Impact of SMAP data in ECCC's numerical predictions

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Soil Moisture and Numerical Weather Prediction (NWP)

- Accurate initialization of the soil moisture state has been shown to be important for skillful weather and climate prediction.
  - Depth and stability of atmospheric boundary layer
  - Controls on evaporation in the pre-squall environment associated with intense convection
  - Influences air quality and the dispersion of pollutants

- At several meteorological centres, soil moisture is inferred from short-range NWP forecast errors in screen-level temperature and humidity, so-called "pseudo-analysis" of soil moisture.

- Increasing applications in hydrology, flood forecasting and agricultural and drought monitoring have placed more emphasis on accurate estimates of soil moisture.

- Gap in soil moisture observations is being alleviated by Soil Moisture Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP), two separate satellite missions dedicated to the measurement of L-band microwave emission.
Objectives

• Quantitatively assess the impacts of assimilating SMAP brightness temperatures (Tbs) upon the estimation of the soil moisture state and the subsequent NWP forecasts with Environment Canada's Regional Deterministic Prediction System (RDPS).

• NWP verification will focus upon:
  
  – (i) upper-level variables with measurements from the radiosonde network over North America;
  
  – (ii) the SYNOP and METAR surface networks will be used to quantify skill improvements in surface temperature, dew-point temperature and precipitation.
Canadian Land Data Assimilation System (CaLDAS)

• Based upon an externalized (off-line) land-surface modeling capability, currently the Canadian implementation of ISBA.

• Uses the Ensemble Kalman Filter (EnKF) methodology.

• CaLDAS is currently run operationally to provide initial soil and snow characteristics to the High-Resolution Deterministic Prediction System.

• CaLDAS has been configured to assimilate passive L-band Tbs using the Community Microwave Emission Modeling (CMEM) Platform (Carrera et al. 2015).
CaLDAS-SMAP Experimental Setup

- T-6
  - RDPS FCST
  - CaLDAS
  - SMAP OBS
  - Analyzed Soil Moisture
- T-3
  - RDPS FCST
  - CaLDAS
  - SMAP OBS
  - Analyzed Soil Moisture
- T
  - RDPS FCST
  - CaLDAS
  - SMAP OBS
  - Analyzed Soil Moisture
- T+3
  - RDPS FCST
  - CaLDAS
  - SMAP OBS
  - Analyzed Soil Moisture
- T+6
  - RDPS FCST
  - CaLDAS
  - SMAP OBS
  - Analyzed Soil Moisture

PERTURBED ATM FORCING

48-h forecast
**Experiment Parameters**

**Strategy**: The current operational assimilation, CaLDAS-Screen soil moisture will be compared with various configurations of the Canadian Land Data Assimilation System (CaLDAS) setup to assimilate the SMAP TBs.

- **Time Period**: July – August 2015.
- **NWP System**: Regional Deterministic Prediction System (RDPS) with a grid spacing of 10 km covering North America.
- **SMAP TBs**: SMAP Level 1B Radiometer Half-Orbit Time-Ordered Brightness Temperatures (Version 3).
- **Soil Moisture Analyses**: Quantitative verification of soil moisture analyses produced using AGDMN, SCAN and USCRN networks.
- **NWP Forecasts**: Impacts upon near-surface parameters from a series of 48-h forecasts with the GEM model issued with soil moistures from the various soil moisture analyses.
# Description of Assimilation Experiments
## July – August 2015

