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Implementation of the Canadian Land Data Assimilation System (CaLDAS) based upon the assimilation of space-based remote sensing observations for soil moisture and skin temperature

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CaLDAS - Contributors

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Land Surface Assimilation Operational at ECCC

- The initialization of soil moisture and surface temperatures is based upon the assimilation of near-surface temperature and humidity observations (Mahfouf 1991; Bélair et al. 2003).

- These near-surface observations are not direct measures of soil moisture, but their assimilation is designed to improve the estimates of surface turbulent fluxes and the resulting NWP forecasts of near-surface variables (Drusch and Viterbo 2007).

- Studies have shown that the increments added to soil moisture through screen-level temperature and humidity assimilation can lead to an overall degradation of soil moisture suggesting that the improved NWP forecasts are not necessarily the results of more skillful soil moisture simulations.

Land Surface Assimilation : Developments at ECCC

- **Observations**
  - **Soil Moisture :**
  - **Soil Moisture and Ocean Salinity (SMOS);**
  - **Soil Moisture Active Passive (SMAP) ;**

  - **Surface Temperature :**
  - **Retrievals from GOES-15 and subsequently GOES-16, 17.**
  - **Retrievals from polar orbiters, AIRS, IASI, and CRIS.**
- **Land Surface Model**

Development of the Soil, Vegetation and Snow (SVS) land surface scheme (Alavi et al. 2016; Husain et al. 2016). SVS uses a tiling approach, considering separate energy budgets for bare ground and low vegetation, high vegetation, and snow within a grid cell.

Within the soil column, the vertical discretization consists of N soil layers where the vertical movement of water following the one-dimensional Richards equation for unsaturated soils.

- **Geophysical Fields**
  - **Soil texture : gridded Global Soil Dataset for Earth System Models (GSDE) (Shangguan et al. 2014).**
  - **Land water mask and Vegetation Fractions: CCI-LC 2015 (ESA Climate Change Initiative) at 300 m resolution and the inland water body data at 150 m resolution.**

Impacts of SMAP TB assimilation on Soil Moisture and NWP

Experimental Set-up : Offline CaLDAS Cycles

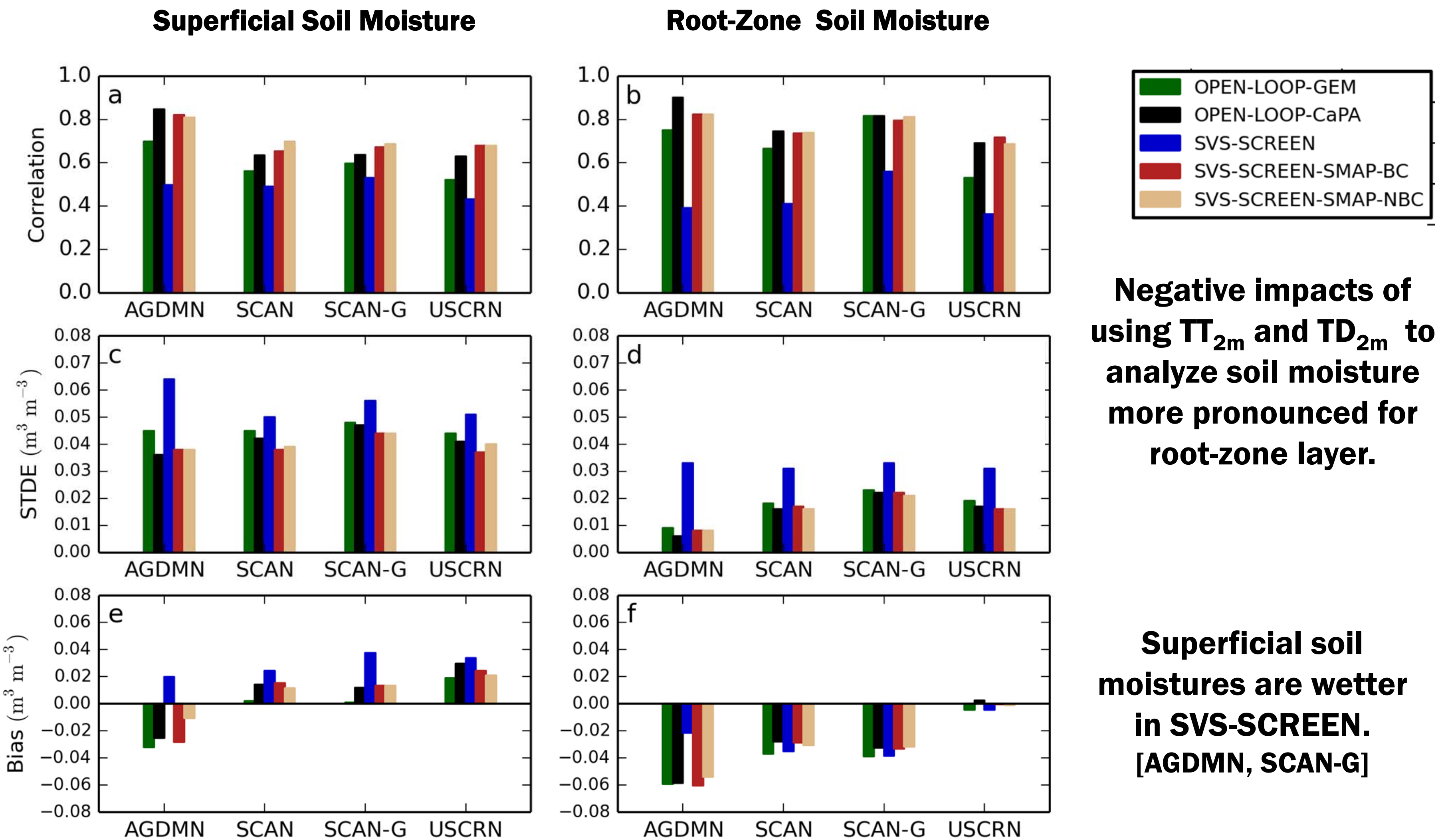
Experiment	Assimilation Methodology	Observations Assimilated	Analyzed Variables	Temporal Frequency	Bias Correction
SVS-SCREEN	EnKF (24)	TT_{2m}, TD_{2m}	T_{GROUND}(1,2), T_{VEG}(1,2), W_{SOIL} (1-5)	3 h	None
SVS-SCREEN-SMAP-NBC	EnKF (24)	TT_{2m}, TD_{2m} SMAP (TBH)	T_{GROUND}(1,2), T_{VEG}(1,2), W_{SOIL} (1-4)	3 h	None
SVS-SCREEN-SMAP-BC	EnKF (24)	TT_{2m}, TD_{2m} SMAP (TBH)	T_{GROUND}(1,2), T_{VEG}(1,2), W_{SOIL} (1-4)	3 h	Linear CDF matching for SMAP TBs

- Time Period : June- August 2015.
- NWP System : Global Environmental Multiscale (GEM) model with a 10-km grid spacing covering North America.
- SMAP TBs : SMAP Level 1B Radiometer Half-Orbit Time-Ordered Horizontal Polarized TBs, version 3.
- TT_{2m} and TD_{2m}; SYNOP and METAR networks over North America.
- NWP Forecasts: Impacts upon near-surface parameters from a series of 48-h forecasts with GEM from the initial conditions from the individual CaLDAS cycles at 0000 UTC.

