First International Surface Working Group (ISWG)

LIS-based operational land data assimilation at the 557th weather wing

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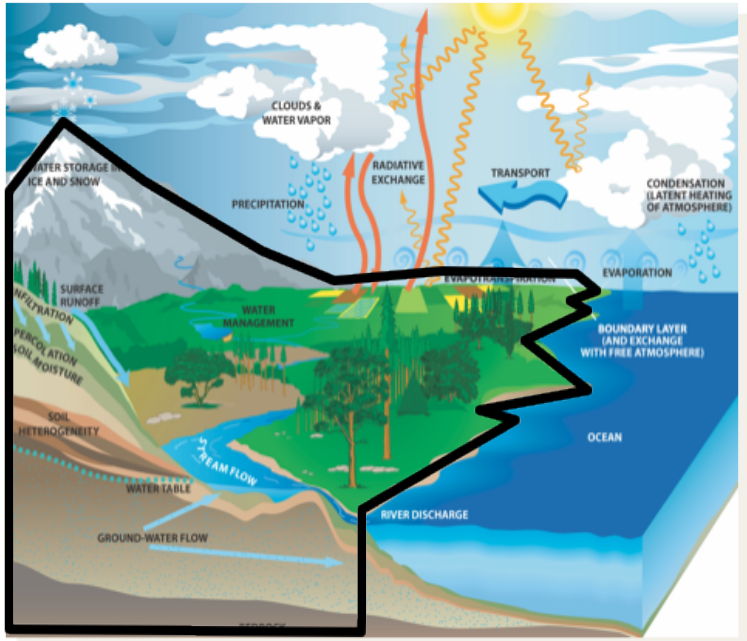
Outline

- Introduction
- Operational land modeling at 557
- Current status
- Planned enhancements
- Summary

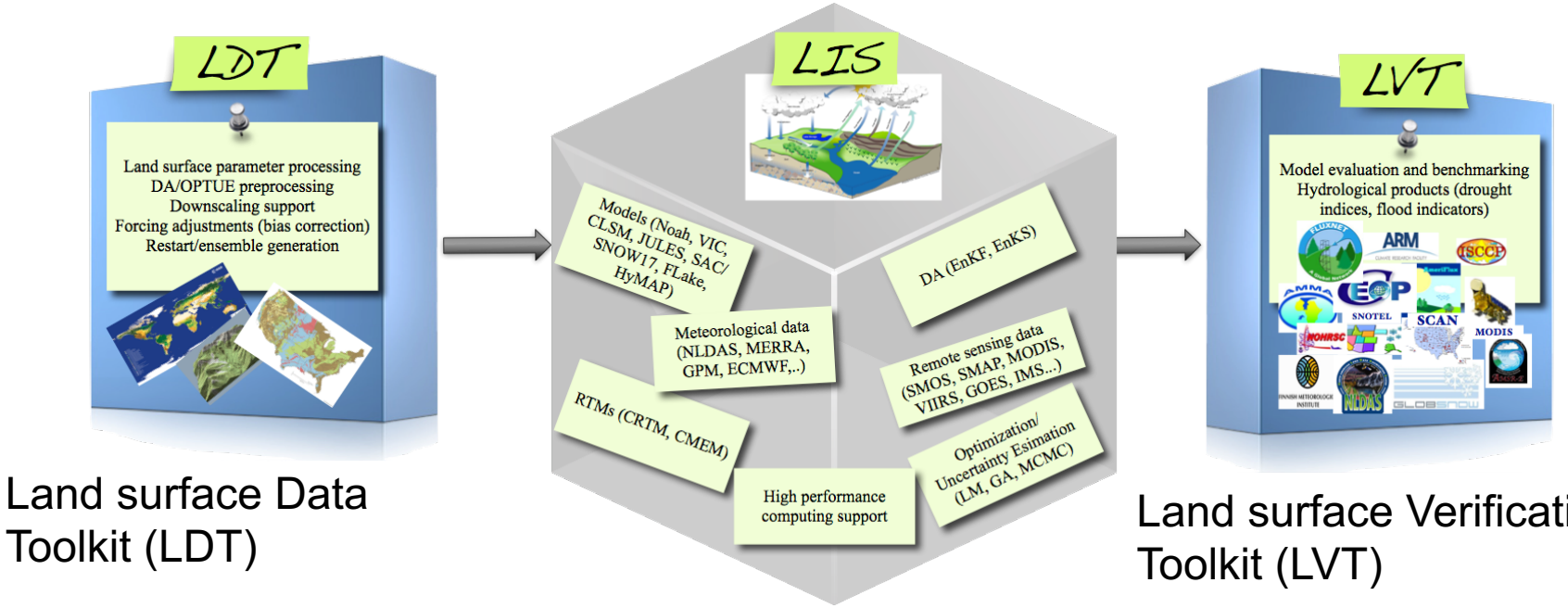
Land Information System (LIS)

- A system for uncoupled and coupled land modeling and data assimilation
- Runs a variety of land surface models (Noah, Noah-MP, SPoRT, CLM, VIC, CABLE, JULES, …..)
- Integrates satellite, ground and reanalysis data
- Includes high performance support for fine resolution and ensemble modeling
- Built as a flexible framework that allows the interoperable use of data and models
- Can be coupled to other Earth system models (through ESMF)
- Includes a number of computational subsystems for exploiting information from observations (DA, Optimization/Uncertainty Estimate).



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.