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Assimilation Methodology</th>
<th>Observations Assimilated</th>
<th>Analyzed Variables</th>
<th>Temporal Frequency</th>
<th>STATUS</th>
<th>LABEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>OI-Operational</td>
<td>Sequential Assimilation</td>
<td>$T_{2m}$, $RH_{2m}$</td>
<td>$T_s$, $T_2$</td>
<td>1 / day</td>
<td>OPERATIONAL RDPS (10 km)</td>
<td>OPER</td>
</tr>
<tr>
<td>CaLDAS-Screen</td>
<td>EnKF (24)</td>
<td>$T_{2m}$, $TD_{2m}$</td>
<td>$w_2$, $T_2$</td>
<td>3 hours</td>
<td>HRDPS (2.5 km)</td>
<td>SCREEN</td>
</tr>
<tr>
<td>CaLDAS-SMAP-BC</td>
<td>EnKF (24)</td>
<td>$TBH$ (SMAP) + $T_{2m}$, $TD_{2m}$</td>
<td>$w_g$, $w_2$, $T_2$</td>
<td>3 hours</td>
<td>Development</td>
<td>SMAP - BC</td>
</tr>
<tr>
<td>CaLDAS-SMAP-no BC</td>
<td>EnKF (24)</td>
<td>$TBH$ (SMAP) + $T_{2m}$, $TD_{2m}$</td>
<td>$w_g$, $w_2$, $T_2$</td>
<td>3 hours</td>
<td>Development</td>
<td>SMAP - no BC</td>
</tr>
<tr>
<td>CaLDAS-SMAP-no BC - SVS</td>
<td>EnKF (24)</td>
<td>$TBH$ (SMAP) + $T_{2m}$, $TD_{2m}$</td>
<td>$w_{1.4}$, $TG_{1.2}$, $TVG_{1.2}$</td>
<td>3 hours</td>
<td>Development</td>
<td>SMAP - no BC - SVS</td>
</tr>
</tbody>
</table>
Soil Moisture Verification
Sparse Networks
Sparse Network Soil Moisture Verification
July – August 2015

Correlation

Superficial Soil Moisture $w_g$

Root Zone Soil Moisture $w_2$

STDE
Sparse Network Soil Moisture Verification: Bias
July – August 2015

CaLDAS: Surface Soil Moisture Bias

Superficial Soil Moisture $w_g$

Root Zone Soil Moisture $w_2$

CaLDAS: Root Zone Soil Moisture Bias
Numerical Weather Prediction Scores

• Series of 48-h integrations with the GEM (Global Environmental Multiscale) NWP model initialized at 0000 UTC for July-August 2015.

• Upper-air radiosonde verification scores.

• Surface verification scores: $TT_{2m}$ and $TD_{2m}$ along with precipitation.
Soil Moisture Forecast Verification: Sparse Network Correlation: July – August 2015

**24h**

CaLDAS: Surface Soil Moisture Correlation

GEM 24hr forecast: Surface Soil Moisture Correlation

**48h**

CaLDAS: Root Zone Soil Moisture Correlation

GEM 48hr forecast: Root Zone Soil Moisture Correlation

Environment and Climate Change Canada

Environnement et Changement climatique Canada
CaLDAS-Screen \((T_{2m}, TD_{2m}, 3\text{hrs}; w_2, T_2)\) vs

SMAP – BC \((T_{2m}, TD_{2m}, TBH(SMAP), 3\text{hrs}; w_g, w_2, T_2)\)
CaLDAS-Screen vs CaLDAS-SMAP – BC
Greater North America: Forecast - Observation

24h

48h
CaLDAS-SCREEN vs CaLDAS-SMAP-BC

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

Temperature (°C)

CaLDAS-SCREEN

CaLDAS-SMAP-BC

warmer

colder

90% confidence interval based upon block bootstrapping

Night

Canada

drier

Dew-Point Temperature (°C)

Night

USA

warmer

colder

wetler
CaLDAS-SCREEN vs CaLDAS-SMAP-BC
Temperature STDE: July - August 2015, 00Z Runs

Temperature (°C)

Dew-Point Temperature (°C)

Canada

USA

Night

Night

Night

Night

Night
CaLDAS-Screen \((T_{2m}, \, TD_{2m}, \, 3\text{hrs}; \, w_2, \, T_2)\) vs

SMAP – no BC \((T_{2m}, \, TD_{2m}, \, TBH(\text{SMAP}), \, 3\text{hrs}; \, w_g, \, w_2, \, T_2)\)
**CaLDAS-Screen vs CaLDAS-SMAP – no BC**

Greater North America: Forecast - Observation

24h

48h
CaLDAS SCREEN vs CaLDAS-SMAP-no BC

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

Temperature (°C)

Dew-Point Temperature (°C)

