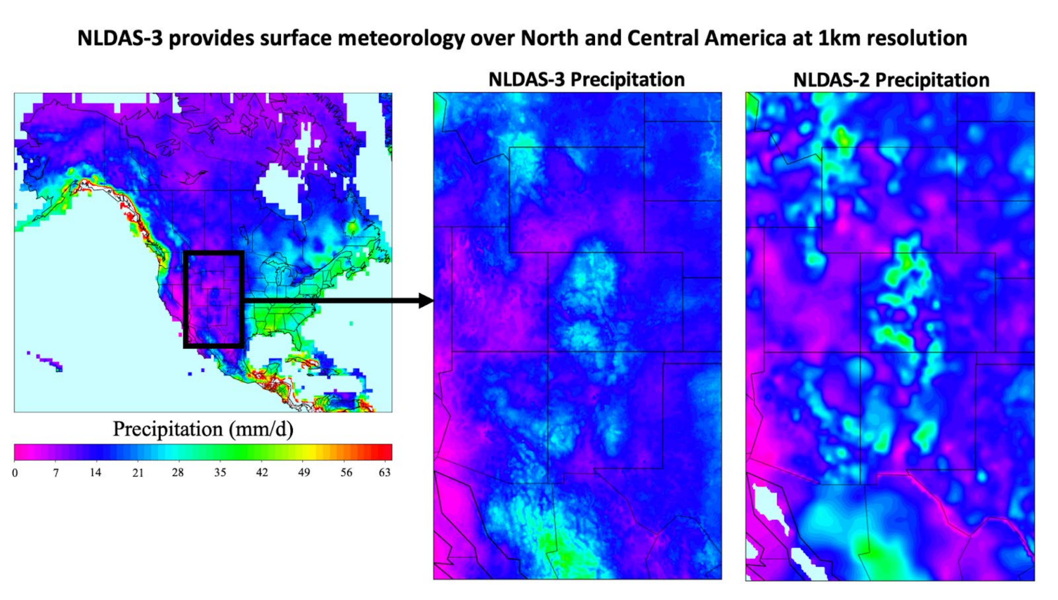
3. Leveraging NASA's investments (AIST)

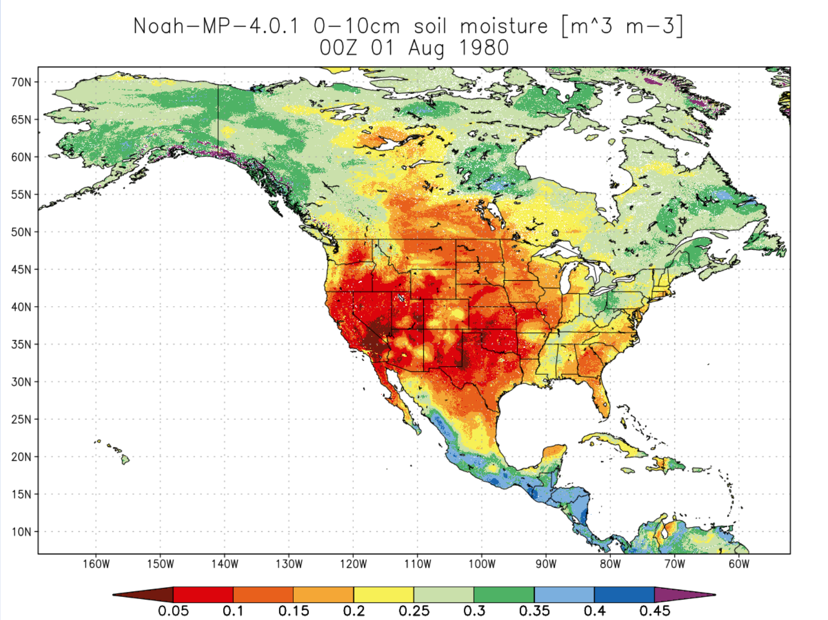
4. An integration of stakeholder requirements and feedbacks

5. A bridge from mature research to operations

NLDAS Phase 3

- NLDAS-3 stakeholder workshop for latest updates, sample data, and community feedback will be held virtually on Monday July 29 from 1:00-3:00pm EDT.
- Please contact me to receive an invitation: David.Mocko@nasa.gov





Summary and take-away messages

- Snow (from SNODEP & USAF-SI) and soil moisture (from ASCAT SMOPS & SMAP) products are assimilated into the LSMs, which were run from Nov 2007 to present.
- Comparisons to in situ soil moisture from ISMN shows that Noah-MP generally has the highest anomaly correlation (AC) and the lowest unbiased RMSE.
- Noah and Noah-MP both perform overall well in simulating SWE over CONUS.
- Noah-MP has the lowest bias of latent heat flux compared to the GLEAM product.
- The NLDAS Phase 3 (NLDAS-3) system is being actively developed, which will have a 1-km grid spacing, including all of North and Central America, including Hawaii, Alaska, and Puerto Rico
- The Miguez-Macho and Fan scheme has been enabled with parallel computation in the LIS system, and being used for groundwater and river channel studies.
- Noah-MP in LIS includes land data assimilation of snow, soil moisture, GRACE, LAI

