Land data assimilation with NASA LIS – Research and operational updates

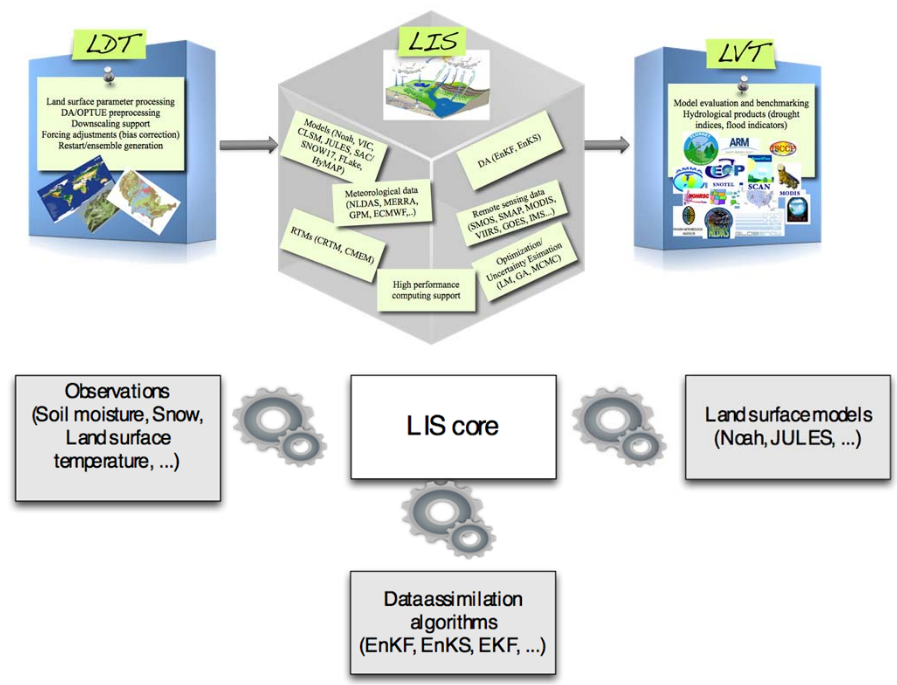
Sujay Kumar

NASA Goddard Space Flight Center, Greenbelt, MD

http://lis.gsfc.nasa.gov

Land Information System (LIS)

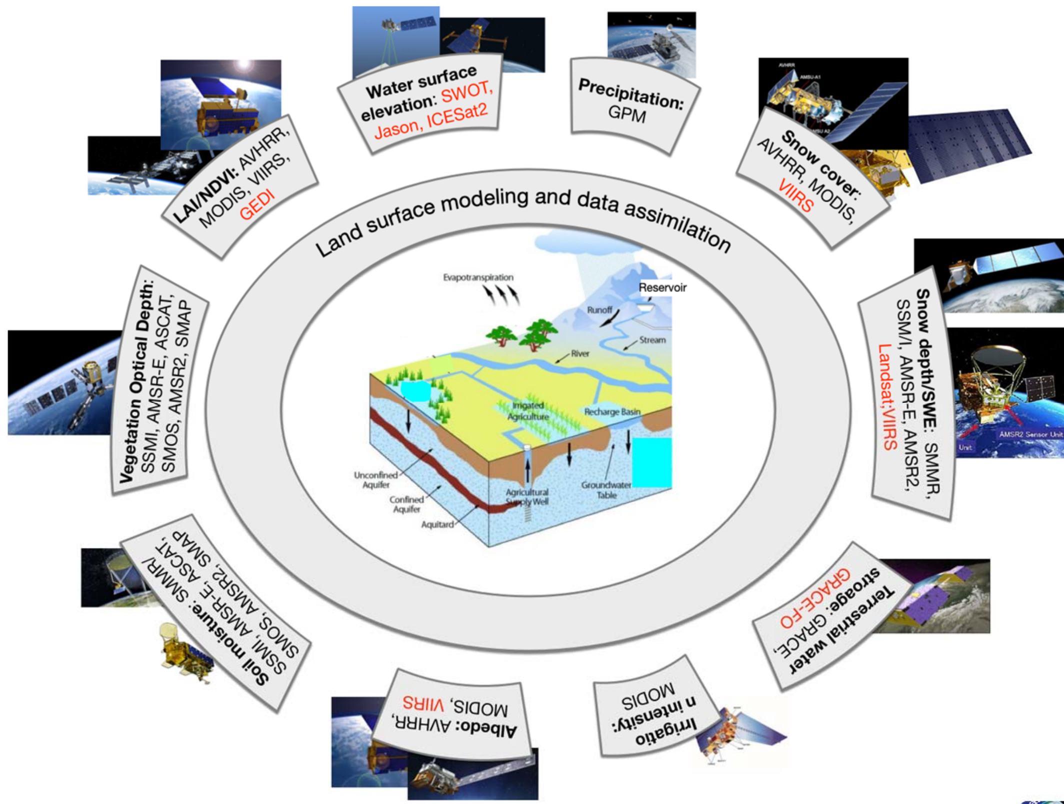
- A system for uncoupled and coupled land modeling and data assimilation
- Runs a variety of land surface models (Noah, Noah-MP, JULES, CLM, VIC, CABLE, …..)
- LIS-DA includes advanced algorithms such as the Ensemble Kalman Filter (EnKF), Ensemble Kalman Smoother (EnKS), built leveraging the NASA GMAO DA infrastructure
- Supports the interoperable use of multiple land surface models, multiple algorithms and multiple observational data sources
- Support for concurrent data assimilation, forward models, radiance assimilation, observation operators.



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.

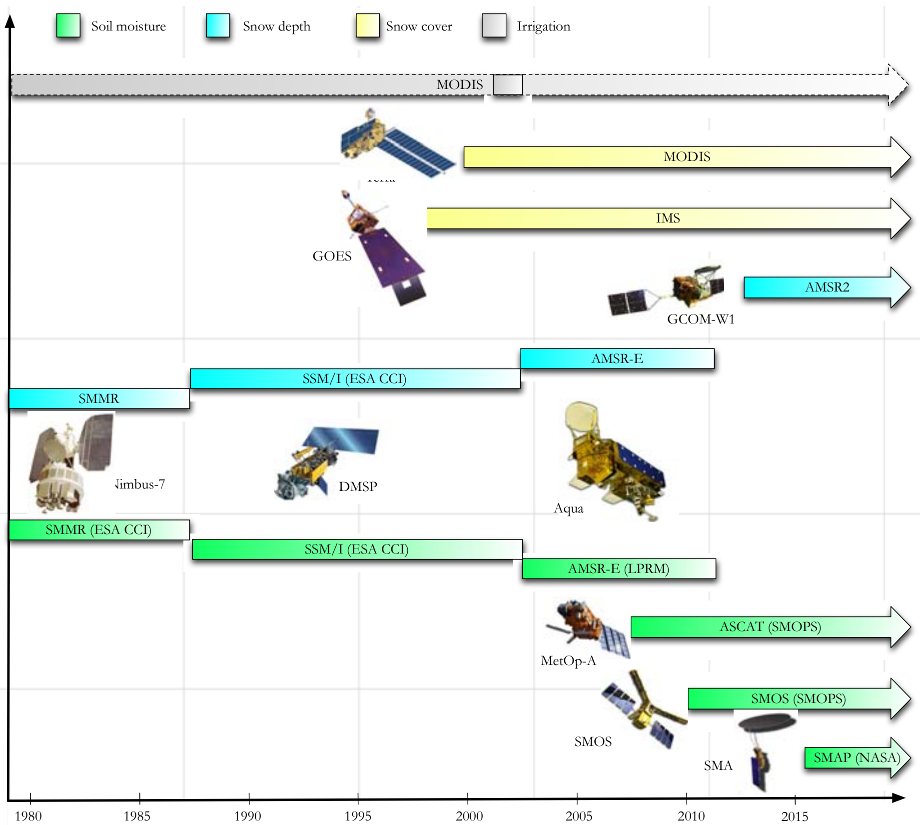
LIS–DA applications

- Supports a large suite of variables and sensors.
- Assimilation is supported across multiple classes of models (LSM, routing, ..)
- Operational/Routine environments:
  - ☑ 557th WW (NWP, hydro, agricultural needs, …)
  - ☑ Famine early warning (FEWSNET)
  - ☑ GLDAS (drought monitoring)
  - ☑ NOAA NCEP (NWP, seasonal forecasting, drought monitoring)
  - ☑ NASA SPoRT (NWP, Flood forecasting)