Night
warmer
Canada

colder

Night
warmer
USA

colder

Forecast Hour

90% confidence interval based upon block bootstrapping

Climate Change Canada

Changement climatique Canada
CaLDAS SCREEN vs CaLDAS-SMAP-no BC

Temperature STDE: July - August 2015, 00Z Runs

Temperature (°C)

Dew-Point Temperature (°C)

Canada

USA

Night

Night

Night

Night

Night

Night

Forecast Hour

Forecast Hour

Forecast Hour

Forecast Hour
CaLDAS-Screen \((T_{2m}, \, TD_{2m}, \, 3\text{hrs}; \, w_2, \, T_2)\) vs

SMAP – no BC \((r_s \times 3) \,(T_{2m}, \, TD_{2m}, \, TBH(\text{SMAP}), \, 3\text{hrs}; \, w_g, \, w_2, \, T_2)\)
CaLDAS SCREEN vs CaLDAS-SMAP – no BC ($r_s \times 3$)

Temperature STDE: July - August 2015, 00Z Runs

**Temperature (°C)**

**Dew-Point Temperature (°C)**

Canada

USA

Night

Night

Night

Night

Forecast Hour

Forecast Hour

Forecast Hour

Forecast Hour
Precipitation Scores
24h Accumulation over North America

FBI = Frequency Bias Index
POD = Probability of Detection
FAR = False Alarm Ratio
ETS = Equitable Threat Score
Precipitation-24 h : North America July - August 2015
CaLDAS-SMAP-no-BC

CaLDAS SCREEN

FBI

POD

FAR

ETS
Precipitation-24 h: North America July - August 2015

CaLDAS-SMAP-no-BC (r₃ₓ3)

FBI

POD

FAR

ETS

CaLDAS SCREEN
SVS (Soil, Vegetation, Snow) Land Surface Model

Alavi et al. (2016), Husain et al. (2016)

• Multi budget energy calculations for bare soil, vegetation and snow.
• Improved soil hydrology with the inclusion of multiple soil layers.

CaLDAS - Screen ($T_{2m}$, $TD_{2m}$, 3hrs; $w_2$, $T_2$) vs

SMAP – no BC – SVS ($T_{2m}$, $TD_{2m}$, $TBH(SMAP)$, 3hrs; $w_{1-4}$, $Tbg_{1-2}$, $Tvg_{1-2}$)

Limited to 13 48-h forecasts in July 2015
CaLDAS SCREEN vs CaLDAS-SMAP - no BC - SVS
Temperature Biases (F - O) : July 2015, (13) 00Z Runs

**Temperature (°C)**

- **Canada**:
  - **Night**: warmer
  - **Forecast Hour**: 90% confidence interval based upon block bootstrapping

- **USA**:
  - **Night**: colder
  - **Forecast Hour**: 90% confidence interval based upon block bootstrapping

**Dew-Point Temperature (°C)**

- **Canada**:
  - **Night**: wetter

- **USA**:
  - **Night**: drier
CaLDAS SCREEN vs CaLDAS-SMAP – no BC - SVS
Temperature STDE: July 2015, (13) 00Z Runs

Temperature (°C)

Dew-Point Temperature (°C)

Canada

USA
Summary

• **Soil Moisture**: Assimilation of SMAP Tb data leads to significant improvements in temporal correlations for both $w_g$ and $w_2$ when compared to the use of screen-level parameters alone. STDEs are also improved. Assimilating screen level variables more frequently, acts to deteriorate the $w_2$ verifications scores.

• Assimilation of screen-level variables appears to be necessary to give a comparable level of skill as to the current operational CaLDAS-Screen.

• **Approaching a configuration where**:

  • Significantly Improved soil moisture with positive impacts on atmospheric forecasts as compared to the current operational assimilation system.

• **Recall**: 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
TB "Downscaling" Strategy; Within EnKF algorithm

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

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.

$$BH^T \cong Cov[(w_g, w_2); TB]; HBH^T \cong Cov[TB, TB]$$
• Principal short-range guidance (days 1-2) used by Meteorological Service of Canada forecasters.

• Grid spacing of 10 km covering North America and adjacent oceans.

• Launched 4x daily out to 48 h.