The NASA Land Information System (LIS) modeling suite



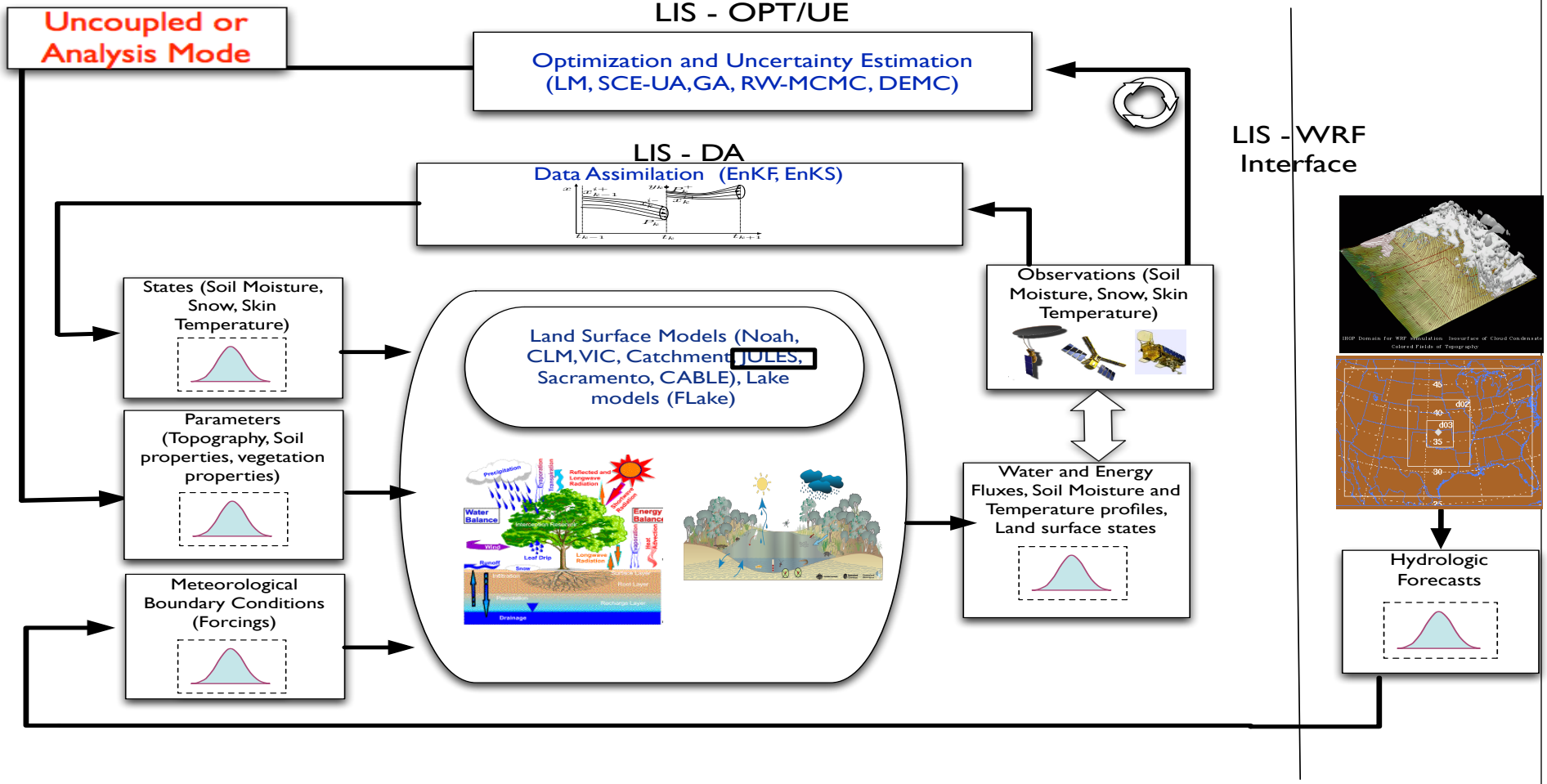
Land surface Data Toolkit (LDT)

Land Information System (LIS)

Land surface Verification Toolkit (LVT)

- LIS – the modeling and data assimilation framework
- LDT - supports the data preprocessing needs for LIS (parameter data processing, data assimilation support, forcing bias correction, …)
- LVT - environment for postprocessing, model benchmarking and evaluation.

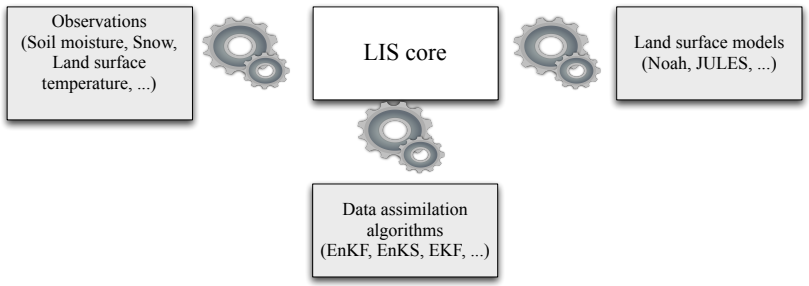
Computational subsystems and coupled models with LIS



Kumar, S.V., C.D. Peters-Lidard, J.L. Eastman, W.-K. Tao (2007), An integrated High Resolution Hydrometeorological Modeling Testbed using LIS and WRF, *Environmental Modeling and Software*, 23(2), 169-181.