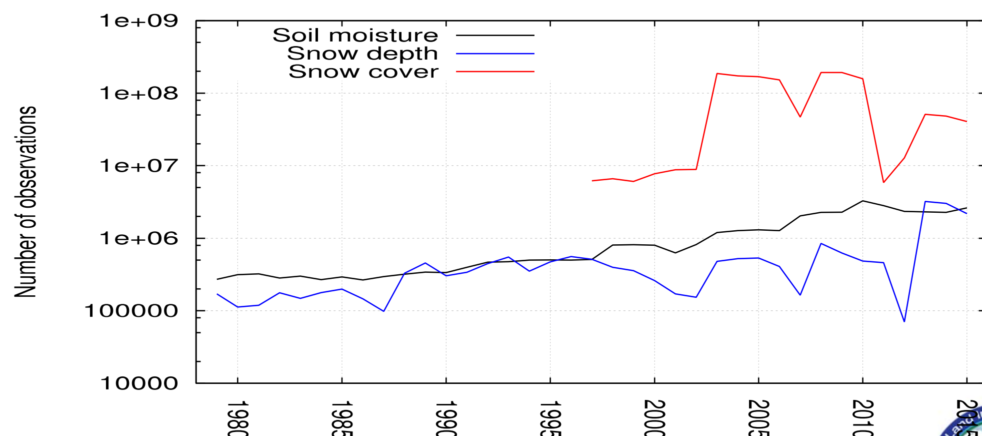


Kumar, S.V., R.H. Reichle, C.D. Peters-Lidard, R.D. Koster, X. Zhan, W.T. Crow, J.B. Eylander, P.R. Houser (2008), A Land Surface Data Assimilation Framework using the Land Information System: Description and Applications, *Adv. Wat. Res.*, 31, 1419-1432.

Multivariate land data assimilation with LIS



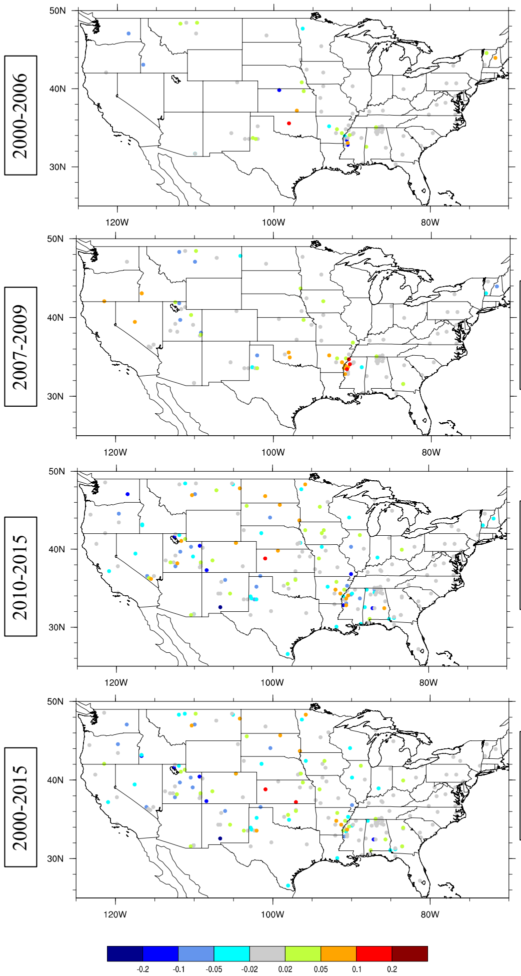
- Concurrent data assimilation capabilities of LIS has been employed to generate a first of its kind, multivariate land analysis for the National Climate Assessment (NCA), over the continental U.S.
- Assimilates passive microwave soil moisture, snow depth, optical snow cover, irrigation intensity retrievals from multiple sensors over the last 30+ years (1979-present)



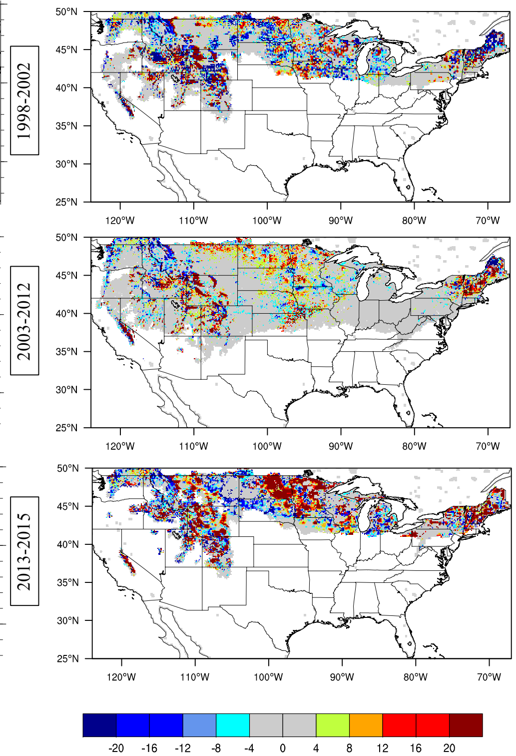
Kumar et al. (2018) : NCA-LDAS land analysis: Development and performance of a multisensor, multivariate land data assimilation system for the National Climate Assessment, J. Hydromet. *In press.*

