SMAP Assimilation Impacts on Land Surface and Numerical Weather Prediction Models

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Mission: Transition unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.

- Close collaboration with numerous WFOs and National Centers across the country
- SPoRT activities began in 2002, first products to AWIPS in 2003
- Co-funded by NOAA since 2009 through Proving Ground activities
- Proven paradigm for transition of research and experimental data to operations

Benefit:
- Demonstrate capability of NASA and NOAA experimental products to weather applications and societal benefit
- Take satellite instruments with climate missions and apply data to solve shorter-term weather problems
Overview of Project

<table>
<thead>
<tr>
<th>Domain</th>
<th>CONUS</th>
<th>East Africa</th>
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<tbody>
<tr>
<td>Assimilate SMAP in LIS</td>
<td>✓</td>
<td>In progress</td>
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<tr>
<td>Evaluate soil moisture vs. station measurements</td>
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<tr>
<td>Coupled NU-WRF Experiments (LIS+WRF)</td>
<td>Preliminary</td>
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<tr>
<td>Evaluate 48-h weather forecasts</td>
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Refinement of methodology
- Vertical layers
- Bias correction methods
- Ensemble size, perturbations, weighting
Framework for running LSMs incorporating a wide variety of meteorological forcing data and land surface parameters
- Developed by NASA-GSFC
- Includes data assimilation capability.
- Can be run coupled with Advanced Research WRF.
- Using Noah 3.3 Land Surface Model (LSM) within LIS
- SPoRT maintains near-real-time and experimental LIS runs
  - SE US (3-km), shared with WFO’s
  - East Africa, shared with Kenya Meteorological Service (KMS)

References:
Kumar et al. (2006)
Peters-Lidard et al. (2007)
SPoRT LIS Unique Features

Full Continental U.S. (CONUS) domain with 0.03° (lat/lon) grid resolution

Unique characteristics of SPoRT-LIS:

- Real-time S-NPP/VIIRS Green Vegetation Fraction
- Albedo scaled to input vegetation
- Restart simulation strategy to produce real-time output (timeline below)
- SPoRT-LIS ingested and displayed in AWIPS II at select NOAA/NWS weather forecast offices
- Land surface variables available to initialize modeling applications (WRF and STRC/EMS/UEMS)

Current SPoRT-LIS CONUS domain, as displayed in AWIPS II
SPoRT LIS Web Interface

https://weather.msfc.nasa.gov/sport/case_studies/lissmapda_CONUS.html
or https://weather.msfc.nasa.gov/sport -> Real-Time Data
-> Land Information System
-> SPoRT LIS + SMAP DA
LIS Web Products from SPoRT: SMAP LIS

- 0-10 cm model soil moisture

https://weather.msfc.nasa.gov/sport/case_studies/lissmapda_CONUS.html
Sampling Strategy

- Level 2 data are available on 36-km EASE grid
- To take advantage of high resolution geophysical properties (topography, vegetation, soils), running model at 3-km
- SMAP observations are assimilated at each model grid point in their FOV
- Downscaling to preserve background variability implemented

Some QC applied on LIS grid

*Depends on LSM/variable (e.g. Noah3.3+soil moisture)*
- Precip (changed to 1 mm/hr)
- Frozen ground
- Snow on ground
- GVF>0.7
- Extreme values

Bias correction will be applied on LIS grid.

SMAP and LIS grids are not aligned. Near boundaries, keep only one observation per cell (closest good ob)

Data flag-based QC applied at observation resolution
- **Retrieval Quality Flag**
- Vegetation Opacity
- Vegetation Water
- Frozen Ground Fraction

SMAP (passive) 36-km cell

LIS grid (3-km)
Assimilation of SMAP Enhanced (9-km) Product

0-10 cm Volumetric Soil Moisture (%)

Note linear and square features (e.g., at arrows) on left resulting from the coarse 36-km resolution of the SMAP data. Reduced on right due to using 9-km Enhanced SMAP data.
Impact of Enhanced SMAP (correlations)