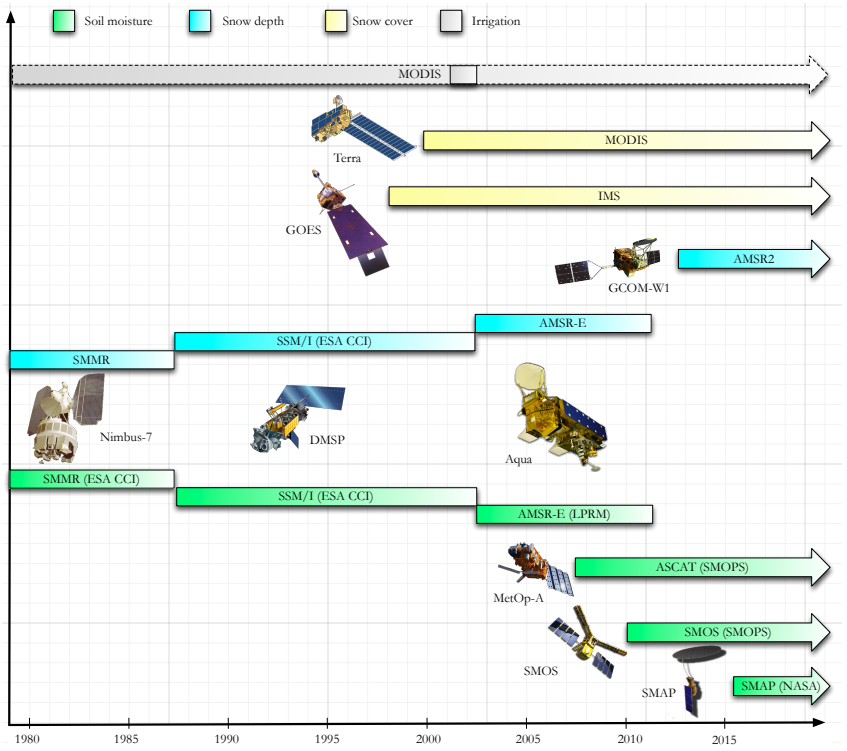
Data Assimilation subsystem in LIS

- Primarily used for state estimation - Corrects model states based on observations
- Advanced algorithms such as the Ensemble Kalman Filter (EnKF), Ensemble Kalman Smoother (EnKS) (originally developed based on the the NASA GMAO 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 employing advanced data fusion methods (deep learning)

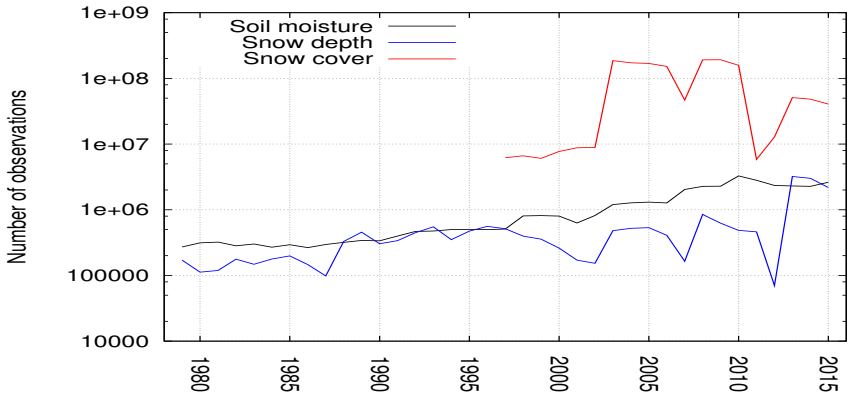


Kumar, S.V., R.H. Reichle, C.D. Peters-Lidard, R.D. Koster, X. Zhan, W.T. Crow, J.B. Eylander, P.R. Houser (2008), A Land Surface Data Assimilation Framework using the Land Information System: Description and Applications, *Adv. Wat. Res.*, 31, 1419-1432.

Multivariate land data assimilation



- Assimilates passive microwave soil moisture, snow depth, optical snow cover, irrigation intensity retrievals from multiple sensors over the last 30+ years (1979-present)



- 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.

- 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)

Kumar et al. (2017) : NCA-LDAS land analysis: Development and performance of a multisensor, multivariate land data assimilation system for the National Climate Assessment, J. Hydromet. *In review.*

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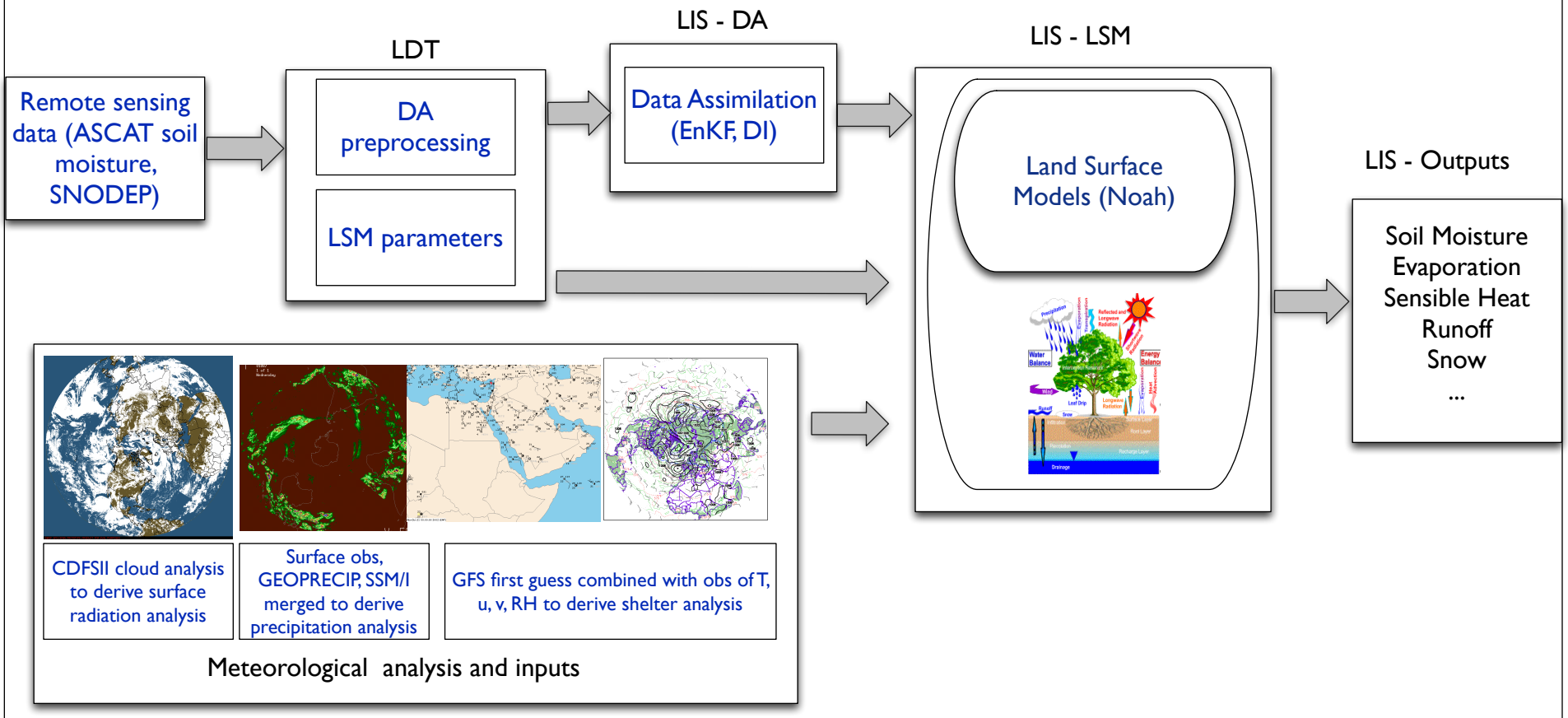
Current LIS-based AGRMET environment