Multivariate land data assimilation

Improvements in soil moisture anomaly R

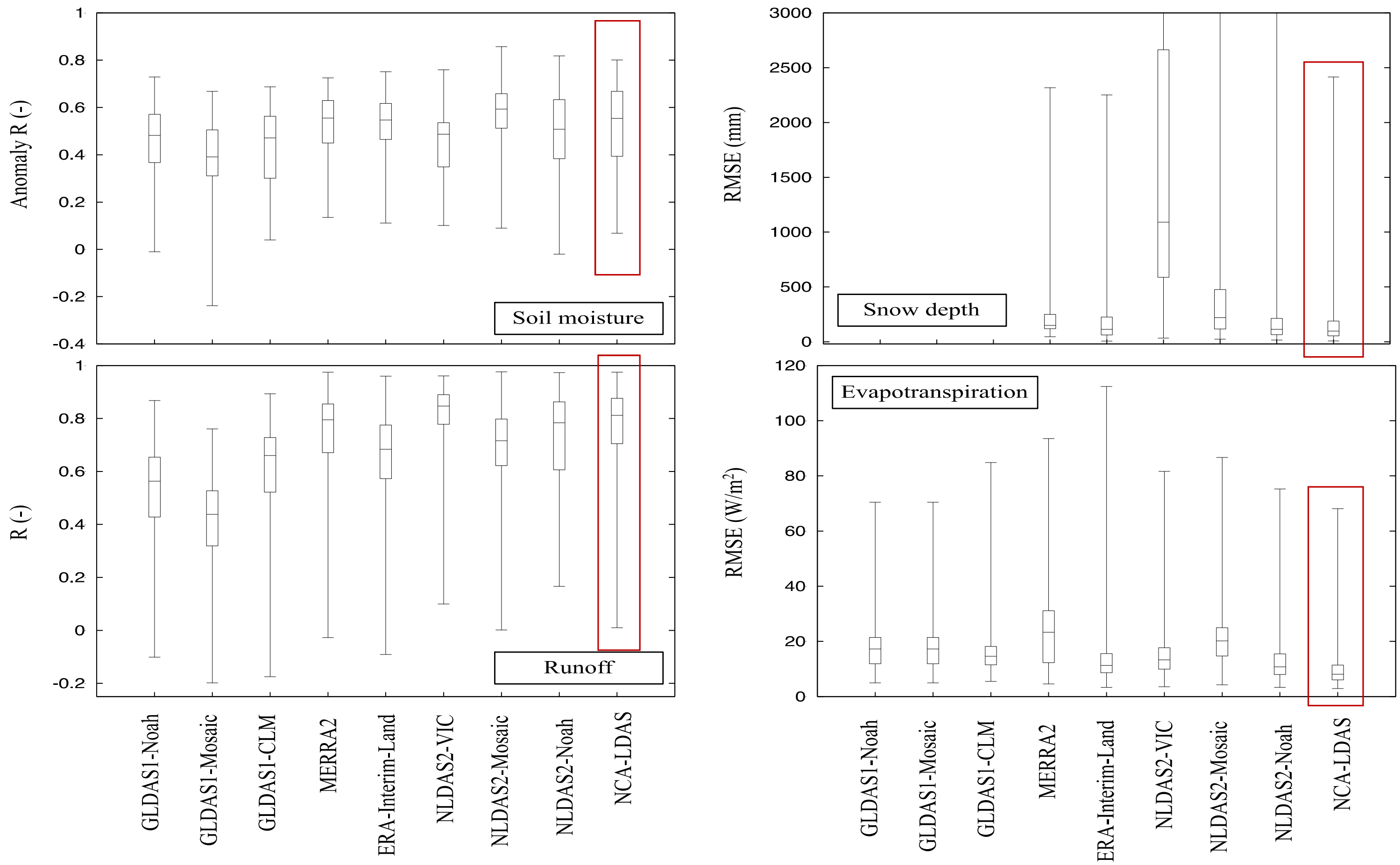


Improvements in snow depth RMSE



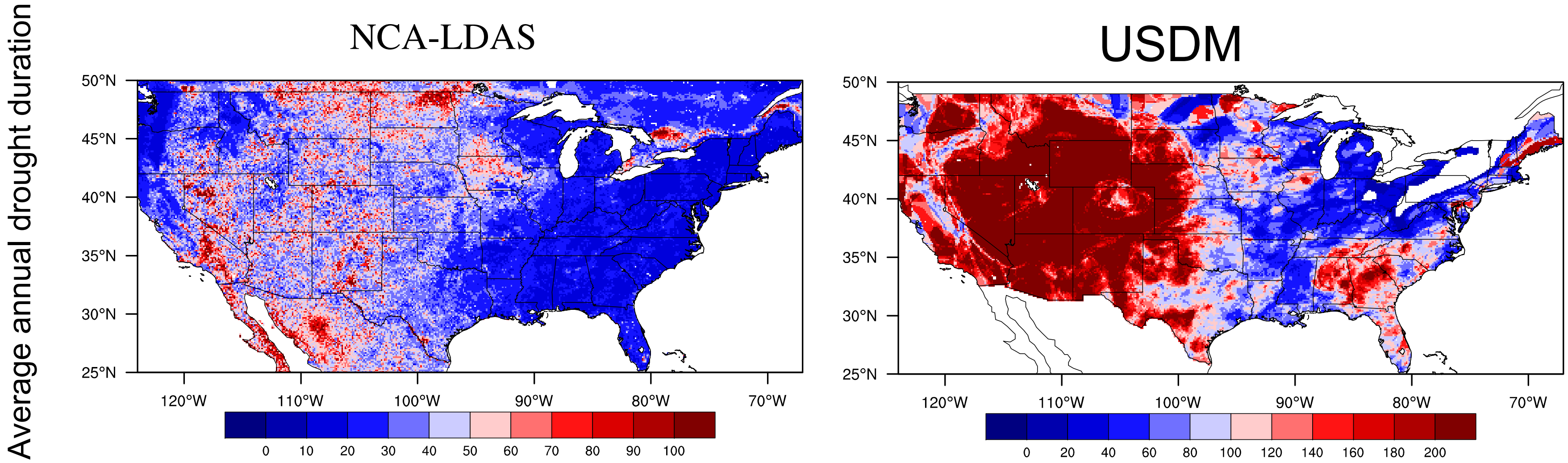
- Improvements from multivariate DA are observed in all water budget components (soil moisture, snow depth, ET, runoff)
- More significant improvements with the use of more modern sensors
- Challenges remain (e.g. over western U.S. with more complex topography)

Multivariate land data assimilation



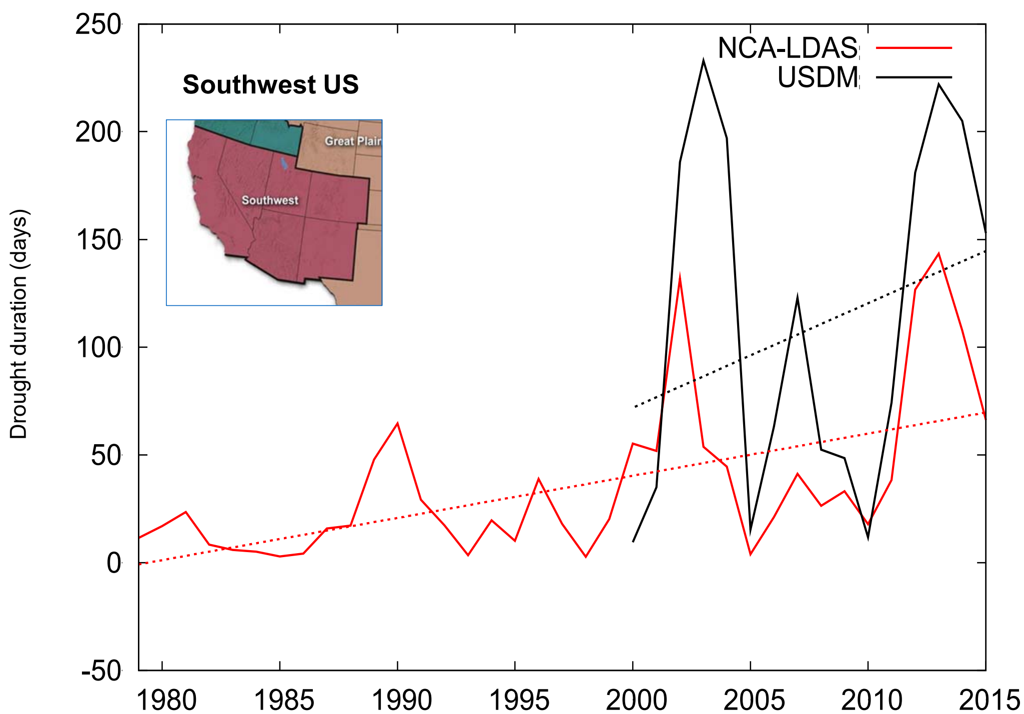
- NCA-LDAS provides consistently high skills for all water budget components, likely due to the observational constraints through data assimilation

Impact of land DA on hydrologic extremes (drought)



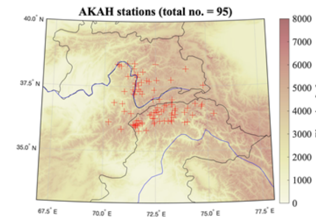
- A general contrast between the eastern and western U.S. with more severe and long lasting droughts occurring in the western U.S.
- The comparison is qualitative; USDM is a subjective blend of many different datasets, only reports drought categories whereas the NCA-LDAS estimates are based on continuous percentile values.

