Assimilation of L-band Soil Moisture Brightness Temperatures (TB) into the Soil, Vegetation and Snow (SVS) Scheme within the Canadian Land Data Assimilation System (CaLDAS)

Marco L. Carrera\textsuperscript{1}, Bernard Bilodeau\textsuperscript{1}, Maria Abrahamowicz\textsuperscript{1}, Stephane Bélair\textsuperscript{1}, Albert Russell\textsuperscript{1}, and Xihong Wang\textsuperscript{2}

\textsuperscript{(1)} Meteorological Research Division, \textsuperscript{(2)} Meteorological Service of Canada

Environment and Climate Change Canada (ECCC)

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Soil Moisture & Numerical Weather Prediction (NWP)

Soil moisture affects:

- Land surface evaporation and evapotranspiration
- Sensible and latent heat fluxes (partition of net radiation)
- Evolution and structure of the boundary layer
- Formation of clouds, precipitation (convection) and weather systems

Common approach in NWP:

- Infer soil moisture from short-range forecast errors in screen-level (2m) temperature and humidity (so-called "pseudo-analysis" of soil moisture)

Issues:

- 2m observations have highly variable spatial and temporal density
- "Tunes" soil moisture of the model to provide accurate fluxes, less focus on improving soil moisture itself

Goal at ECCC:

Improve both (1) the initialization and (2) modeling of soil moisture to improve:

1. Standard NWP variables (Air temp., humidity, precipitation)
2. Soil moisture (and related variables: runoff, drought and flood conditions etc.) (** Increasing focus on environmental prediction)
Canadian Land Data Assimilation System (CaLDAS)

- **Ensemble Kalman Filter (EnKF)** (24 members)
- **Observations** assimilated:
  - Screen-level Temp and Humidity, Snow depth, **NEW: SMAP L-band TBs**
- **Analyzed variables:**
  - Land surface temperature, snow depth, Soil Moisture (superficial, and root zone)
- **Background/First guess:**
  - Off-line land surface prediction system with 2 choices of land surface scheme:
    - **ISBA**: Interaction between Surface, Biosphere, Atmosphere
    - **SVS**: Soil Vegetation and Snow (**New at ECCC**)
  - One energy budget for land surface
  - Force-restore equation for soil moisture + 2 soil layers
  - Separate energy budget for bare ground, veg. and snow
  - Vertical soil water diffusion + 7 soil layers
  - Updated parametrizations for snow, runoff, stomatal resistance etc.

**NOTE:** ISBA & SVS also in full 3D GEM model (GEM: Global Environmental Multiscale)

Carrera et al., 2015: The Canadian Land Data Assimilation System (CaLDAS): Description and Synthetic Evaluation Study
Alavi et al., 2016: Warm Season Evaluation of Soil Moisture Prediction in the Soil, Vegetation, and Snow (SVS) Scheme
Husain et al., 2016: The Multibudget Soil, Vegetation, and Snow (SVS) Scheme for Land Surface Parameterization: Offline Warm Season Evaluation
CaLDAS and SMAP:

**Goal:**
Evaluate the impact of assimilating SMAP (Soil Moisture Active Passive) brightness temperatures (TBs) in CaLDAS upon the estimation of the soil moisture state and the subsequent NWP forecasts.

**Experimental Set-up:**
- **Assimilation time period:** June-August 2015
- **Evaluation time period:** July-August 2015
- **Domain:** North America at ~10km grid spacing
- **Forward Model:** Community Microwave Emission Modelling Platform (CMEM)
- **SMAP:** SMAP Level 1B Radiometer Half-Orbit Time-Ordered Brightness Temperatures (Version 3)

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<th>EXPERIMENT</th>
<th>Observations Assimilated</th>
<th>Temporal Frequency</th>
<th>Control Variables</th>
<th>Land - Surface Model</th>
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<tr>
<td>SCREEN</td>
<td>TT, TD @2m</td>
<td>3hr</td>
<td>mean surface temp. surface and root zone soil moisture</td>
<td>ISBA</td>
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</tbody>
</table>
| SMAP-ISBA  | TT, TD @2m
SMAP (TBs) | 3hr                | mean surface temp. surface and root zone soil moisture | ISBA                |
| SMAP-SVS   | TT, TD @2m
SMAP (TBs) | 3hr                | surface temperatures and soil layers 1-4 (depth=5,10,20,40cm) | SVS                 |
Soil Moisture Verification: Sparse Networks
Impact of SMAP TBs & Land Surface Schemes