- JULES and Noah-MP added to LIS
- SNODEP DA is currently done with direct insertion

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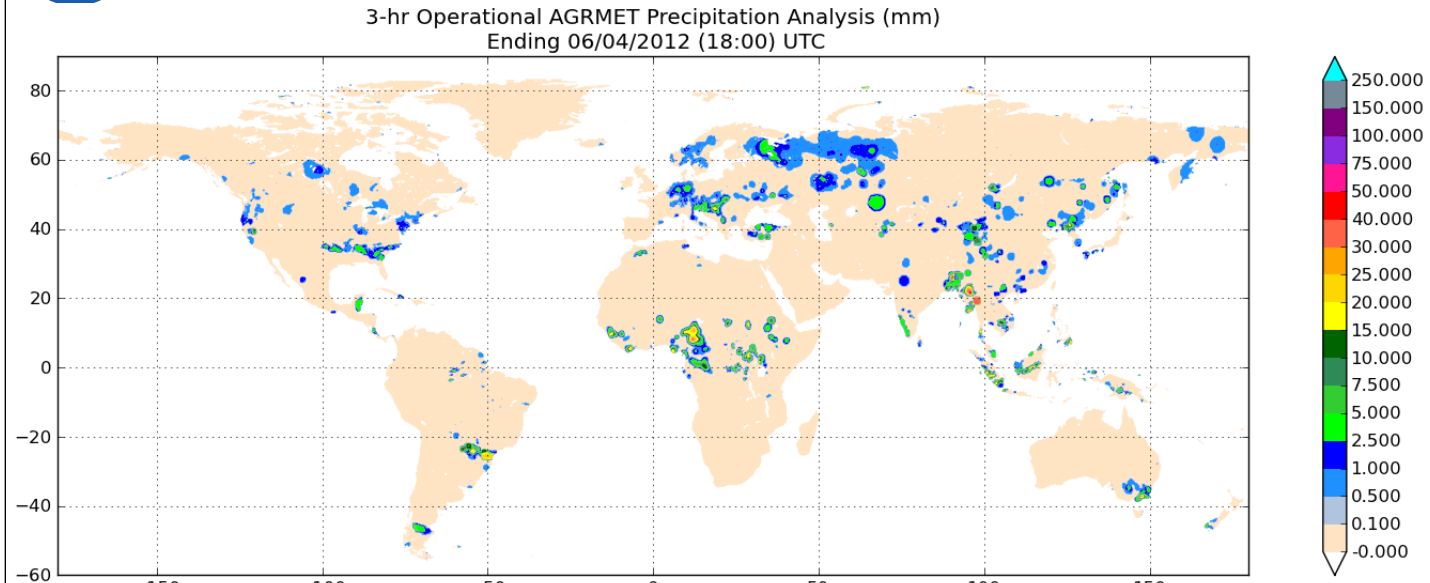
Updating precipitation analysis

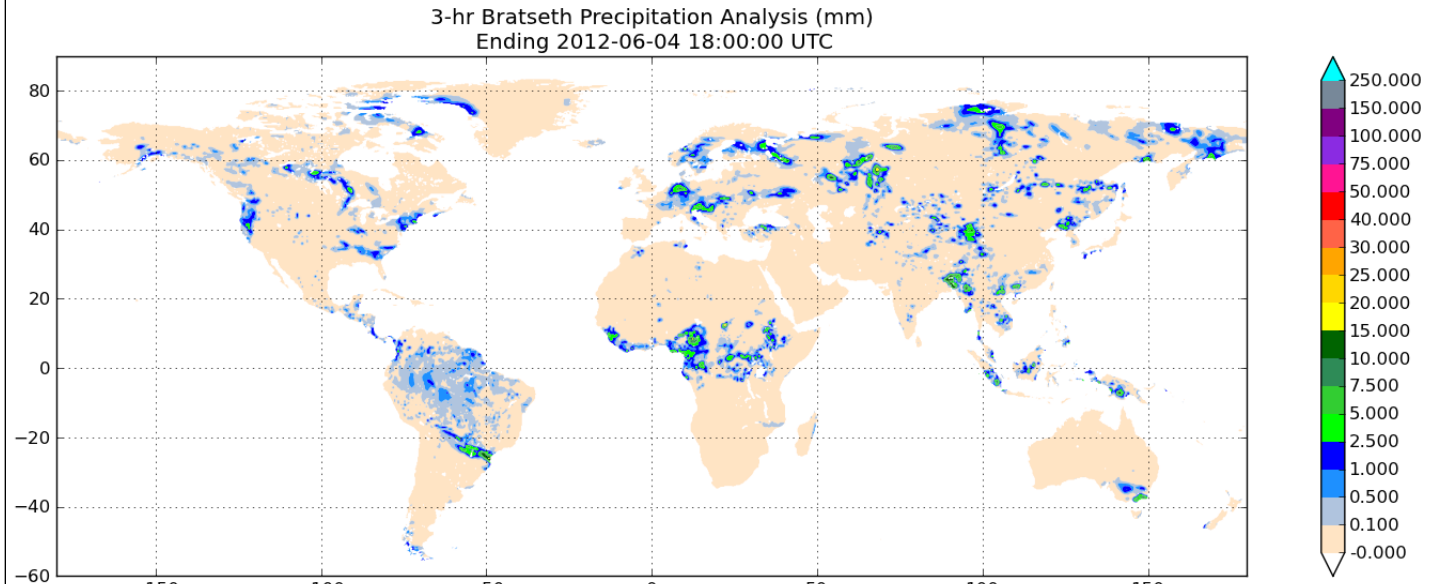
- Upgrade GEOPRECIP to use next generation geostationary satellites.
- Updates to the surface blending algorithms in the AGRMET processing
  - Current processing uses barnes scheme – "bulls eye" features prevalent in the outputs
  - Improve ground observation data coverage
- Developed new precipitation analysis based on Bratseth (1986) scheme
  - Successive correction method with weights incorporating observation and background error covariances
  - Converges to Optimal Interpolation – i.e., best linear unbiased estimation of true state (assuming covariances are correct and input data are unbiased)
  - No explicit matrix inversion – major computational savings over OI
- Analysis is **global** – no "halos" used (reduces discontinuities)
- Single source for background field; all other data sources are observations.