Impacts on Soil Moisture

Evaluation period is short (2 months) but these results are consistent with more extensive, multi-year soil moisture evaluations (e.g., Reichle et al. 2017; De Lannoy et al. 2016ab).

Sparse in-situ networks : July – August 2015

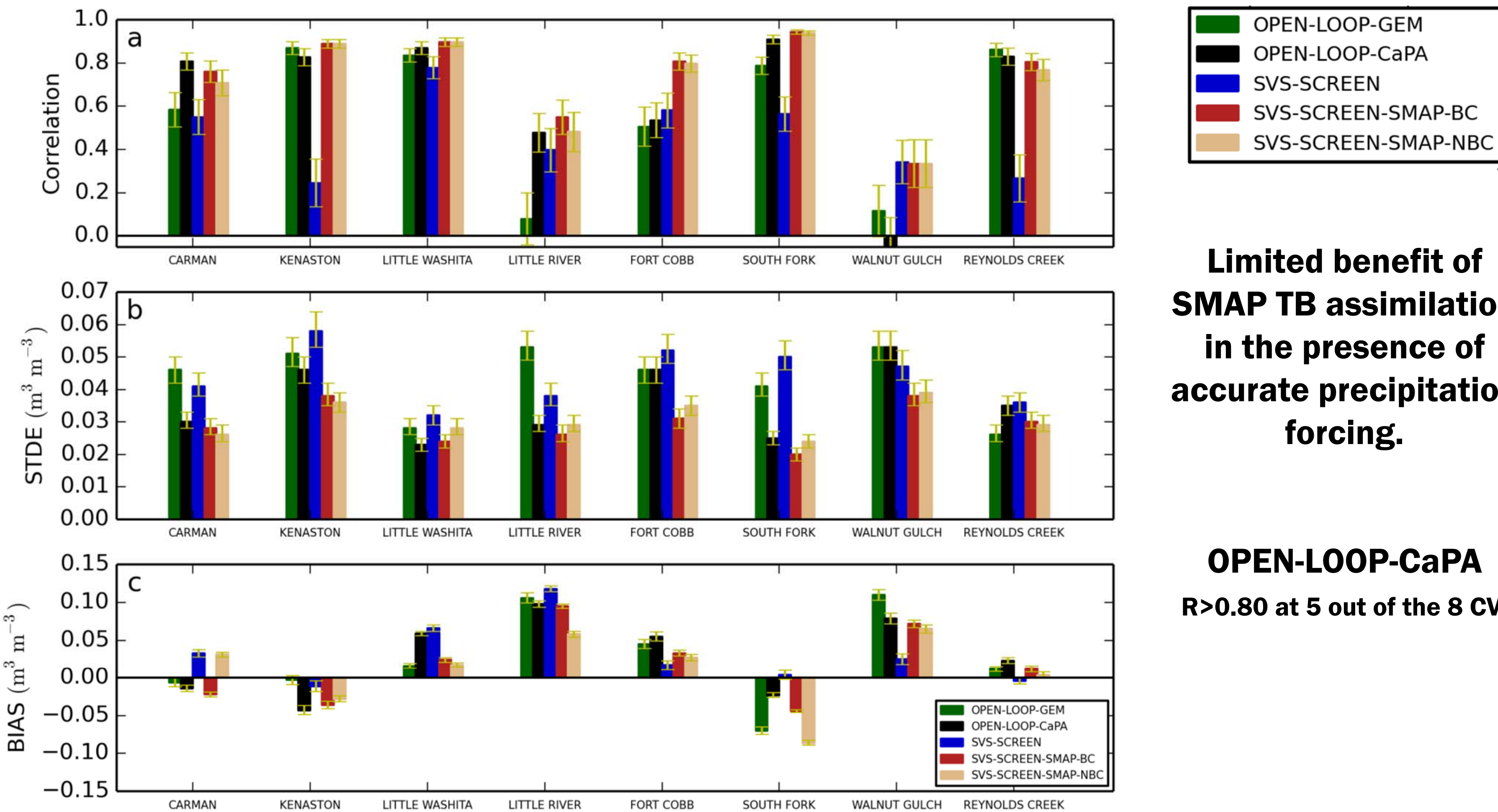


Negative impacts of using TT_{2m} and TD_{2m} to analyze soil moisture more pronounced for root-zone layer.

Superficial soil moistures are wetter in SVS-SCREEN. [AGDMN, SCAN-G]

SMAP core validation sites : July – August 2015

Superficial Soil Moisture



Limited benefit of SMAP TB assimilation in the presence of accurate precipitation forcing.