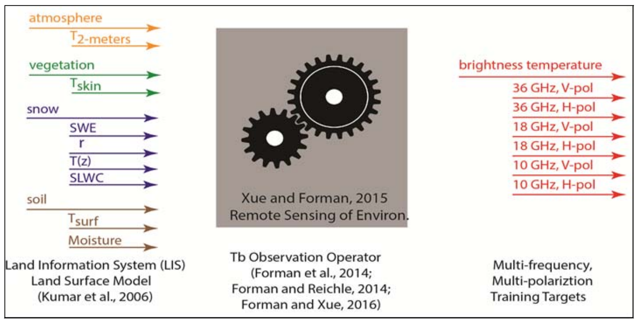
Trends in drought annual duration/severity



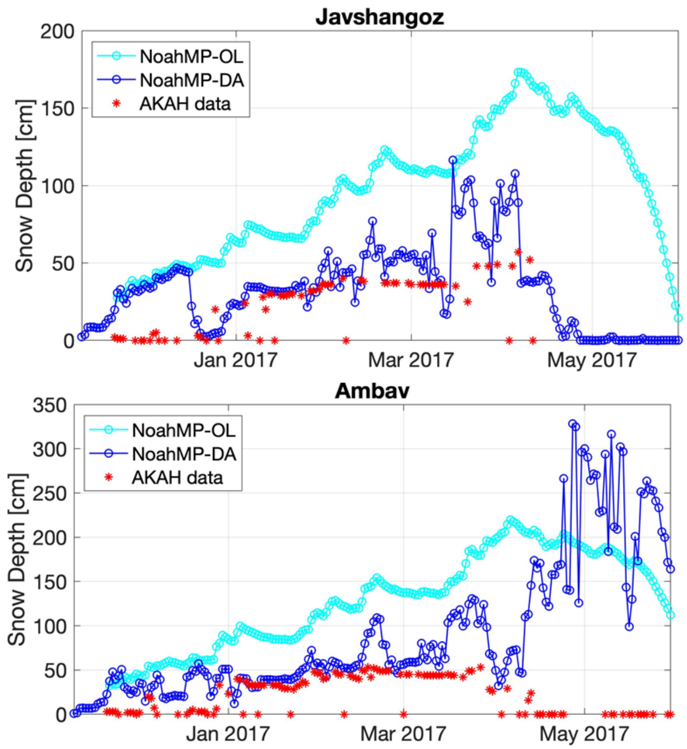
- Root zone soil moisture based drought indicators based on the NCA-LDAS demonstrate an increasing trend in average annual drought duration over the Southwest U.S., consistent with the patterns from the US Drought Monitor.
- The slope of the trendlines is highest over the Southwest region, followed by Northwest and Southeast
- USDM data is based on a shorter record, based on categorical drought estimates

Assimilation of passive microwave dTB assimilation with machine learning





A support vector machine-based forward operator was developed by training to microwave brightness temperature differences in 10, 18, 36, 89 GHz



DA performs best during ablation/dry season likely due to better sensitivity to SWE and less contribution from the presence of liquid water

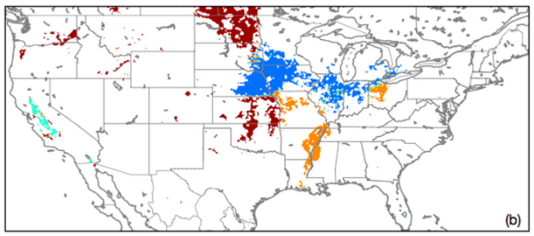
Machine learning-based observation operators lose sensitivity and controllability during deep and/or wet snow conditions. Discrimination of such instances would provide valuable input for DA

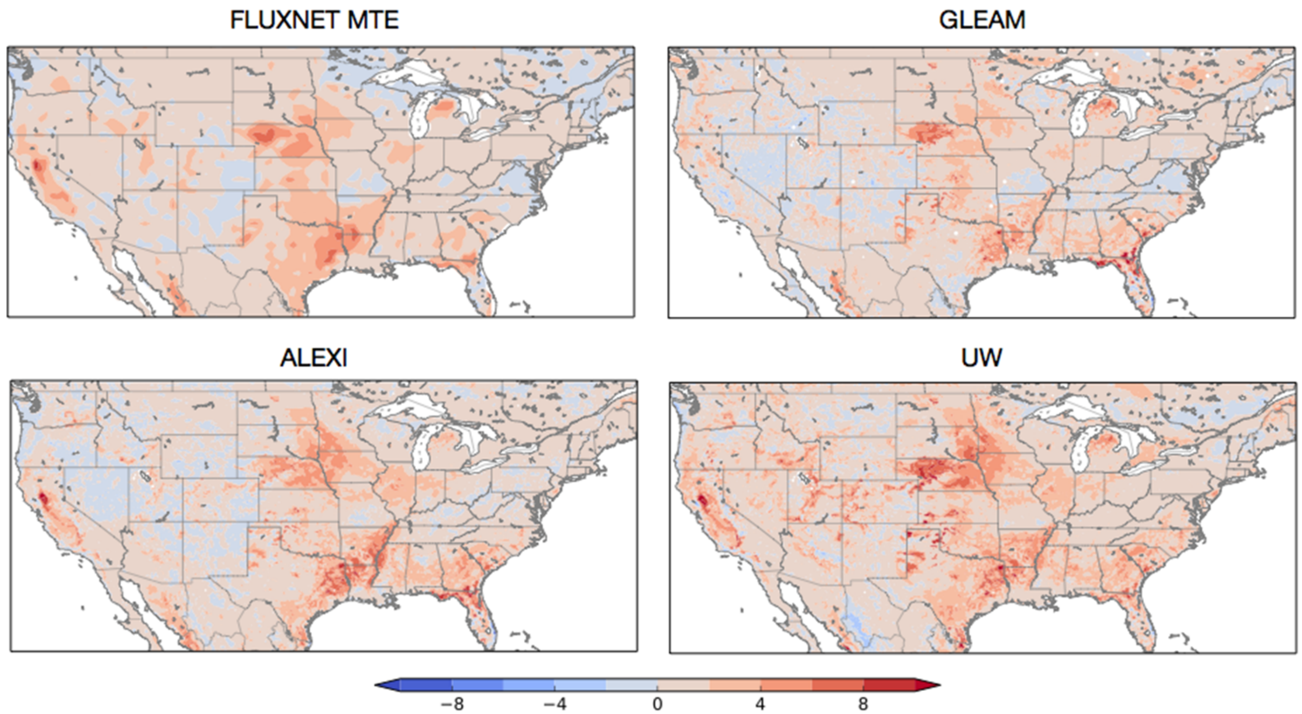
Kwon, Y., B.A. Forman, J. Ahmad, S.V. Kumar, Y. Yoon : Pitfalls and perils of machine-learning passive microwave brightness temperature data assimilation over terrestrial snow in High Mountain Asia, *Frontiers Earth Sci.. In review.*

Assimilation of Leaf Area Index (LAI)