Impact of the Bratseth scheme



Example 3-hr Operational Product

- Note “balloons” around gauges

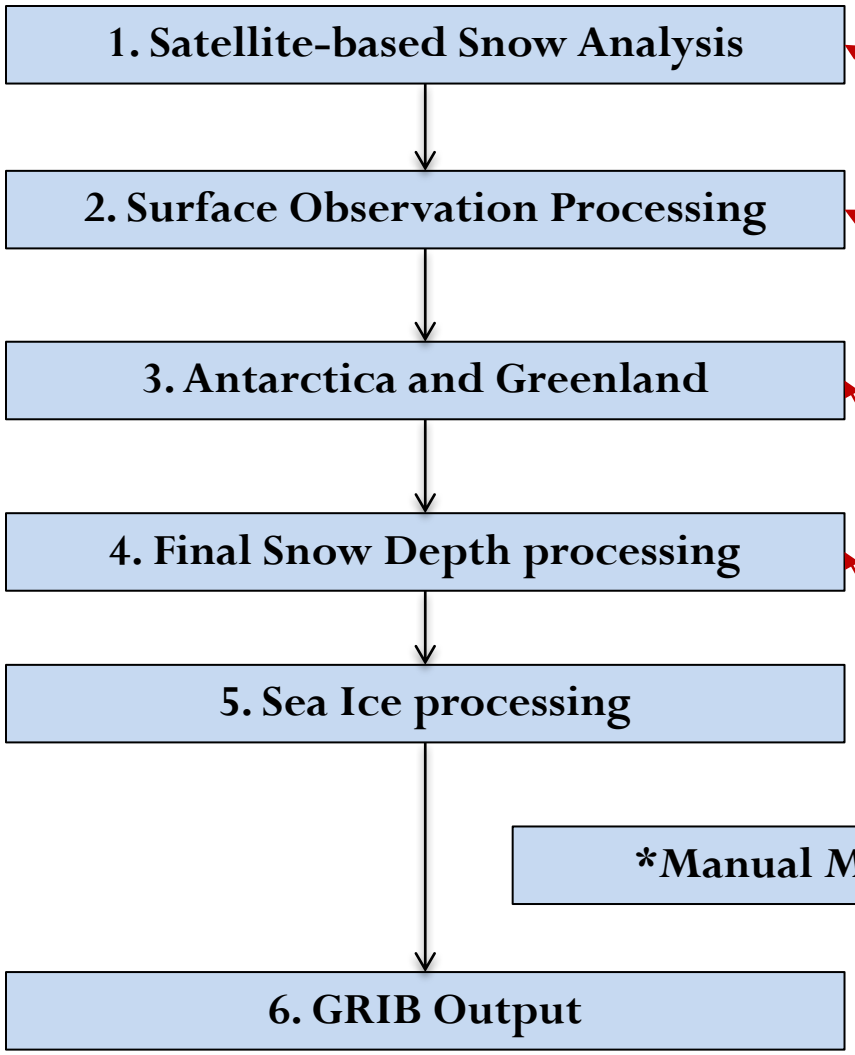


Example 3-hr Bratseth Product

- Fewer balloons, more structure

Integrate SNODEP into LIS

Current processing (outside of LIS) blends in individual data streams (passive microwave, optical, surface obs) to produce a global snow analysis, which do not account for the relative uncertainties of individual data streams



Uses SSMIS to compute snow depths using old single channel algorithm based on Tb@ 37V (Hollinger, 1991)

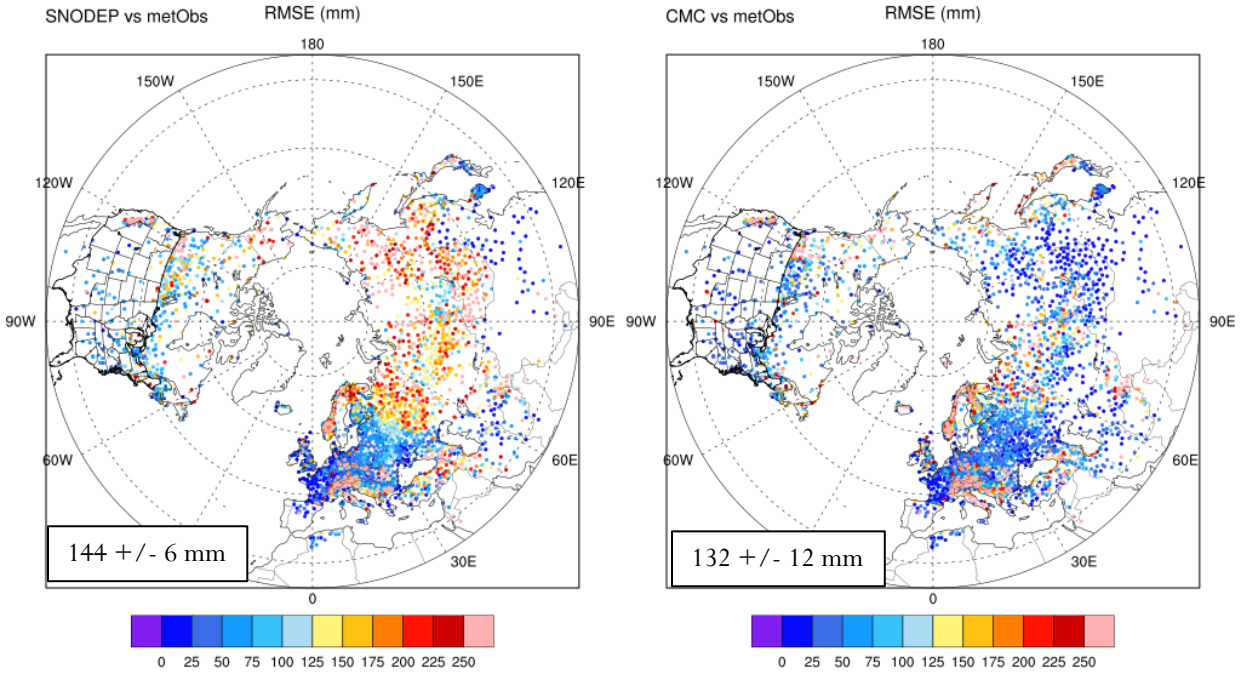
Amount of observations is limited; use inverse linear weighting method for observation interpolation. Similar to the precip analysis, "balloon" features prevalent.