OPEN-LOOP-CaPA

R>0.80 at 5 out of the 8 CVS

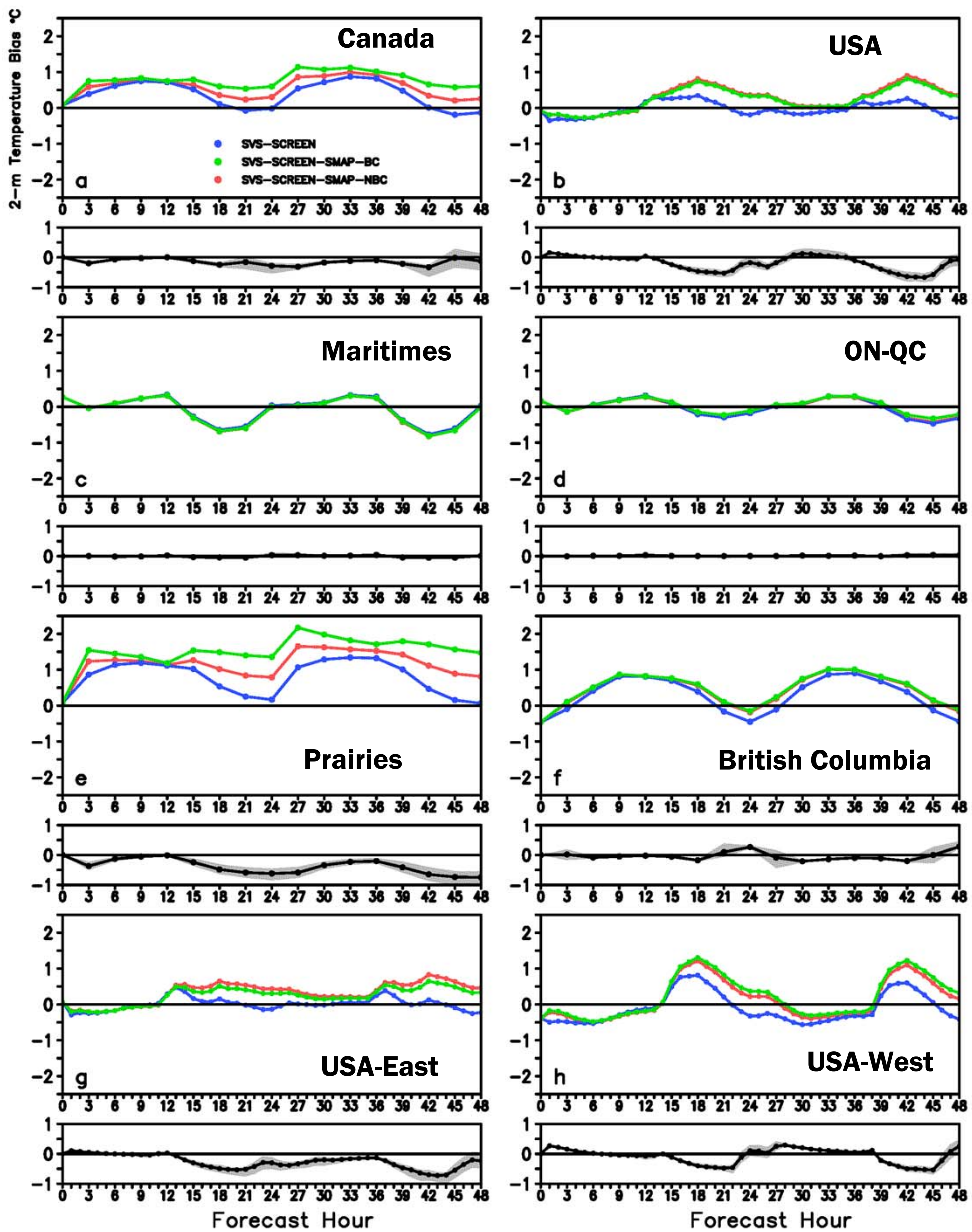
Impacts on Short-Range NWP

Series of 31 48-h forecasts
Initialized at 0000 UTC with different CaLDAS Initial Conditions
July – August 2015

TT_{2m} biases as a function of forecast range

Both SMAP experiments are warmer than SVS-SCREEN

Impact of bias correction is mixed

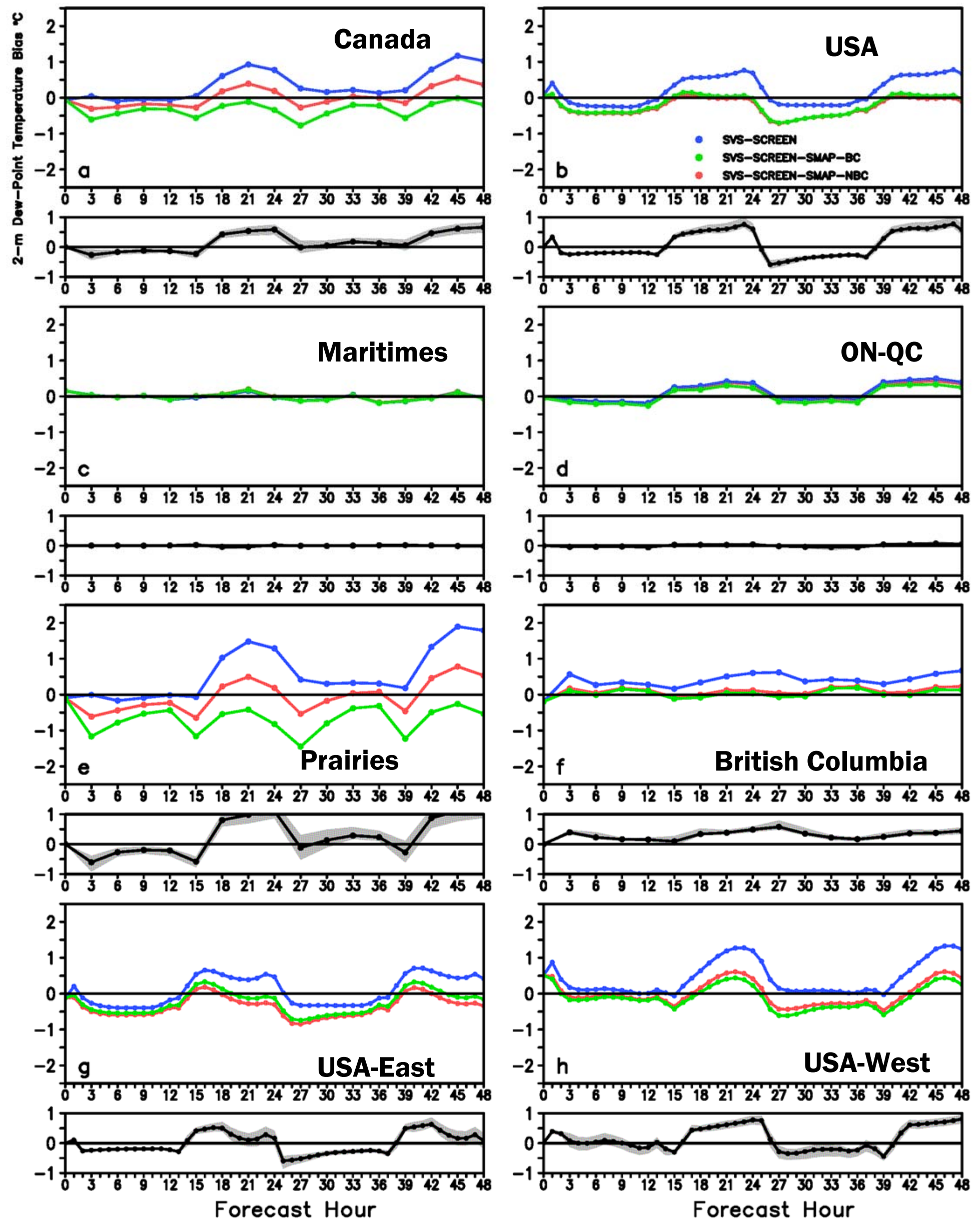


SVS-SCREEN

SVS-SCREEN-SMAP-BC

SVS-SCREEN-SMAP-NBC

TD_{2m} biases as a function of forecast range



Greater impacts when compared to TT_{2m}.