Y2015 0-10 cm SM SMAPENHDA-SMAPDA RCORR Diff at SCAN+USCRN Stations

Key:
- Red: -0.16
- Orange: -0.12
- Yellow: -0.08
- Light blue: -0.04
- Light gray: 0.00
- Dark gray: 0.04
- Dark blue: 0.08
- Purple: 0.12
- Light purple: 0.16
Bias Correction

- Assimilation systems assume unbiased observations
- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and obs at each grid point.
- We have implemented CDF matching aggregated by soil type
  - Described for SMOS in Blankenship et al. 2016 (IEEE TGRS)
  - Idea is to let the observations influence the model climatology
- Other methods will be explored including using only nearby points
- Using a thinner soil moisture layer may reduce forward operator error and subsequently the magnitude of bias corrections

Correction Curves
By Soil Type
**SMAP Assimilation Reduces Errors due to Poor QC in Forcing Data**

- Land surface models such as SPoRT LIS are forced using precipitation inputs (NLDAS-2 in this case).
- In 2015, NLDAS-2 included data from a bad rain gauge (consistently near zero) in southern Arkansas causing an anomalously dry soil moisture “bullseye” (upper left, arrow).
- Through assimilation of SMAP L2 soil moisture fields, which do not exhibit this feature (lower left), this anomaly is greatly reduced over time (upper right) to provide a more representative soil moisture field.
  - Snapshot is 24 days after beginning of assimilation.
  - This results in a more accurate depiction of local conditions.

0-2 m Column Integrated Relative Soil Moisture (%)
12Z 24 Apr 2015

Baseline SPoRT LIS

SPoRT LIS with SMAP DA

SMAP Retrieved Soil Moisture
0-5 cm, volumetric (m³/m³ x100)
Non-localized CDF-matching bias correction applied

LIS Difference
(SMAP DA Minus Baseline SPoRT)
Column Integrated RSM (%)

Credit: Youlong Xia, Pingping Xie (NCEP/EMC); David Mocko (NASA/GSFC)
Soil moisture discontinuities can occur in regions where different precipitation inputs are blended.

- NLDAS-2 uses radar-derived precipitation over U.S. and reanalysis outside of U.S.
- Results in anomalous dry conditions in southern Ontario (upper left, oval)
- SMAP retrieved soil moisture (lower left) does not have this feature.

Through assimilation of SMAP L2 soil moisture fields, this anomaly disappears over time (upper right) to provide a more representative soil moisture field.

This should help forecasters better assess current regional conditions and provide more accurate initialization of NWP models.
Previous Validation Results (SMOS DA)

<table>
<thead>
<tr>
<th></th>
<th>Near Surface (0-10 cm)</th>
<th>Root Zone (10-100 cm)</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.6%</td>
<td>23.5%</td>
</tr>
<tr>
<td>SMOS DA</td>
<td>-0.5%</td>
<td>21.8%</td>
</tr>
</tbody>
</table>
Quantitative Validation Results

Station Validation

Correlation

Bias

ubRMSE
SMAP Correlation change 2015

Y2015 0-10 cm SM SMAPENHDA-SPORTLIS RCORR Diff at SCAN+USCRN Stations

Key:
- Red: -0.16
- Red-orange: -0.12
- Orange: -0.08
- Light orange: -0.04
- Yellow: -0.04
- Grey: 0.00
- Blue: 0.04
- Light blue: 0.08
- Dark blue: 0.12
- Purple: 0.16
Y2016 0-10 cm SM SMAPENHDA-SPORFLIS RCORR Diff at SCAN+USCRN Stations
Possible Issues

- SMAP Data Accuracy
- Bias Correction
- AM/PM data
- Representativeness (point vs grid cell, also vertical) of validation data
- Depth discrepancies
  - (10 cm model layer, 5 cm or less SMAP measurement)
- Initial LIS is too hard to improve upon
  - 3-km resolution has more detail than 36 or 9-km observations
  - Forcing data (NLDAS-2) is high quality
New Validation Results (SMAP DA)

- Corr increases from .79 to .84 (NOBC)
- ubRMSE decreases from .054 to .043
New Validation Results (SMAP DA)