SSMIS snow depths are unreliable; estimates primarily relies on monthly climatological depth

No melt algorithm, so snow is removed only based on Obs., surface temperature, or climatology

Manual processing for the 12Z SNODEP by 2WS analysts

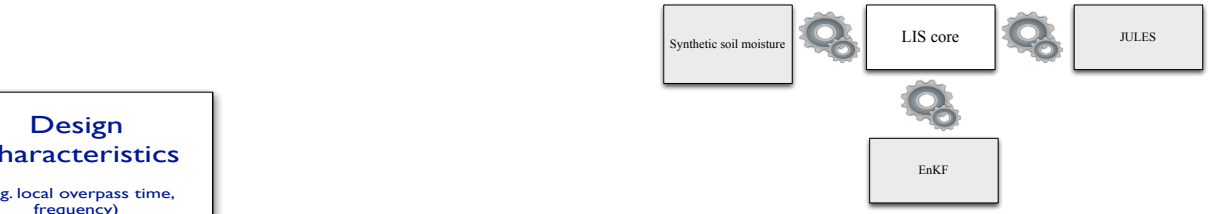
SNODEP evaluation (vs SNODEP met. obs)

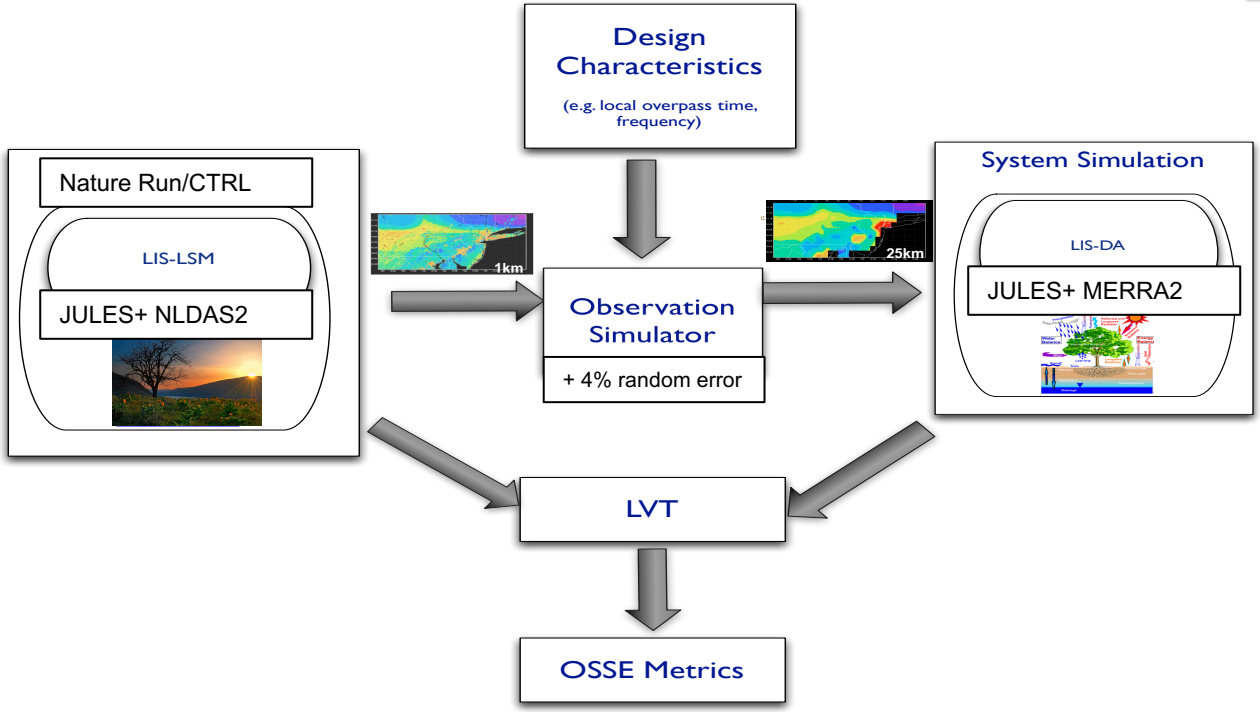


In several regions (Eastern Europe, Siberia, and Mongolia), SNODEP performs worse than CMC when compared to the same gauge data that was ingested!

- Improve/develop observation blending algorithm (e.g. Bratseth)
- Update or replace single channel satellite-derived snow depth
- SNODEP will be incorporated within LIS and will leverage the use of the LIS-DA subsystem; will allow consistency with the LSM analysis
- VIIRS snow cover data will be used as added constraint in the assimilation system (Kumar et al., JHM (2015))
- Configuration to assimilate the updated SNODEP processing will be developed for Noah, Noah-MP and JULES.