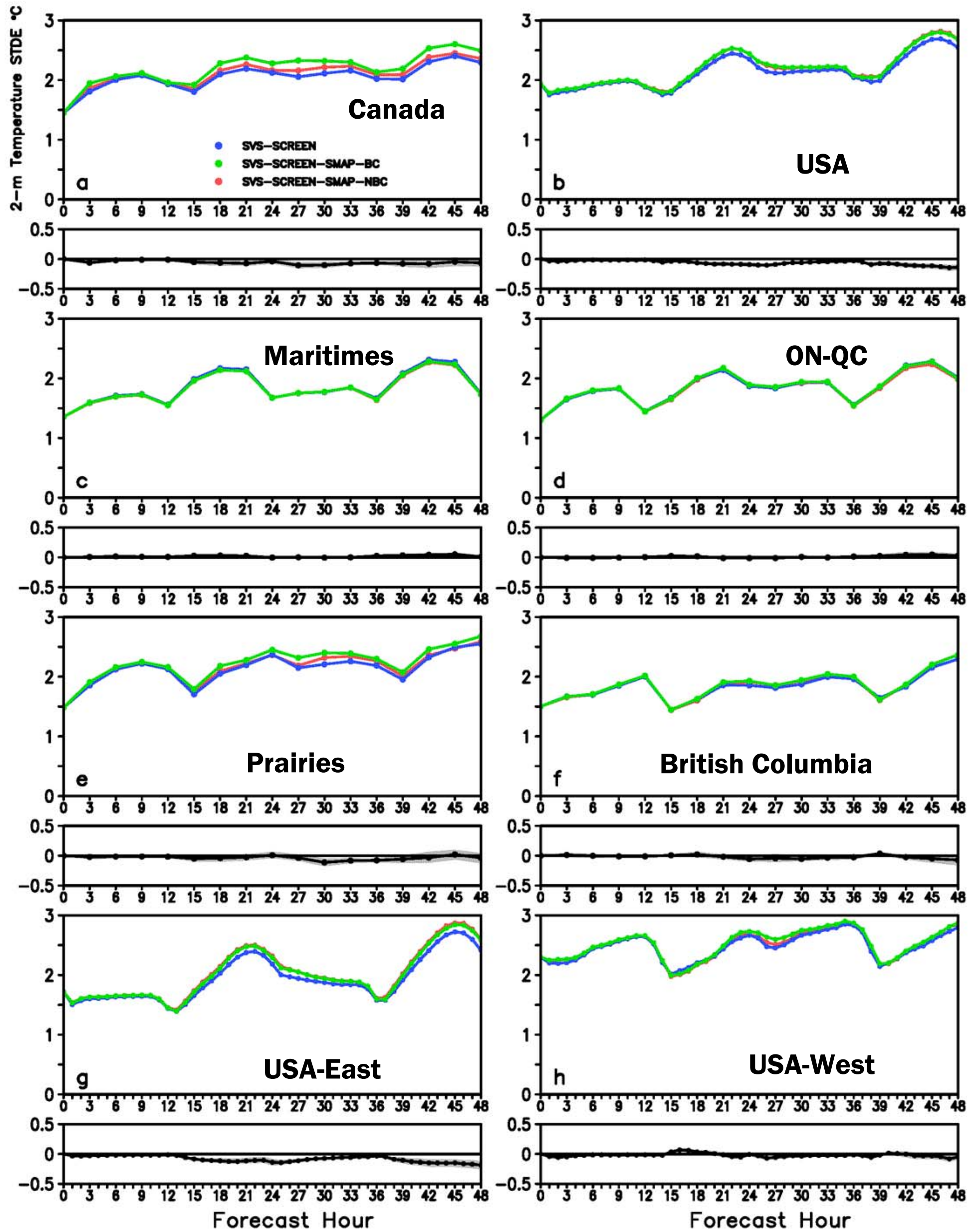
Clear TD_{2m} gradient between experiments.

Pronounced daytime wet TD_{2m} bias in SVS-SCREEN

- **SVS-SCREEN**
- **SVS-SCREEN-SMAP-BC**
- **SVS-SCREEN-SMAP-NBC**

TT_{2m} STDE as a function of forecast range

Enhanced TT_{2m} STDE during the daytime in the SMAP experiments.

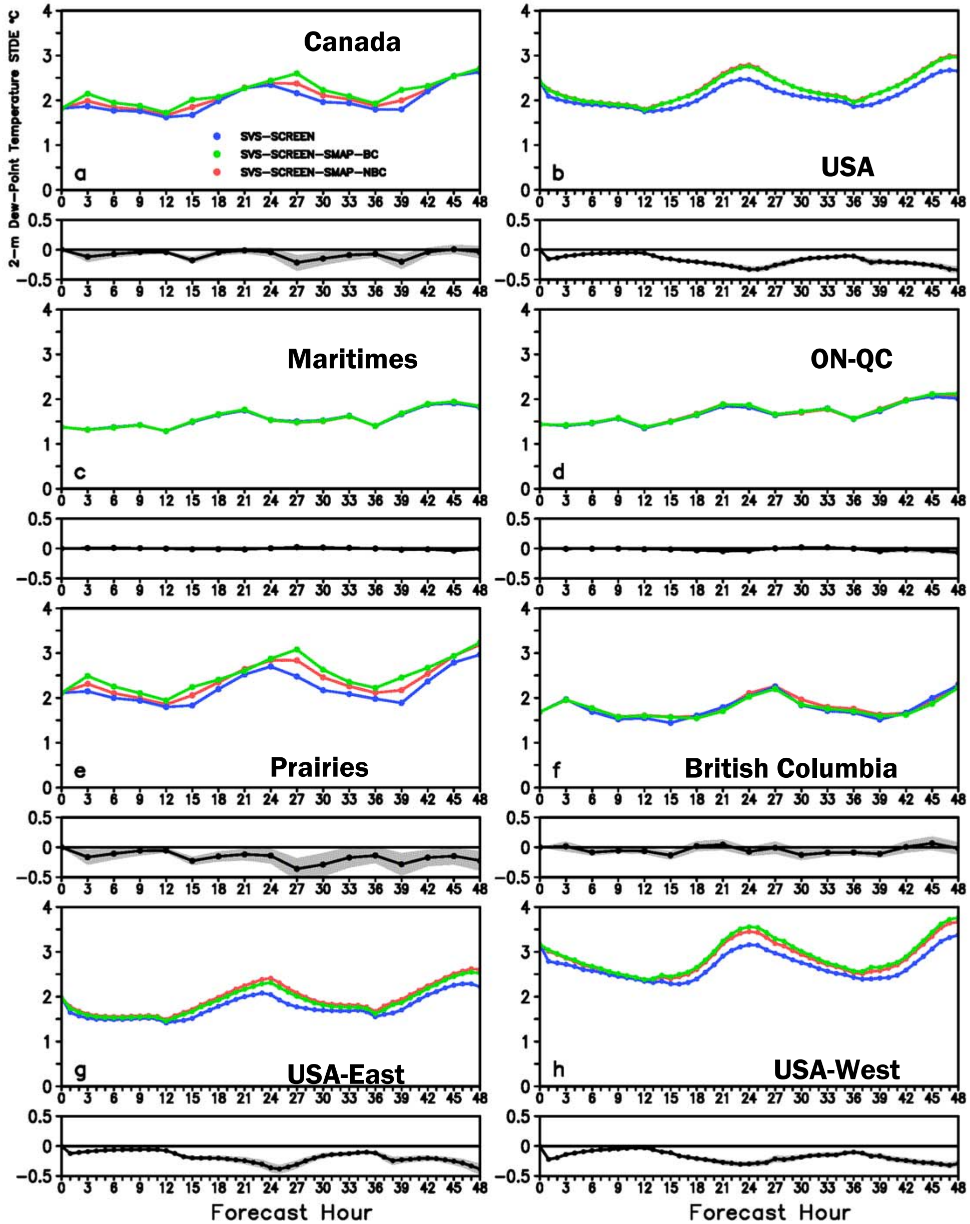


- **SVS-SCREEN** (blue)
- **SVS-SCREEN-SMAP-BC** (green)
- **SVS-SCREEN-SMAP-NBC** (red)

TD_{2m} STDE as a function of forecast range

Enhanced TD_{2m} (~10%) STDE during the daytime in the SMAP experiments.