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

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

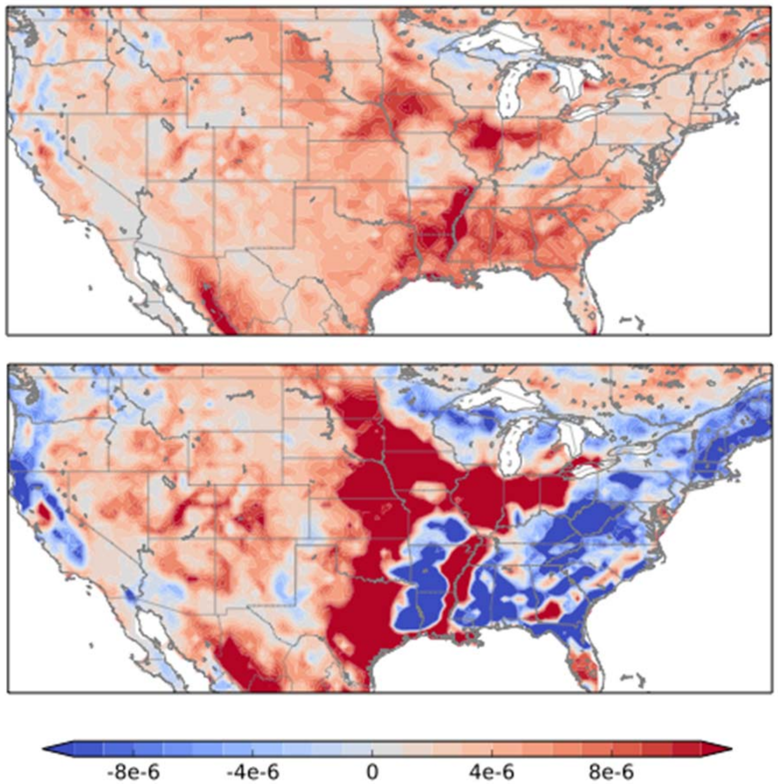




- Systematic and consistent improvements over the Central Plains, lower Mississippi, central California valley. Larger improvements are over agricultural areas of maize and soybean

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. Hydrometeorology*, 10.1175/JHM-D-18-0237.1

LAI assimilation impacts on carbon fluxes

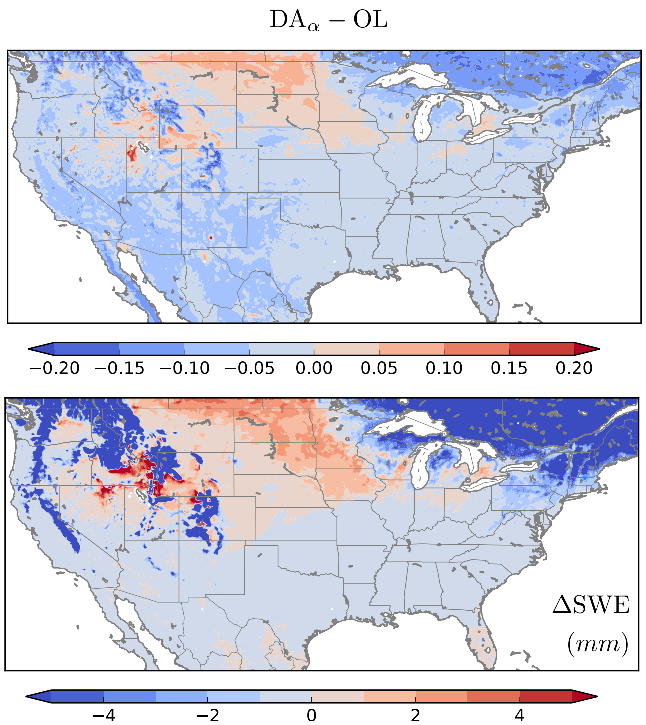


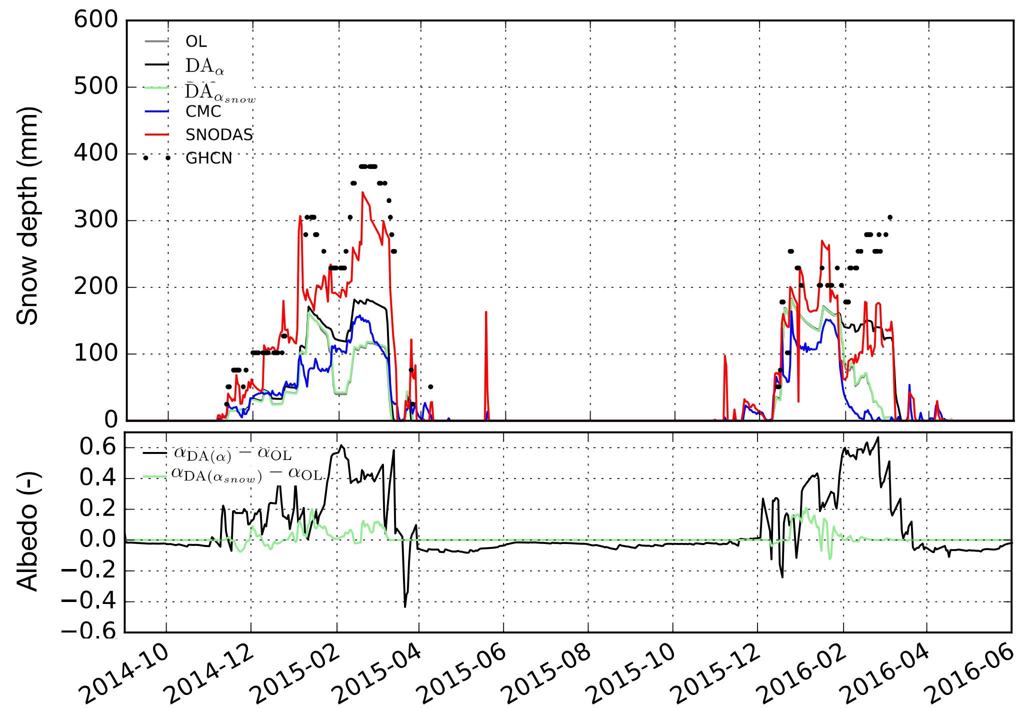
Strong improvements in GPP over agricultural areas

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

Assimilation of remotely sensed albedo

Black-sky and white-sky albedo and snow albedo estimates from MODIS was assimilated into the Noah-MP land surface model during 2000-2018





- Albedo influences the available net radiation, snow melt, runoff and evaporation
- Increase in albedo leads to increase in SWE and better agreement with observations

Kumar, S.V., D. Mocko, C. Vuyovich, C.D. Peters-Lidard (2019), Impact of surface and snow albedo assimilation on terrestrial water budget and snow estimation, *in review*

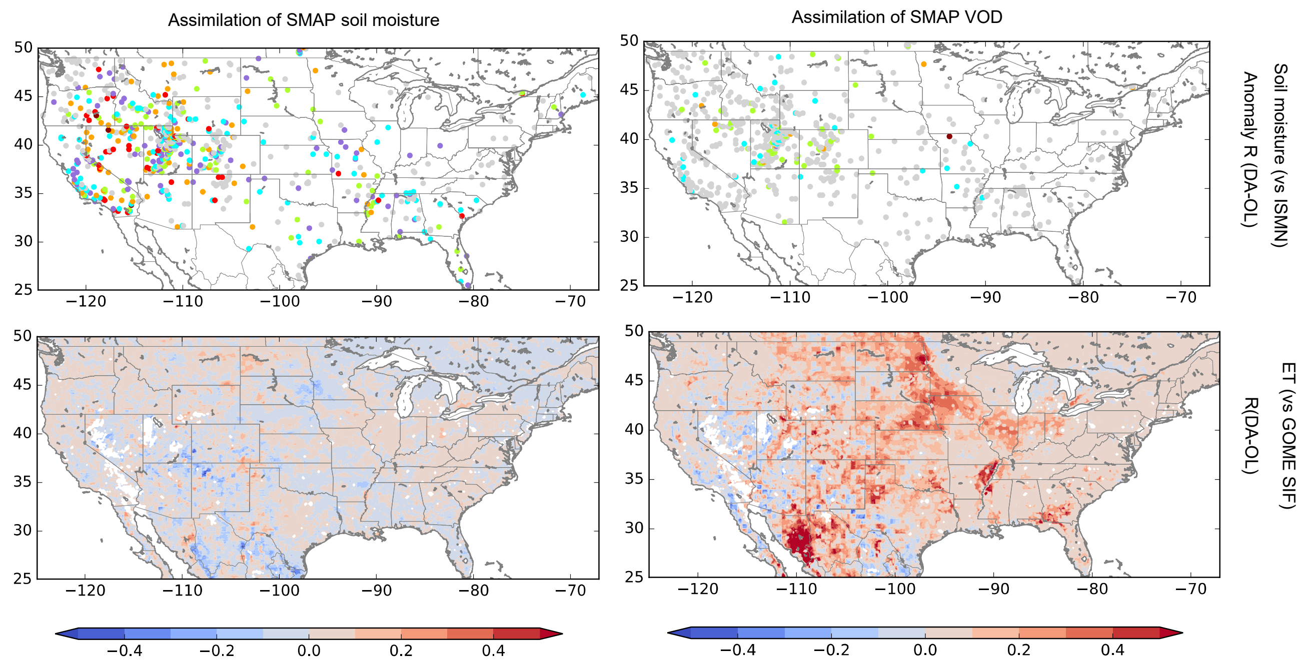
Assimilation of Vegetation Optical Depth (VOD)