Soil moisture DA updates

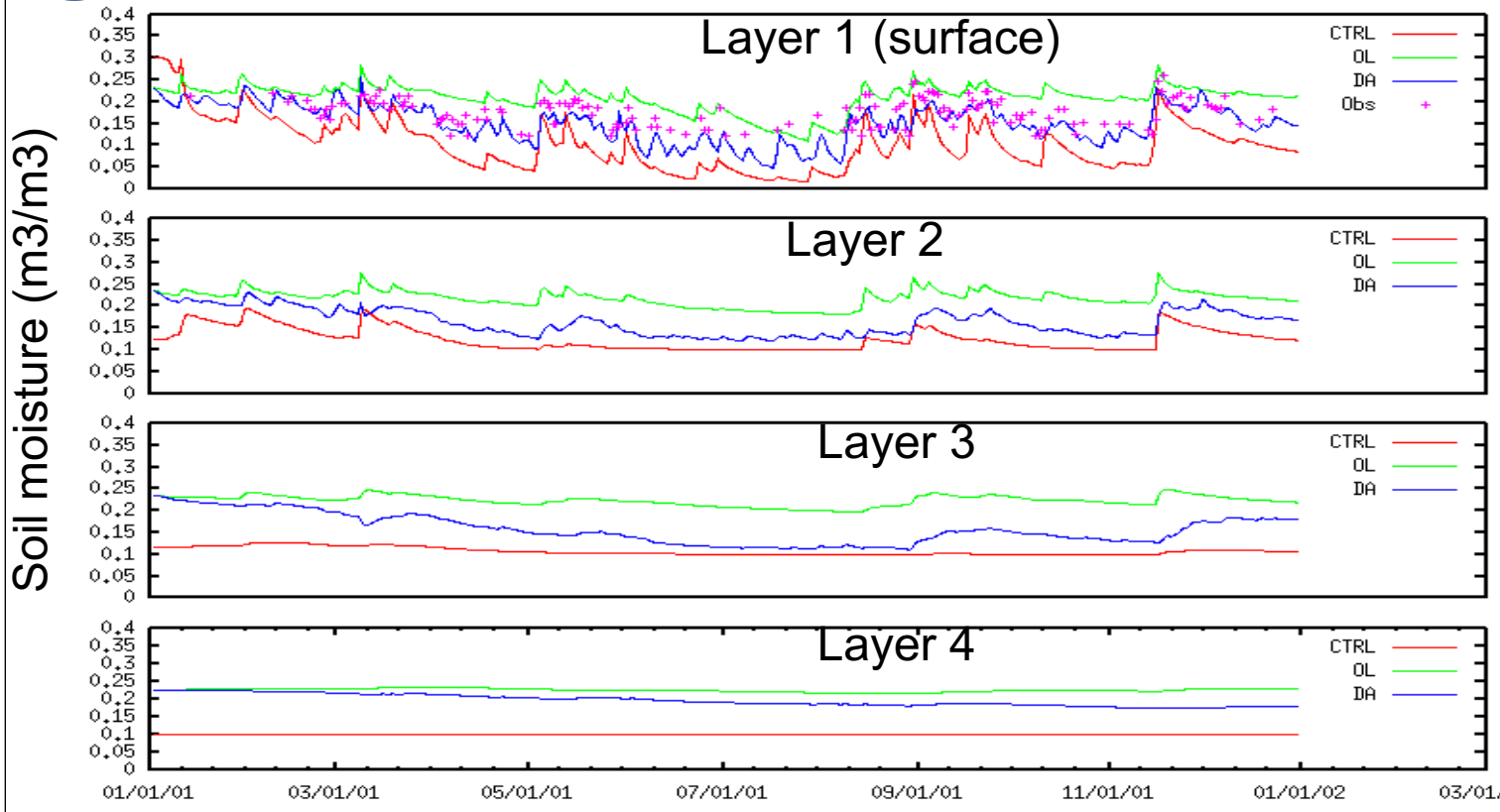


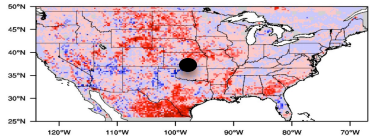


- STEPS
  Simulate the true state with a nature run
- Simulate observations accounting for uncertainty and error
- Run an anticipated run using simulated observations
- Quantitatively evaluate the anticipated run against the nature run
- This structure was used to develop DA interfaces for Noah-MP & JULES LSM.

- For both Noah-MP and JULES, the required DA interfaces have been developed.
- A synthetic DA experiment setup was used to verify and evaluate the DA implementation
- First instance of EnKF-DA with the JULES LSM.
- Observation interfaces for SMAP L2/L3 data have been completed.

Soil moisture DA updates





The DA implementation in JULES allows both the surface and sub-surface soil layers to respond in response to the observations.

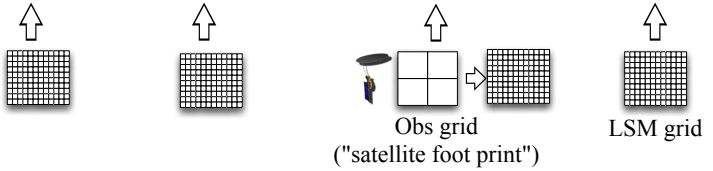
Testing of the configuration over large spatial scales and with bias correction ongoing

- Define SMAP-DA instances with JULES and Noah-MP and test and evaluate the configuration against in-situ data (requires the availability of a stable precip. climatology for bias correction)
- Implement support for SMAP L-band radiance DA in LIS.
- Calibration of the tau-omega forward model to enable the assimilation of L-band SMAP radiances.

LIS –DA system updates

- LISv7.2 was released in May 2017 and it includes several DA related updates (support for new sensors – AMSR2, SMAP; computational enhancements; flexible support for innovation calculations)
- In previous versions, observations were always interpolated/upscaled to the model grid to perform the innovation calculations.
- LISv7.2 allows the capability to compute the innovations in a user defined exchange grid (ideally the same as the observation grid); The analysis increments are computed and applied on the model grid.

$$x_k^{i+} = x_k^{i-} + K_k(y_k - H_k x_k^{i-})$$



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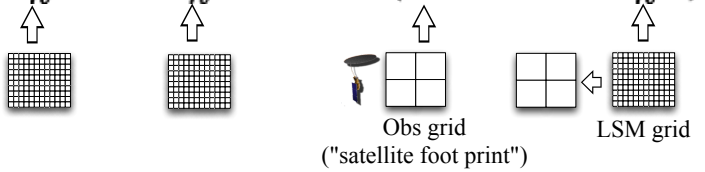

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Summary and ongoing work

- New capabilities include the support for advanced observation operators (RTMs, ANNs, DNNs), support for innovation computations in observation space.