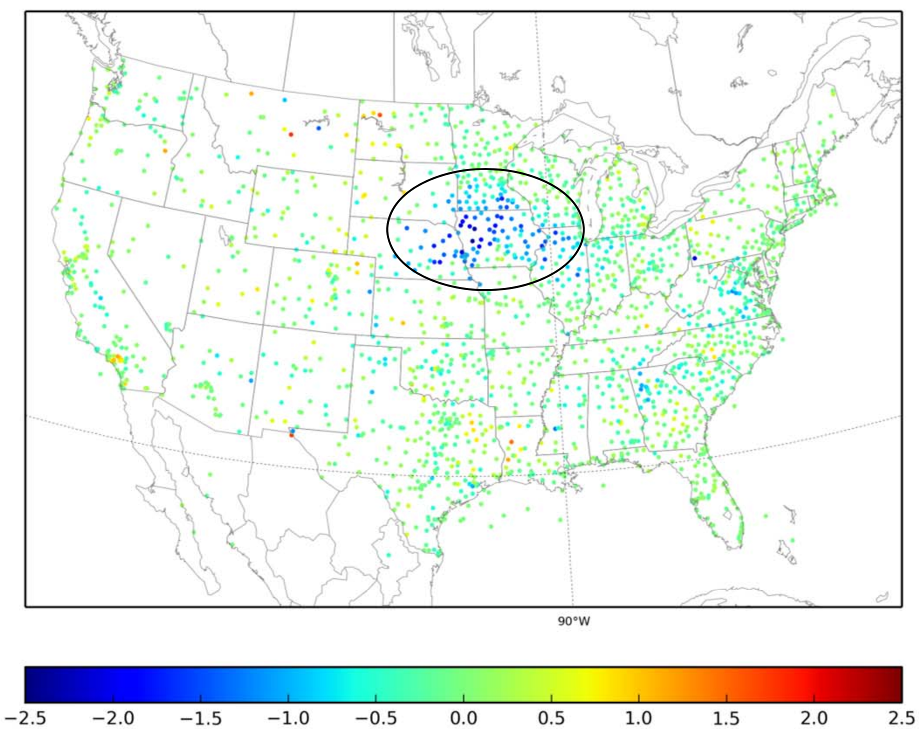
- SVS-SCREEN
- SVS-SCREEN-SMAP-BC
- SVS-SCREEN-SMAP-NBC



2-m Dew-Point Temperature (TD_{2m})
SVS-SCREEN vs SVS-SCREEN-SMAP-NBC

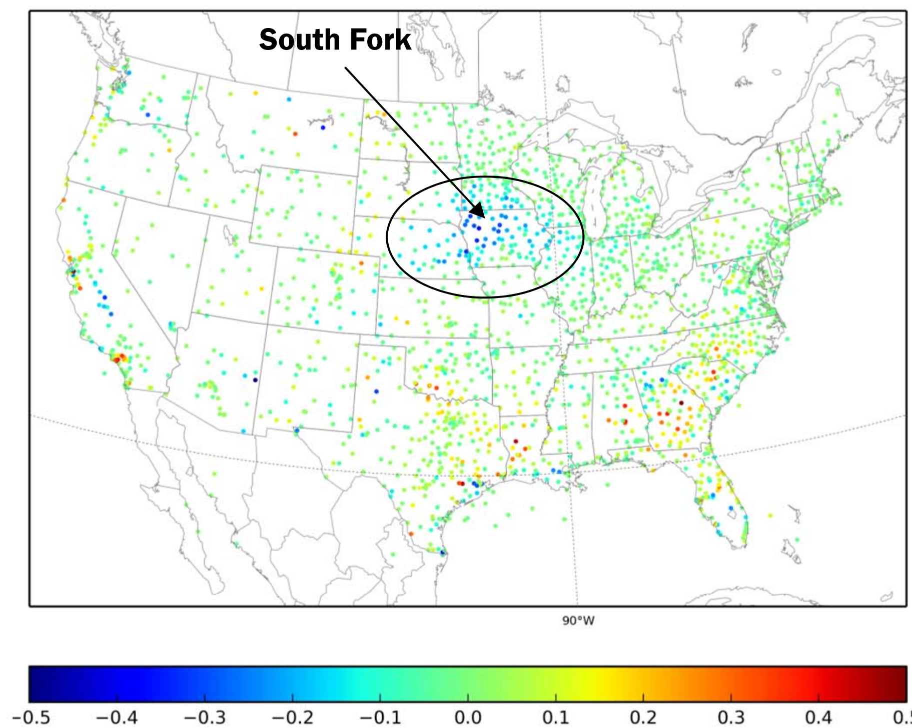
T=24h

STDE TD_{2m}
[SVS-SCREEN – SVS-SCREEN-SMAP-NBC]



SVS-SCREEN Better | **SVS-SCREEN-SMAP-NBC Better**

Correlation TD_{2m}
[SVS-SCREEN –SMAP-NBC– SVS-SCREEN]

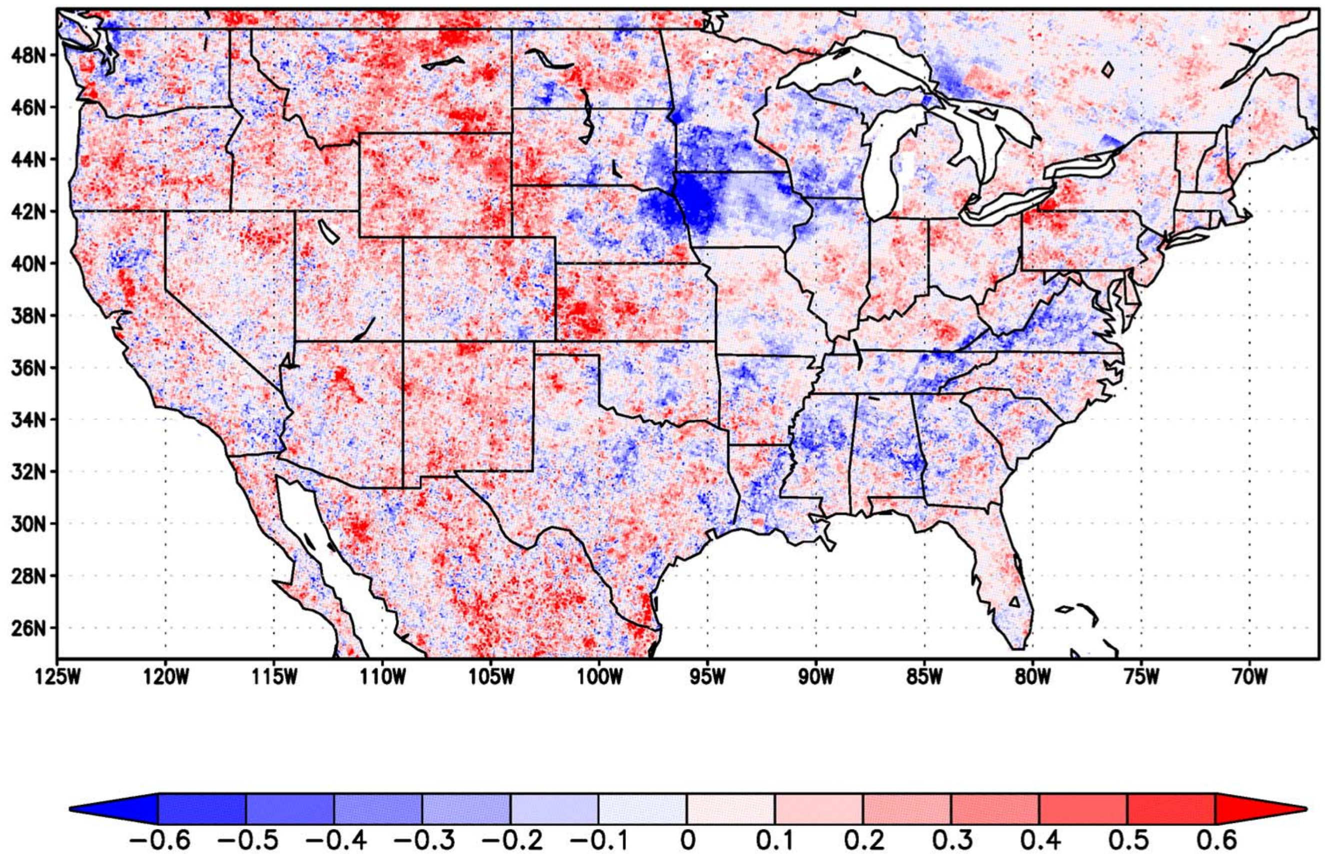


SVS-SCREEN Better | **SVS-SCREEN-SMAP-NBC Better**

Correlation Daily Evapotranspiration

[SVS-SCREEN-SMAP-NBC ; ALEXI] – [SVS-Screen; ALEXI]