- Corr increases from .78 to 85 (NOBC)
- ubRMSE decreases from .071 to .057
New Validation Results (SMAP DA)

- Corr decreases from .93 to .67 (NOBC)
- ubRMSE increases from .031 to .059
Possible Issues (and findings)

- Bias Correction
  - NoBC run indicates BC has a minor effect on statistics
- AM/PM data
  - Validation of retrievals indicates small difference
- Representativeness (point vs grid cell, also vertical) of validation data
  - Previously got positive impact (correlations) with SMOS
  - Others getting good impact
- Depth discrepancies
  - (10 cm model layer, 5 cm or less SMAP measurement)
  - Experiment in progress
  - Previously got positive impact with SMOS
- Information content of 3-km LSM is too hard to match with 9-km obs
  - Previously got positive impact with SMOS
6-7 May 2015 Southern Plains tornado outbreak: NASA Unified-WRF (NU-WRF) sensitivity simulations
NASA Unified-WRF (NU-WRF) model runs: Model configuration and experiment details

- **Domain/grid set up (images at right)**
  - Contiguous U.S. at 9-km horizontal grid spacing
  - Convection-allowing 3-km mesh nested grid

- **Sixty-hour forecasts**
  - 0000 UTC 6 May to 1200 UTC 8 May
  - Initialized at 0000 UTC 6 May 2015
  - Initial/boundary conditions from NCEP Global Forecast System model

- **Model physics parameterization choices**
  - Noah land surface model (same as in LIS runs)
  - Convection: Scale-aware Kain-Fritsch (9-km grid only)
  - Planetary Boundary Layer: Yonsei University scheme
  - Microphysics: NASA/Goddard 4-ice parameterization
  - Radiation: NASA/Goddard short- and long-wave radiation schemes

- **Two land surface initialization simulations**
  - “sportlis”: 0-h land surface fields from SPoRT’s “operational” LIS run; no DA
  - “smapenhda”: 0-h land surface fields from SMAP-Enhanced DA LIS run
NASA Unified-WRF (NU-WRF) model runs:
Soil Moisture Initial Condition Differences on 3-km nest

SMAP-Enhanced data assimilation run generally produced drier soil moisture fields than sportlis.
NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

smapenhda-initialized NU-WRF runs generally simulated warmer/drier daytime temperatures/dewpoints, with slightly lower instability where convection/supercells developed.

**All simulated fields shown are from the 21-hour NU-WRF forecast, valid on 2100 UTC 6 May 2017**
NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

24-hour NU-WRF forecasts and observed radar imagery valid at 0000 UTC 7 May 2015
NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

25-hour NU-WRF forecasts and observed radar imagery valid at 0100 UTC 7 May 2015

Observed regional radar reflectivity (dBZ)
NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

26-hour NU-WRF forecasts and observed radar imagery valid at 0200 UTC 7 May 2015
NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

27-hour NU-WRF forecasts and observed radar imagery valid at 0300 UTC 7 May 2015
NASA Unified-WRF (NU-WRF) model runs:
*Slight improvement in simulated convective evolution*

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

28-hour NU-WRF forecasts and observed radar imagery valid at 0400 UTC 7 May 2015

**Observed regional radar reflectivity (dBZ)**
NASA Unified-WRF (NU-WRF) model runs: 
*Slight improvement in simulated convective evolution*

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

29-hour NU-WRF forecasts and observed radar imagery valid at 0500 UTC 7 May 2015
NASA Unified-WRF (NU-WRF) model runs:
*Slight improvement in simulated convective evolution*

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.

30-hour NU-WRF forecasts and observed radar imagery valid at 0600 UTC 7 May 2015
Future Plans

- Soil Moisture
  - Validation of soil moisture against ground probes
  - Investigation of bias correction methods
- Coupled NWP
  - Validation of 48-hr NWP forecasts
    - High-impact case studies
    - Comprehensive seasonal validation
- Africa domain
- Possible Alaska domain

https://weather.msfc.nasa.gov/sport
  -> Realtime Data
  -> SMAP Soil Moisture
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Questions and Comments?

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