- The LIS suite is being updated for LSM modeling with JULES and support for synthetic SM DA with JULES; Support for JULES ancillaries, satellite DA with JULES, screen level assimilation based on existing SURF capabilities, verification and benchmarking with LVT.

- An improved SNODEP will be incorporated into LIS and Configuration to assimilate SNODEP will be developed for Noah, Noah-MP and JULES LSM

LIS –DA plans, visions

- **New sensor support**: Current support includes data from a large suite of satellite sensors (SMMR, SSM/I, AMSR2, SMOS, ASCAT, MODIS, VIIRS, GRACE, SMAP, among others); Continue to target data from other relevant (LandSAT, GOES-R) and upcoming missions (GRACE-FO, GRACE-2, SWOT, ….)
- **Support for new DA algorithms**: The LIS-DA system is primarily reliant on ensemble methods that include Gaussian error assumptions. Alternative algorithms such as Particle Filter (PF), non-ensemble (EKF) and variants of EnKF (e.g. square root filters) and 4-d variational methods (more suited for reanalysis) will be implemented.
- **Radiance assimilation**: Future development will focus on the direct use of radiance measurements. Forward models based on radiative transfer models (RTMs) and machine learning tools are being incorporated.
- **New assimilation scenarios**: LIS-DA capabilities will be extended to include the assimilation of altimetry, water storage, discharge, terrestrial carbon and biogeochemical budget observations.
- JEDI (Joint Effort for Data Assimilation Integration): LIS will be contributing to and following the JEDI development.

Recent DA Initiatives

- In the summer of 2015, NASA/GSFC engaged a subset of the LIS operational and research stakeholder community (i.e., USAF 557WW, NOAA/NCEP, UK Met Office, KMA, BoM, NIWA, and FNMOC/NRL-MRY) to advocate and substantiate the need for NOAA NESDIS Center for Satellite Applications and Research (STAR) to enhance Soil Moisture Operational Product System (SMOPS) NRT data feed

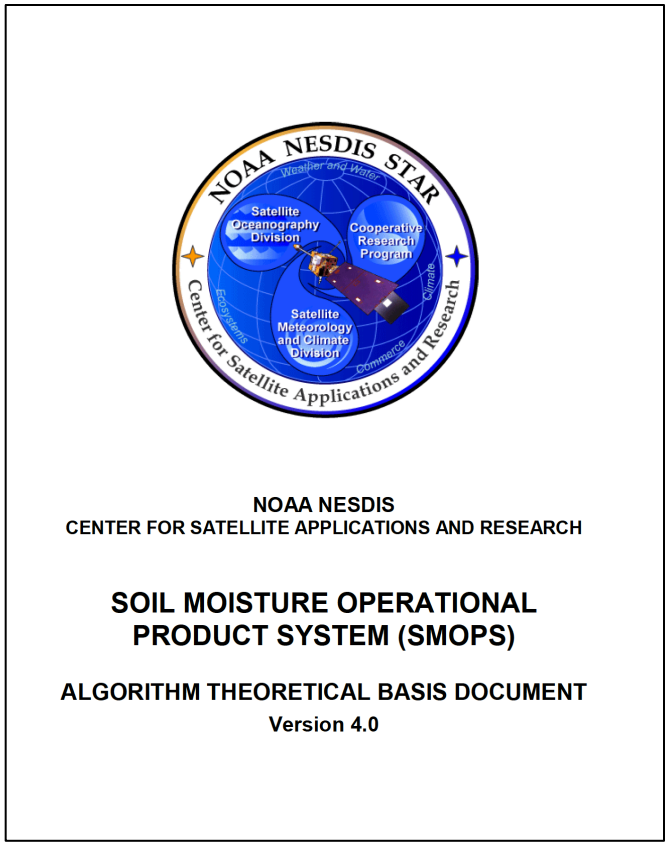
  - As a result, Advanced Microwave Scanning Radiometer 2 (AMSR2) on board JAXA's Global Change Observation Mission – Water "Shizuku" (GCOM-1) and the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) Soil Moisture (SM) retrievals were added to SMOPS NRT data feed via the implementation of Version 4.0 on 31 October 2016.

  - These new SM retrievals compliment the Advanced Scatterometers (ASCAT) aboard the EUMETSAT METOP-A and METOP-B satellites. Note: WINDSAT SM retrievals were retired/removed from SMOPS with this implementation.

  - SMOPS-V3 will include SMAP SM data (August 2017)

Future Land DA Activities

Working with Dr. Xiwu (Jerry) Zhan in developing a project plan for NESDIS FY18 funding consideration to further enhance SMOPS to include T_b--will enable community to build the bridge from a SM product-based to direct radiance Land Data Assimilation paradigm/era



Candidate Areas for Collaboration w/ WMO Commission for Hydrology

Near-term (0-2 years):

- Leverage NASA/GSFC Land Information System (LIS) to fulfill validated, yet unsatisfied, WMO-HydroHub (Global Hydrometry Support Facility) and GEO existing and future requirements
- Assist with *establishing LVT-based benchmarking methodology and standards for the "National Meteorological and Hydrological Services (NMHS)" by amendment*
  - Possibly, Commission for Basic Systems via Seventeenth Session (anticipated in 2018): whereby the Land Surface- and Hydro- Modeling stakeholder community would come to agreement on the specifications for a new "Appendix 2.2.24. titled, "Standardized Benchmarking System for offline Global and Regional Land Data Assimilation Systems (GLDAS/RLDAS); and/or
  - WMO Manual-No. 485, Section II.7, Table G, "Factors and methods used in standardized benchmarking of deterministic and ensemble GLDAS/RLDAS"
  - WMO-HydroHub *could* serve as host of benchmarking methodology/stds


Questions
& Answers