VOD describes the vegetation attenuation of the passive microwave signal. It is directly related to the water content of the vegetation. VOD retrievals from X, C and L-band (SMAP) was assimilated into Noah-MP

VOD from microwave radiometry provides an all-weather capability for vegetation sensing

Stronger improvements (and degradations) in soil moisture and streamflow from soil moisture DA

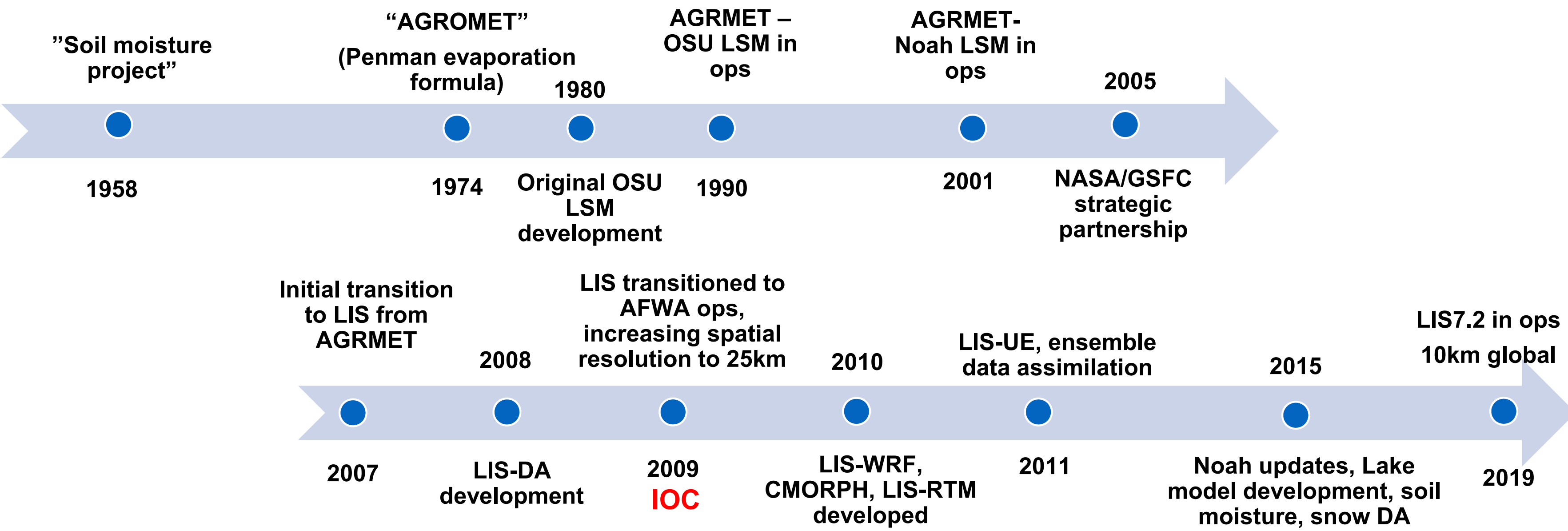
More impacts (particularly over agricultural areas) from SMAP VOD assimilation



Kumar, S.V., et al. (2019), Assimilation of vegetation optical depth retrievals from passive microwave radiometry, *in prep.*

Land Characterization at the U.S. Air Force 557th Weather Wing

- 557 WW (DoD's Executive Agent for Land Information) provide routine geospatial intelligence information to war-fighters, planners, and decision makers at all echelons and services of the U.S. military, government and intelligence community.
- 557th Weather Wing (557 WW) and its predecessors have been home to the DoD's ***only*** operational regional and global land data analysis systems (GLDAS) ***since January 1958***.



Operational DA updates at 557WW
LIS7.2 configuration (to be operational in the summer of 2019)

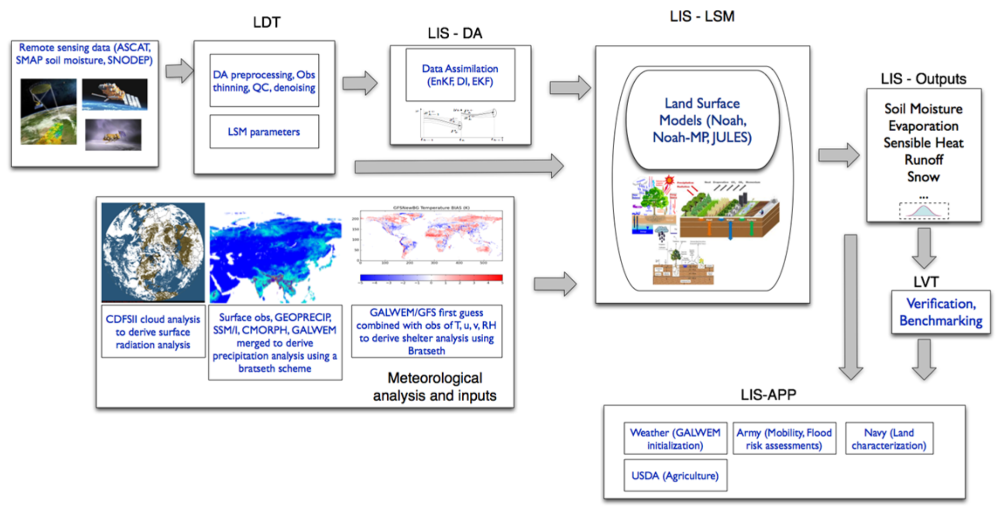
An observation-based precipitation product generated through a Bratseth analysis

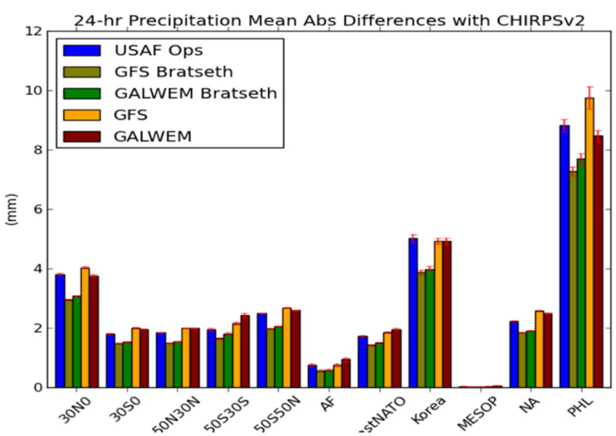
Uses GALWEM precipitation as the first guess and then assimilates CMORPH, SSMIS, GEOPRECIP and rain gauge data.