Websites and references

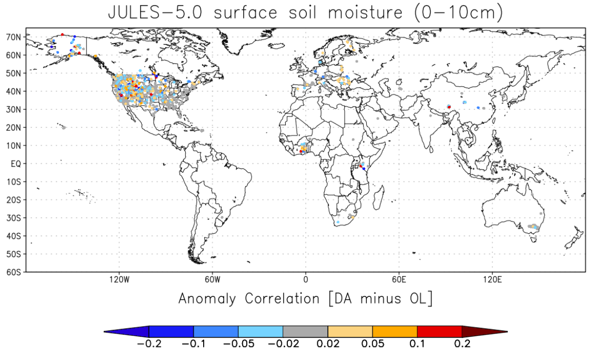
- NAFPA (Kemp et al., 2022): https://doi.org/10.1175/JHM-D-21-0228.1
- USAF-SI (Yoon et al., 2022): https://doi.org/10.1016/j.rse.2022.113080
- LIS website: https://lis.gsfc.nasa.gov/
- LIS (Kumar et al., 2006): https://doi.org/10.1016/j.envsoft.2005.07.004
- LIS (Peters-Lidard et al., 2007): https://doi.org/10.1007/s11334-007-0028-x
- LVT (Kumar et al., 2012): https://doi.org/10.5194/gmd-5-869-2012

Thank you!

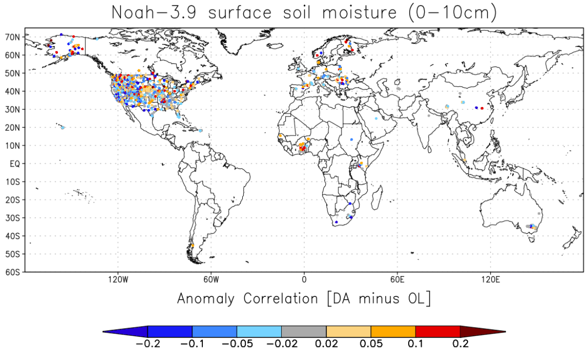
Backup slides

ISMN AC difference (DA minus OL) – Global

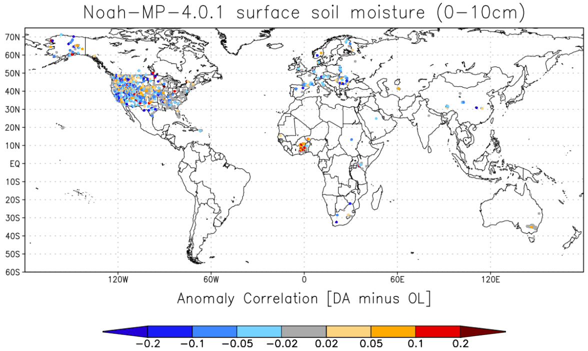
JULES-5.0



Noah-3.9



Noah-MP-4.0.1



Difference in the anomaly correlation between the DA simulation and OL simulation (both as compared to ISMN for 2009-2021).

Warm colors (from orange to red) show areas where there is improved correlation to ISMN observations from data assimilation.

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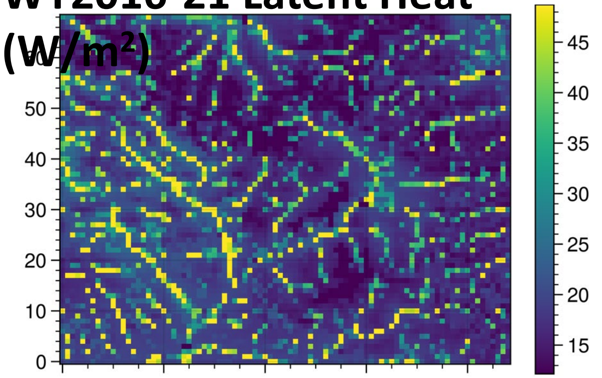
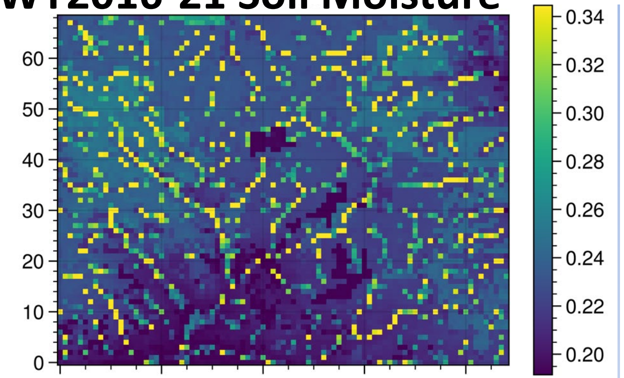
East River MMF vs. Control Runoff (0.01 deg)