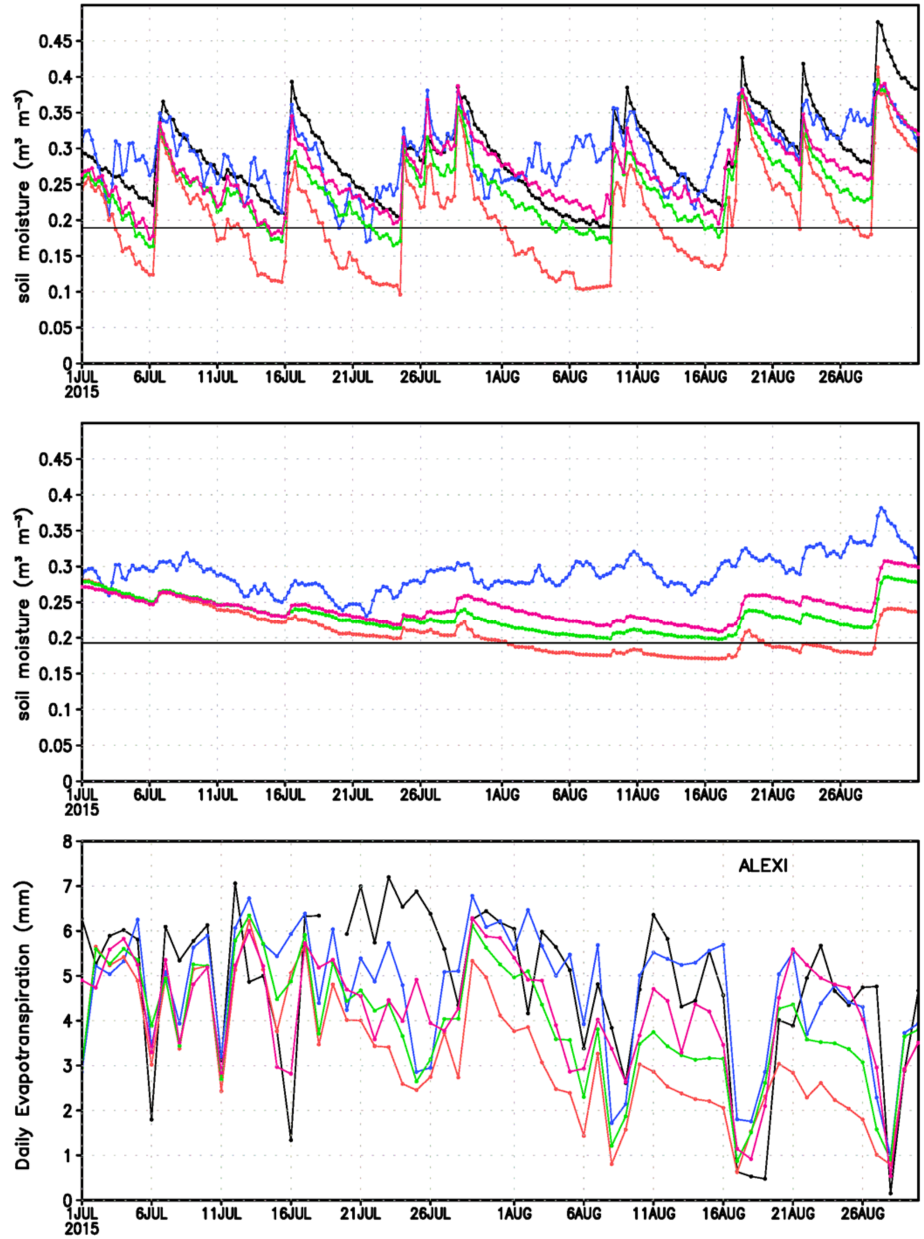
August 2015



SVS-SCREEN Better

SVS-SCREEN-SMAP-NBC Better

SMAP Core Validation Site : South Fork, IA



- **SVS-SCREEN**
- **SVS-SCREEN-SMAP-BC**
- **SVS-SCREEN-SMAP-NBC**
- **OBSERVATIONS**
- **OPEN-LOOP-CAPA**

Summary

- Analyzing soil moisture with SMOS/SMAP TBs has lead to superior correlation and STDE scores when compared to in-situ observations. Results are consistent with more extensive, multi-year evaluations.

- The improvements in simulated soil moisture result from a combination of an improved land-surface model (SVS), including geophysical fields, and the assimilation of SMOS TBs.

- Daytime TD_{2m} biases are improved (i.e., drier) in the SMAP experiments, when compared to SVS-SCREEN which are notably wetter.

- A deterioration in TD_{2m} STDE scores was found for the SMAP experiments, concentrated during the daytime period over the Northern Great Plains.

- A comparison of modelled evapotranspiration fluxes with those derived from ALEXI found a deterioration in the temporal correlations located over the same regions as for the TD_{2m} STDE scores.