Superficial Soil Moisture

Correlation

Unbiased RMSE

Root Zone Soil Moisture

Correlation

Unbiased RMSE
NWP Forecast Verification

Screen-Level (2m) Temperature (TT) and Dew point Temperature (TD) and Soil Moisture Verification against Sparse Networks

July-August 2015

48 hr forecasts every 48hrs, initialized using CaLDAS analysis at 00Z (31 cases)

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<td>SMAP (TBs)</td>
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*Note: Land surface scheme (ISBA or SVS) in forecast same as in CaLDAS experiment

Verification against:
SYNOP stations
0.1°C precision for Temperature
Temporal resolution of 3hrs
SCREE+ISBA vs SMAP+SVS

Temperature Biases (F - O) : July - August 2015, 00Z Runs

CaLDAS-SCREEN
CaLDAS-SVS-SMAP

90% confidence interval based upon block bootstrapping
SCREEN+ISBA vs SMAP+SVS
Temperature: July-August 2015, 00Z Runs

CaLDAS SCREEN
CaLDAS-SVS-SMAP

Canada

USA
SCREEN+ISBA vs SMAP+SVS
Temperature (TT) STDE: July - August 2015, at 00Z day 2 (24Z) ~mid/late afternoon

- SCREEN+ISBA better
- SMAP+SVS better

Localized problem areas... Central USA for example...
SVS and Vegetation

- Assuming that soil moisture is well specified, the vegetation becomes key in correctly simulating latent heat fluxes.

- **Current hypothesis**: soil moisture is well initialized and simulated in SVS, but errors in evapotranspiration lead to errors in fluxes, which lead to low-level air temp. and humidity errors.

- **Ongoing tests to:**
  - Improve parametrization of stomatal resistance (one of the main factors controlling vegetation latent heat fluxes)
  - Fine-tune vegetation characteristics (e.g., root depth) in problem areas using soil moisture and screen-level errors for guidance given lack of data.

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### SVS stomatal resistance tests

- **USA Southeast TD 2m STDEs**

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**Note**: Land surface model changes affect both CaLDAS assimilation cycle and forecasts.
SUMMARY

• Assimilating SMAP TBs leads to significant improvements in temporal correlations for both $w_g$ and $w_2$ when compared to the use of screen-level parameters alone. Unbiased RMSEs are also improved.

• Using a more complex land surface model (SVS vs. ISBA) further improves the correlations and unbiased RMSEs.

• Better soil moisture (and land surface temperature) at start time generally leads to improved short-range (0-48hr) NWP forecasts (TT,TD) ... but a few problem areas persist... ongoing work to address the areas where we see a deterioration in screen-level (2m) scores

• Ongoing tests focused on simulation of stomatal resistance and specification of vegetation characteristics (e.g., roots) in SVS. Modification to SVS impacts both the CaLDAS analysis cycle and the NWP forecasts.

• Irrigation (un-modeled processes)

• Next Step: Global Domain

**NWP tests were performed over North America where the screen-level data coverage can be considered good. Anticipate larger impacts over more data sparse regions.**
Thank you for your attention
(Nothing like SMAP and Vegetation...)

https://blog.junshin.com/lynnrn.do
CaLDAS-SMAP Experimental Setup

RDPS FCST

PERTURBED ATM FORCING

SMAP OBS

Analyzed Soil Moisture

48-h forecast
TB "Downscaling" Strategy; Within EnKF algorithm

- Observation: TB at 40 km.
- Each sub tile \( T_i \) seems the same innovation:
  \[
  TB(SMOS) = \frac{1}{16} \sum_{i=1}^{16} TB_i
  \]

- This innovation needs to be distributed to each sub tile.
- Correlations between the fine-scale (10 km) model states and the coarse-scale (40 km) observation predictions downscales the coarse-scale innovations.

\[
BH^T \cong \text{Cov}[\left(w_g, w_2\right); TB]; HBH^T \cong \text{Cov}[TB, TB]
\]