LIS-MMF (WY2015-2021)

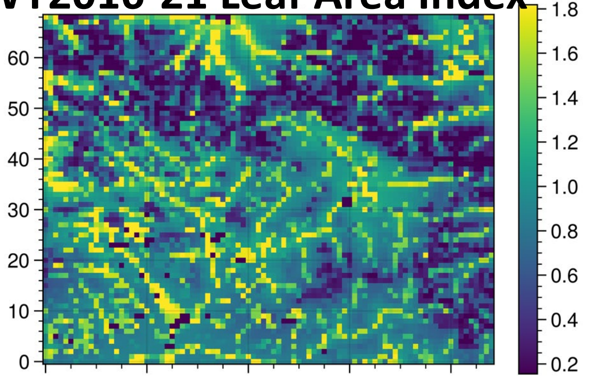
WY2016-21 Latent Heat (W/m²)



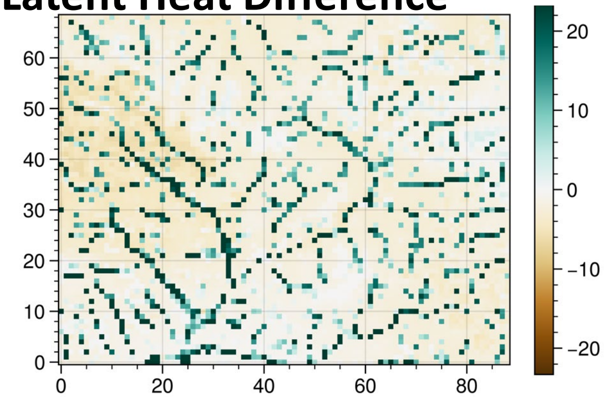
WY2016-21 Soil Moisture



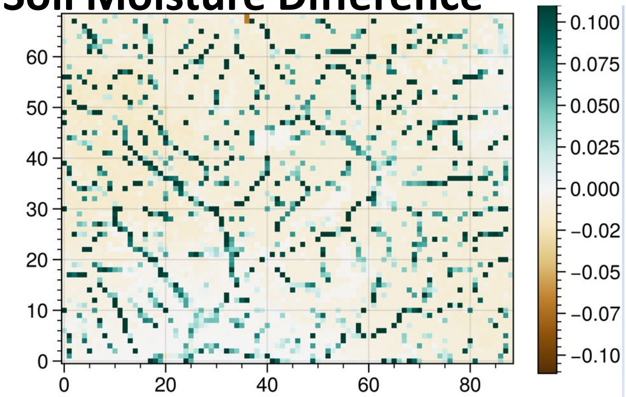
WY2016-21 Leaf Area Index



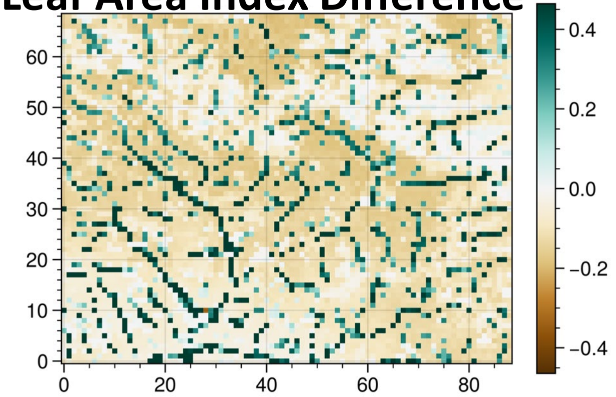
Latent Heat Difference



Soil Moisture Difference



Leaf Area Index Difference

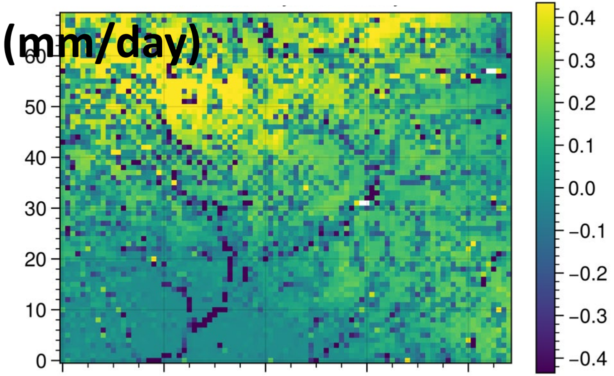


MMF moves water down from hillslopes, resulting in lower soil moisture ET, and vegetation;
soil moisture increases near channels, affecting ET and increasing vegetation