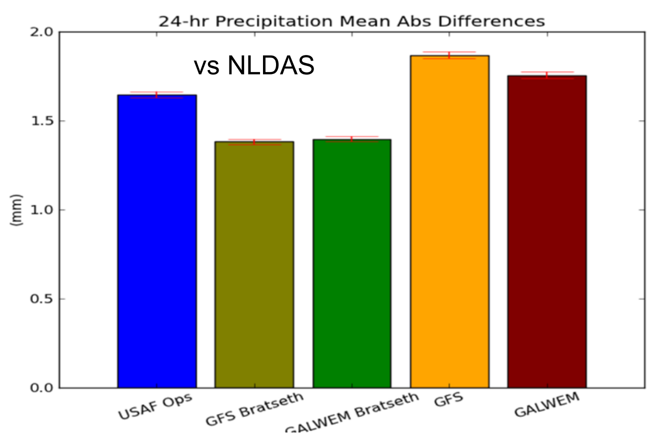
Assimilates ~1.74 million observations in 3 wall clock minutes

Extended support for satellite DA (assimilation of SMAP SM from JPL, ASCAT Metop- A/B SM from SMOPS, SNODEP snow analysis) using Ensemble Kalman Filter

Fully global at 10km resolution





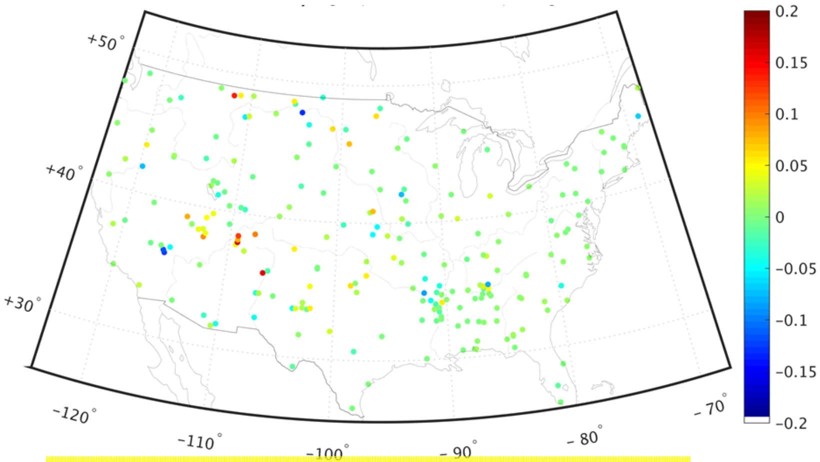


Best results using GALWEM background data; Comparable quality to NLDAS, as verified from (indirect) evaluation of soil moisture

Operational DA updates at 557WW: Assimilation of SMAP data in JULES

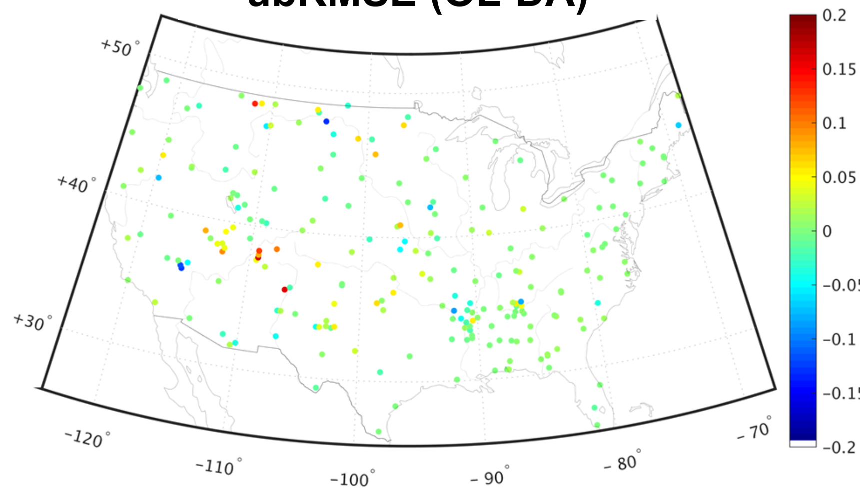
Surface soil moisture retrievals from SMAP were assimilated into JULES in the 557WW configuration (2015-2017)
Evaluated against USDA ARS, SCAN and USCRN station data

Anomaly R (DA – OL)



Improved: 63.8%; Degraded: 36.2%

ubRMSE (OL-DA)

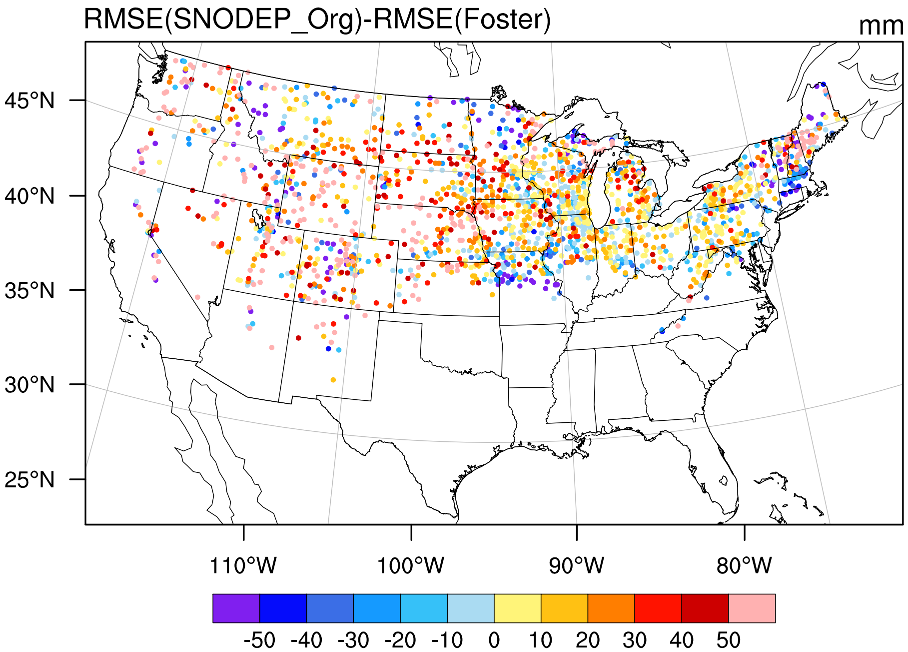


Improved: 75.4%; Degraded: 24.6%

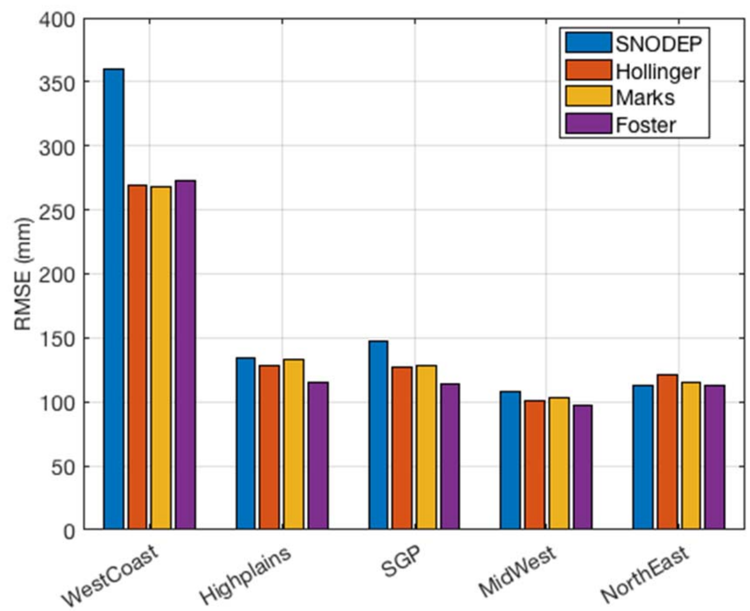
Statistically significant improvements in soil moisture over most parts of the domain (improved anomaly R and reduced ubRMSE)

Operational DA updates at 557WW: New snow analysis

A new 557WW snow analysis is being developed, replacing the SNODEP product. Major changes include updates … nding of gauge data is performed with the Bratseth approach.