Thank you
Merci

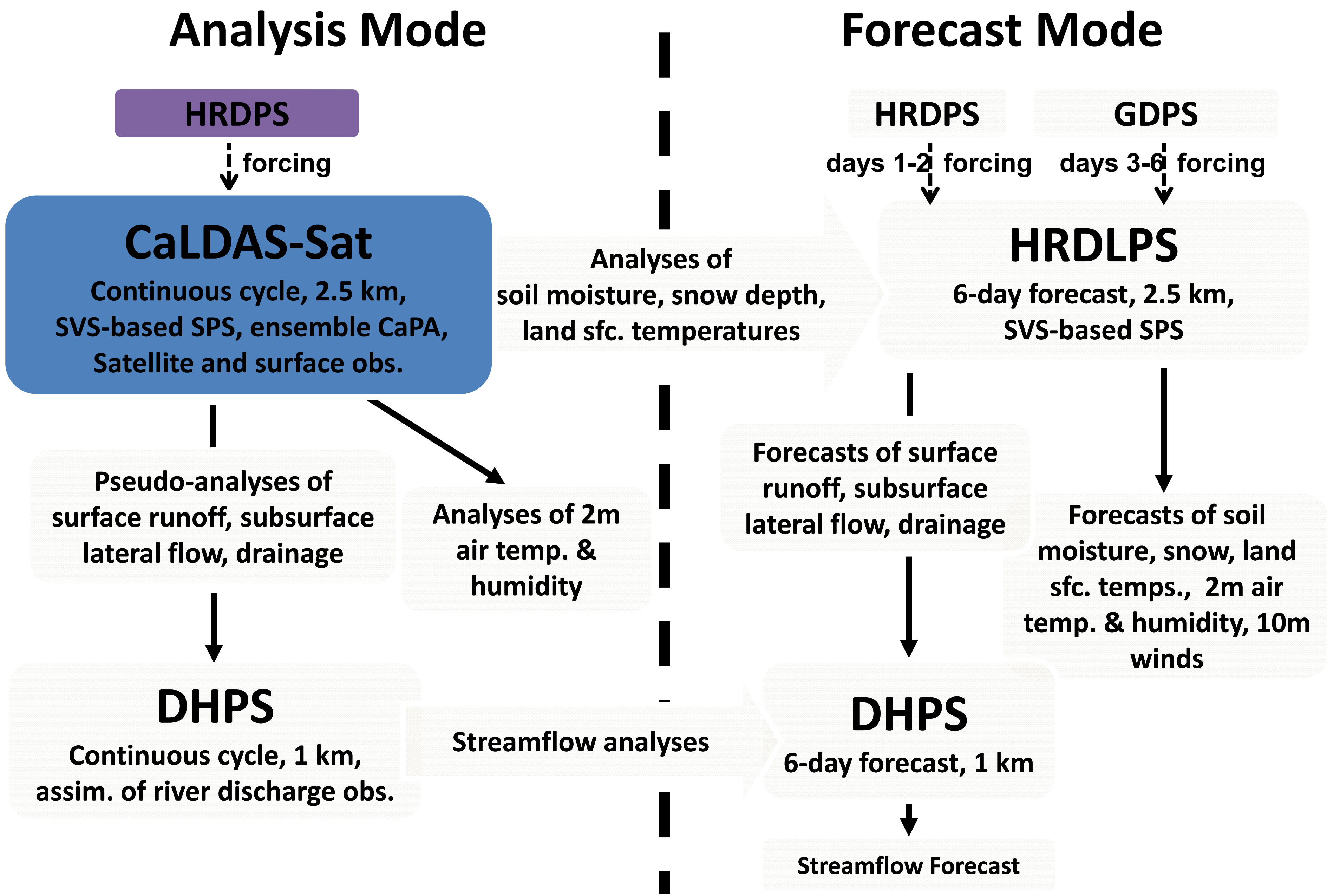
Technical specifications : CaLDAS-Sat

- Land-surface model : SVS, SPS5.9-svs.5 – to be updated to SPS5.9.8 (bit pattern validates)
- EnKF Forecast step : 3h, 24 members
- Resolution : 2.5 km grid spacing, core HRDPS domain
- Latency : 10 h
- Forward Model : Community Microwave Emission Modeling Platform (CMEM) developed at ECMWF. Needed to convert the SVS land-surface into a first-guess L-band brightness temperature.

- Observations assimilated:
  - Soil Moisture and Ocean Salinity (SMOS) horizontal brightness temperatures (TB)
  - GOES Skin Temperature retrievals
  - Snow depth observations from SYNOP, METAR and SWOB networks
  - Precipitation gauge observations from the METAR and SYNOP networks

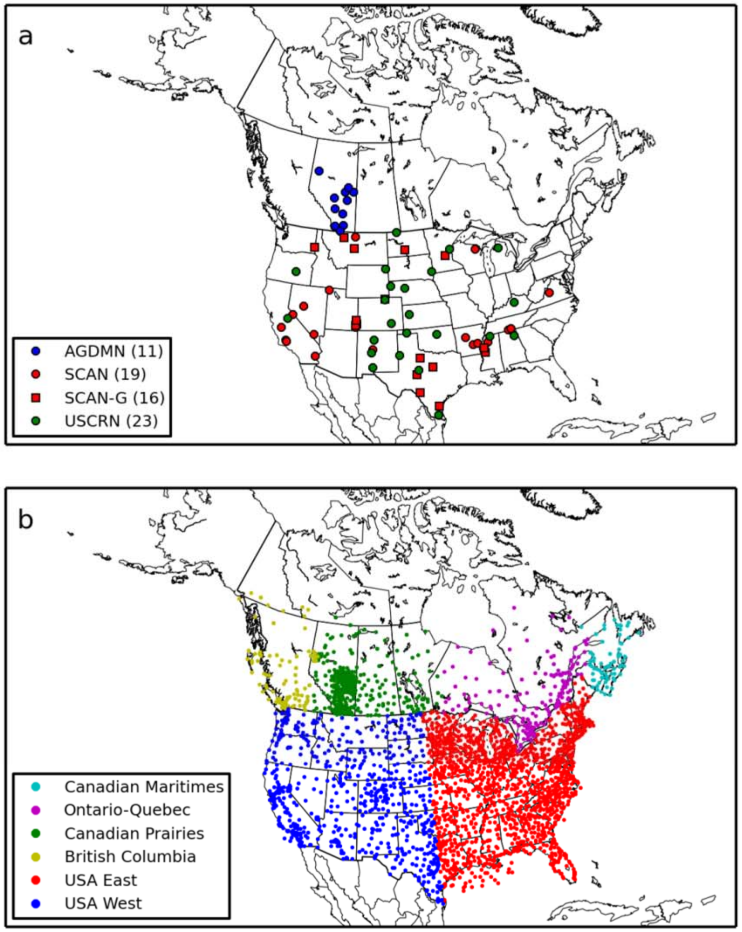
- Control and Analyzed variables:
  - Soil moisture (layers 1-4 down to a depth of 40 cm)
  - Surface temperatures : bare ground, vegetation, and snow
  - Snow depth
  - Screen-level temperatures