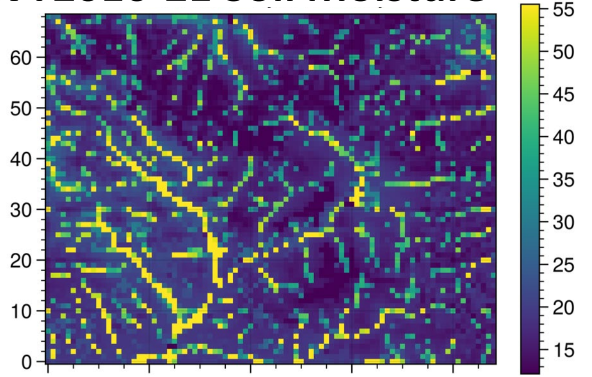
East River MMF; Impact of HyMAP Channels

LIS-MMF w/HyMAP 2-Way Coupling (WY2015-2021)

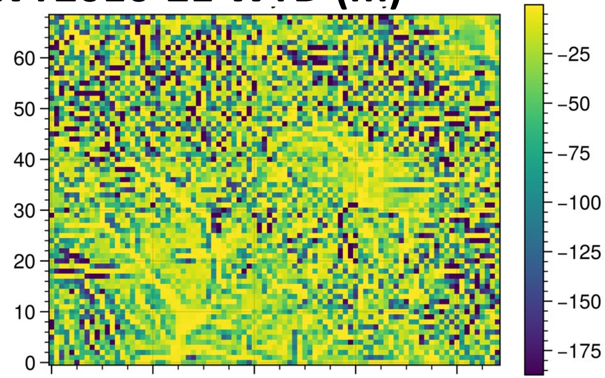
WY2016-21 Exfiltration (mm/day)



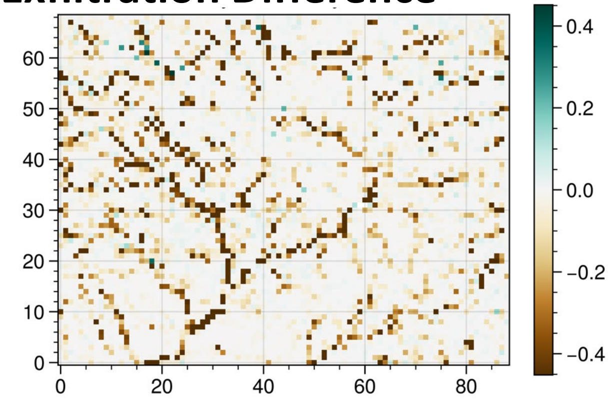
WY2016-21 Soil Moisture



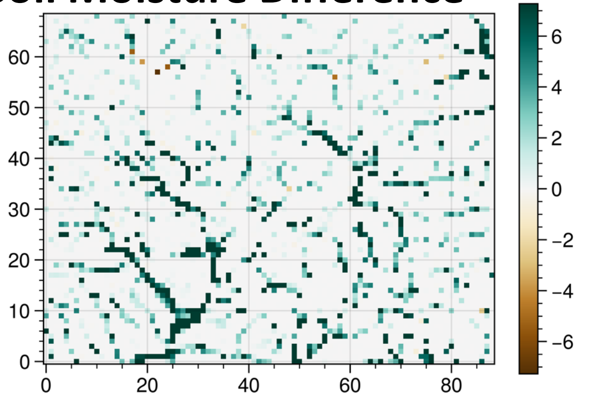
WY2016-21 WTD (m)



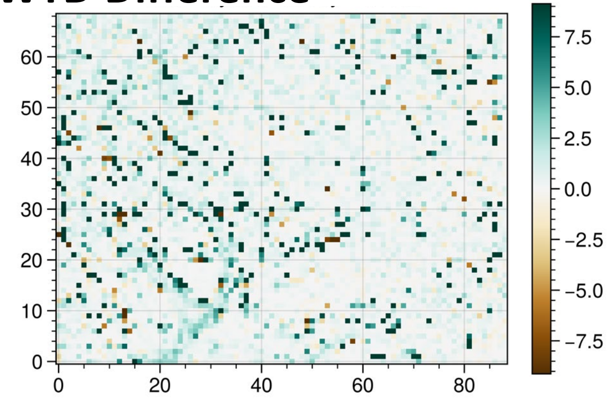
Exfiltration Difference



Soil Moisture Difference



WTD Difference



Exfiltration decreases in most areas, especially near channels (turns negative)

Increased latent heat over most channels

Reduced exfiltration and recharge near channels increases groundwater