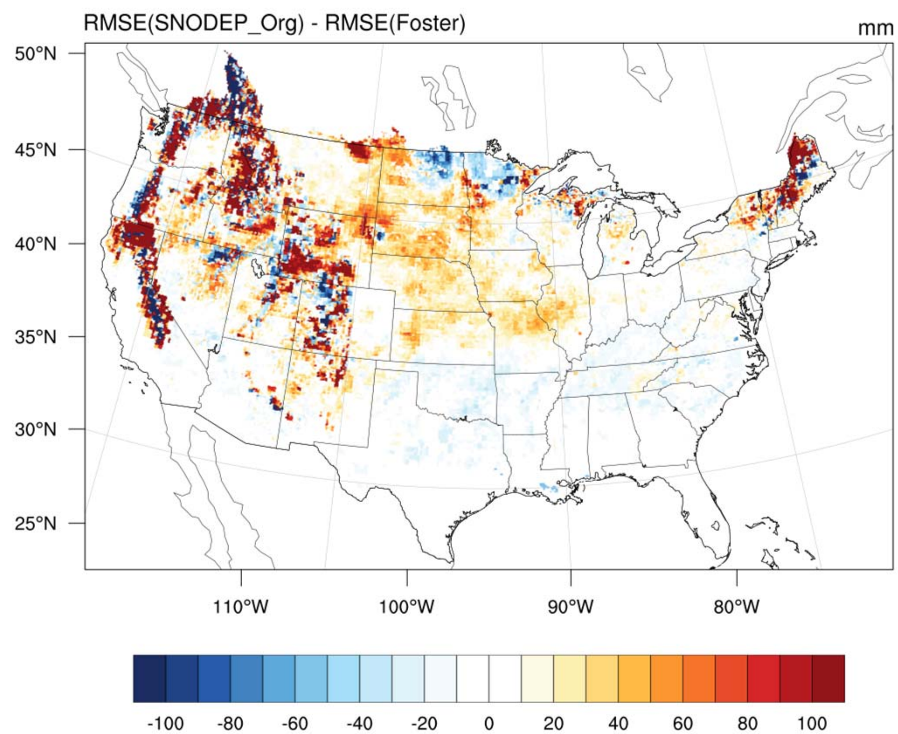


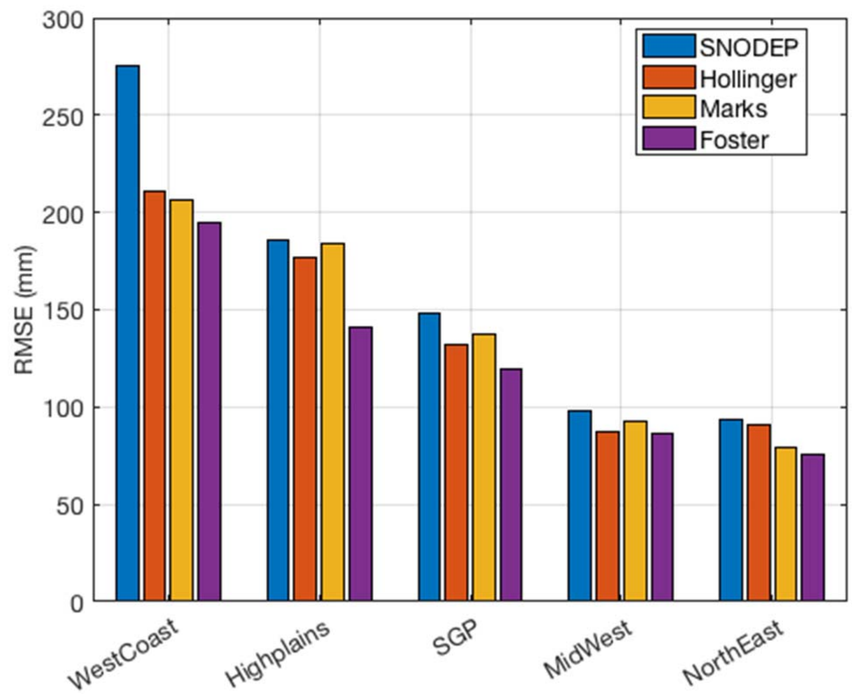
16.8% improvement during the winter of 2018 (using GHCN data as the reference)



More improvements with newer algorithms and the Bratseth analysis

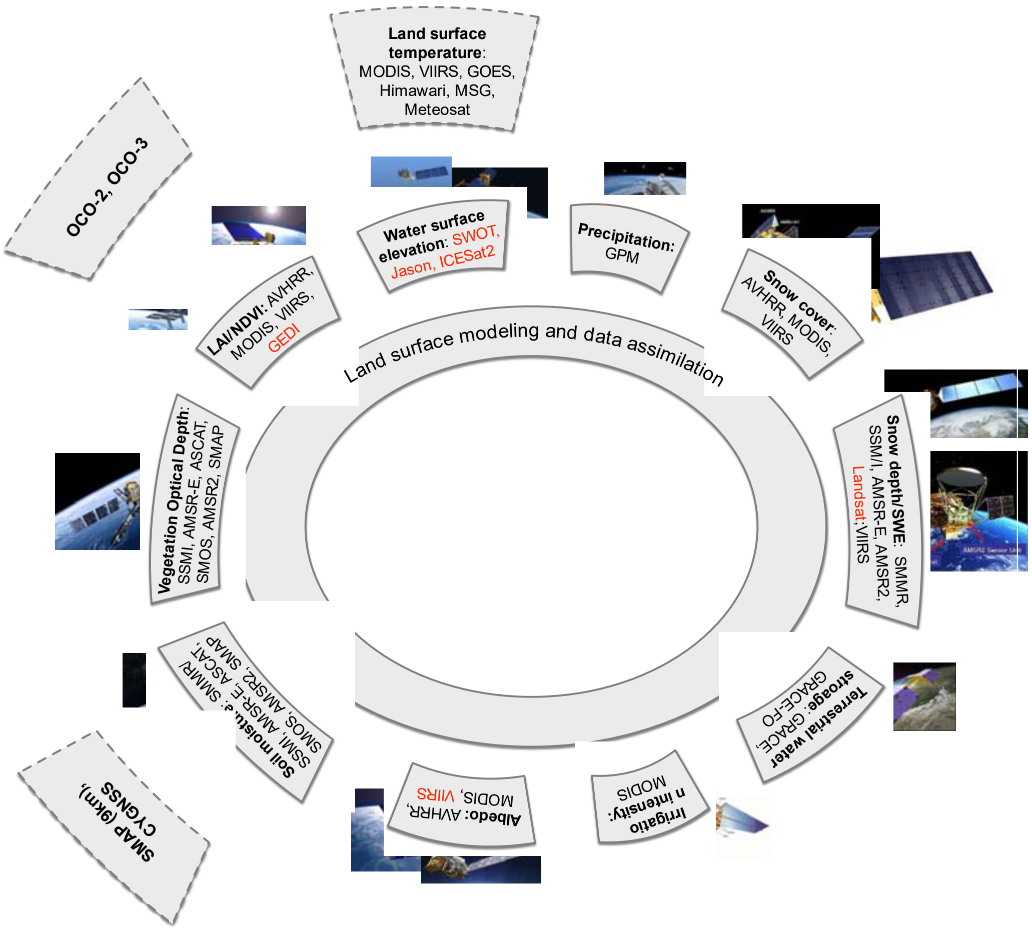
Operational DA updates at 557WW:
Evaluation of the new snow analysis vs SNODAS





More improvements with newer algorithms and the Bratseth analysis

LIS-DA near-term plans



- LIS repository is now on github (https://github.com/NASA-LIS/LISF) and accessible to the community.
- Extending LDA to support DA of time averaged solutions; support for particle Filters;
- Use of additional data from newer sensors (GEDI, SWOT, CYGNSS, SWOT, ICEsat2)
- Use of new (operational) data products (SMAP 9km), blended SMAP-Sentinel, SMAP-SMOS products
- Development of machine learning-based forward operators for assimilating radiances (support vector machine, deep learning)

- JEDI - no LDA capabilities currently exist
- LIS will target the use of UFO within JEDI
- Concerns – top down design, I/O reliant DA infrastructure