Surface and River Prediction System

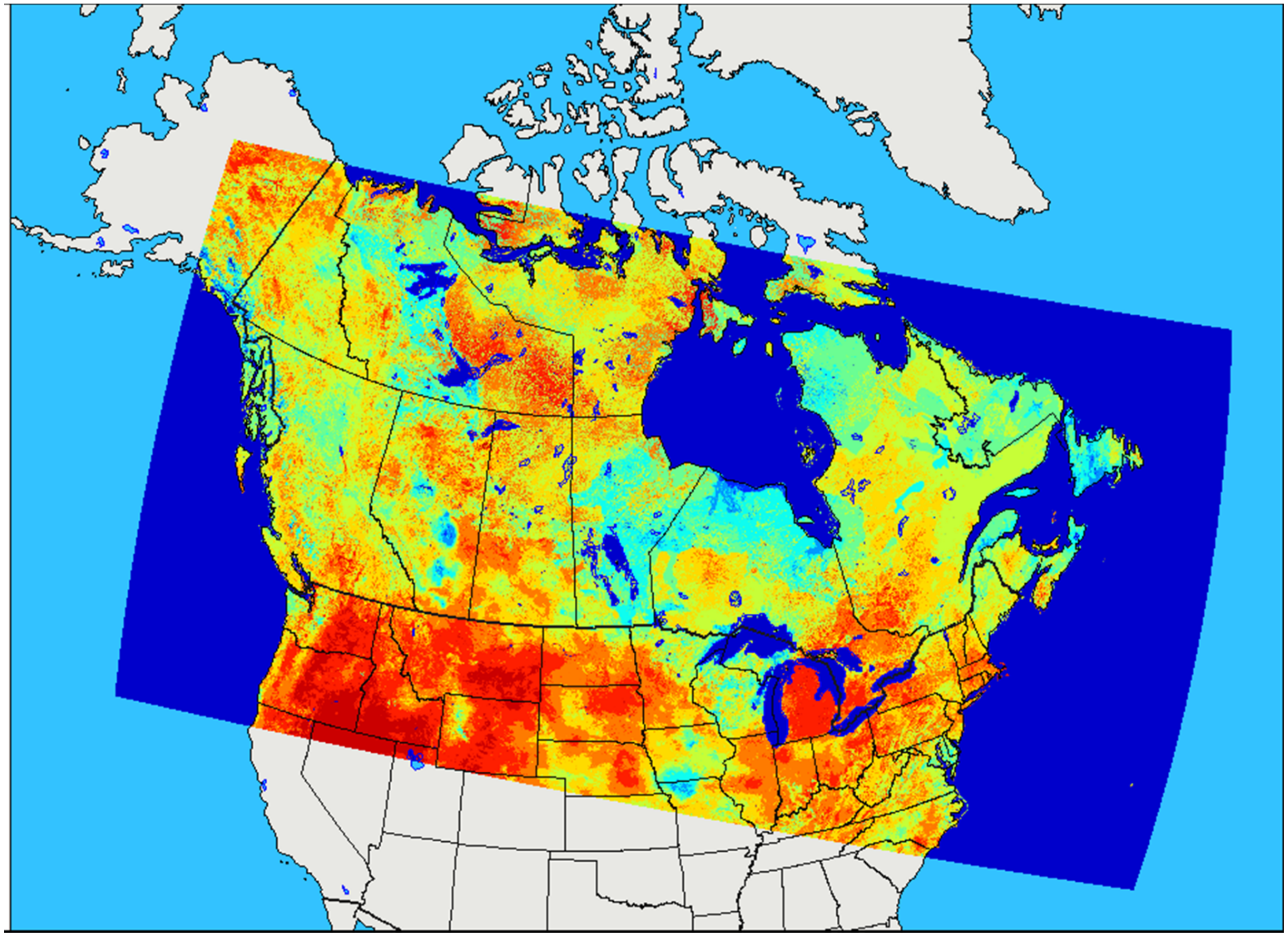


Extra Slides

Soil Moisture and NWP verification

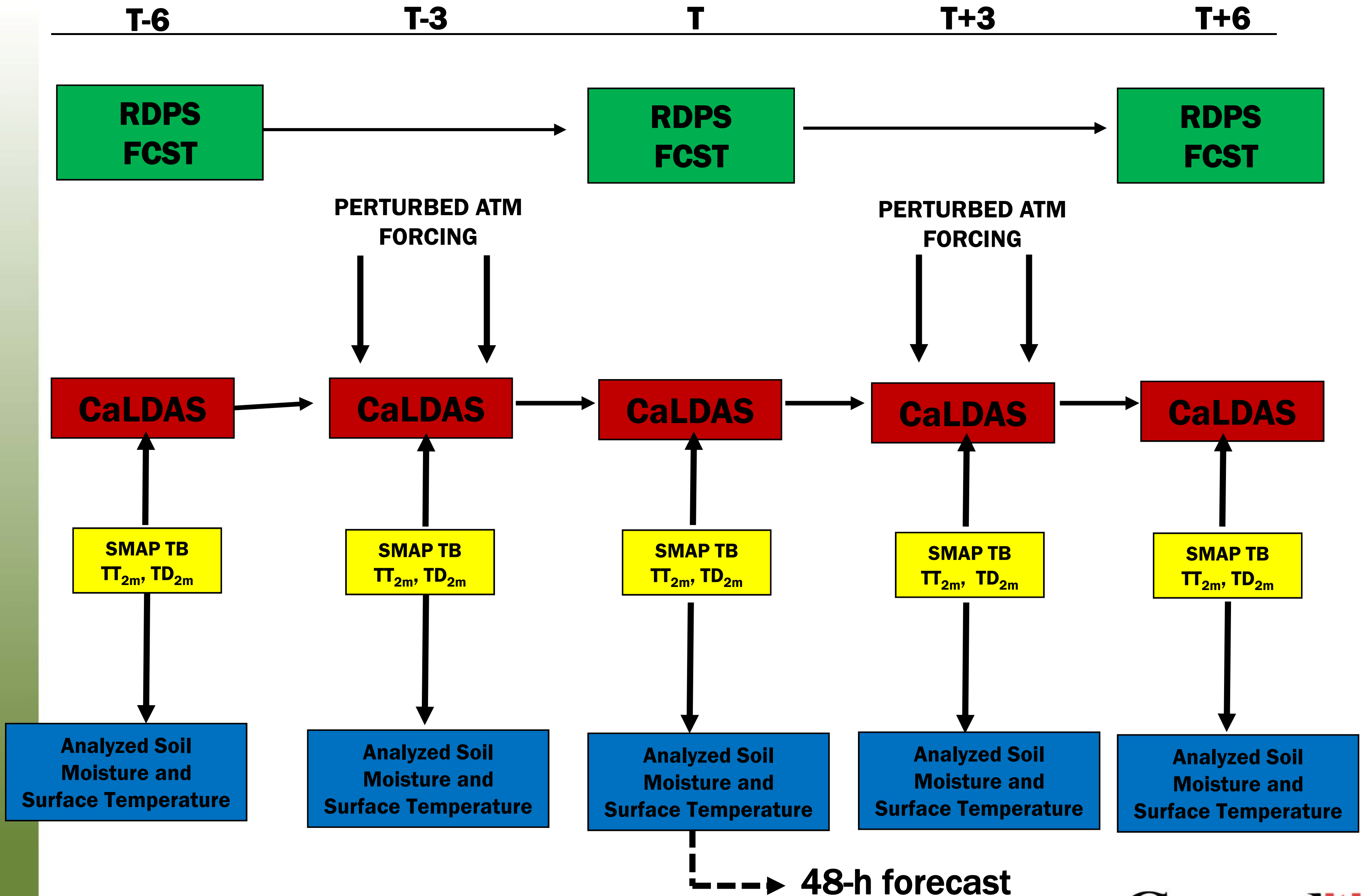


CaLDAS-Sat Domain



Same core domain as for CaLDAS screen which is coupled to the HRDPS (2578 x 1328) at a 2.5 km grid spacing.

CaLDAS - Offline Experimental Setup



Atmosphere-Land Exchange Inverse model (ALEXI)

- **ALEXI is based upon thermal infrared imagery and is coupled to a two-source energy balance model (TSEB) (Anderson et al. 2007). For this study the infrared data comes from the GOES-East (13) and GOES-West (15) platforms.**

- **The land-surface within TSEB is treated as a composite of soil and vegetation components, where separate energy budgets are calculated for both.**

- **To simulate land-atmosphere feedbacks, ALEXI has been coupled to an atmospheric boundary layer model.**

- **Extrapolation of instantaneous evapotranspiration fluxes to daily fluxes is based upon the conservation of evaporative fraction (EF) during daylight hours (Anderson et al. 2007). EF is the ratio of the latent heat to available energy.**

CaLDAS-Sat (Satellite)

- <u>Objective</u>: Produce the most accurate estimate of the land surface state, including soil moisture, surface temperatures, and snow.

- Emphasis on the assimilation of observations derived from space-based remote sensing platforms; SMOS/SMAP and GOES surface temperature retrievals.

- An Ensemble Optimum Interpolation is used for the snow analysis.

- The SVS land-surface model is used to evolve the land surface.

- Makes use of the operational HRDPS for the lower atmospheric forcing.

- The CaLDAS-Sat analyses do not feed back to the operational models at CMC.