Assimilation of L-band data into the Canadian Land Data Assimilation System (CaLDAS)

Marco L. Carrera, Stéphane Bélair, Dorothée Charpentier, Shunli Zhang and Bernard Bilodeau

Meteorological Research Division

Environment Canada

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Current Research Soil Moisture Data Assimilation MRD Environment Canada

- Assimilation of screen-level data for the deterministic and ensemble NWP prediction systems ;

- Synthetic experiments for the assimilation of L-band passive data ;

- Assimilation of SMOS data for the CanEx-SM10 experiment and the larger Canadian Prairies region.

- Assimilation of SMOS data over North America for the 2012 drought period and SMAPVEX12.

The CANADIAN LAND DATA ASSIMILATION SYSTEM (CaLDAS)

IN

Ancillary land surface data

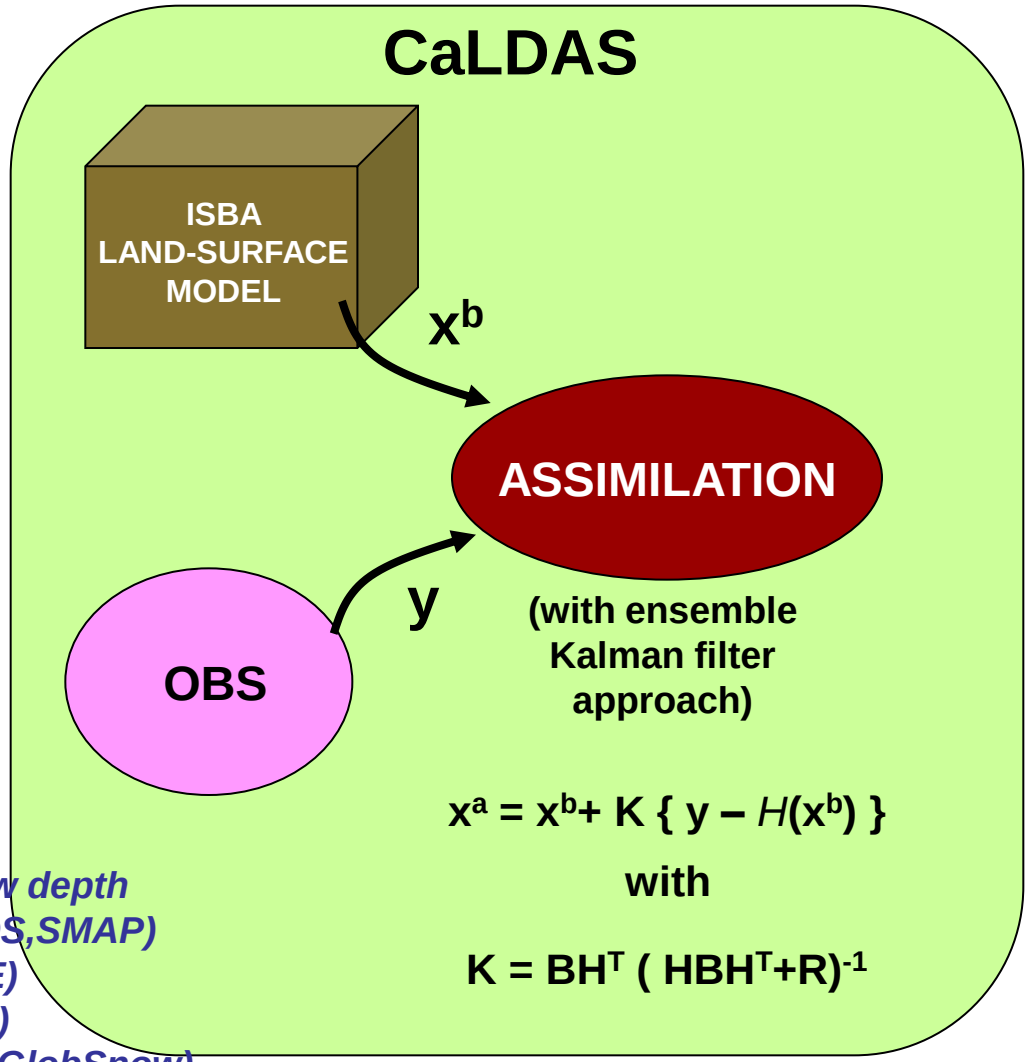
Orography, vegetation, soils, water fraction, ...

Atmospheric forcing

T, q, U, V, Pr, SW, LW

Observations

Screen-level (T, Td)
Surface stations snow depth
L-band passive (SMOS,SMAP)
MW passive (AMSR-E)
Multispectral (MODIS)
Combined products (GlobSnow)



OUT

Land surface initial conditions for NWP and hydro systems

Land surface conditions for atmospheric assimilation systems

Current state of land surface conditions for other applications (agriculture, drought, ...

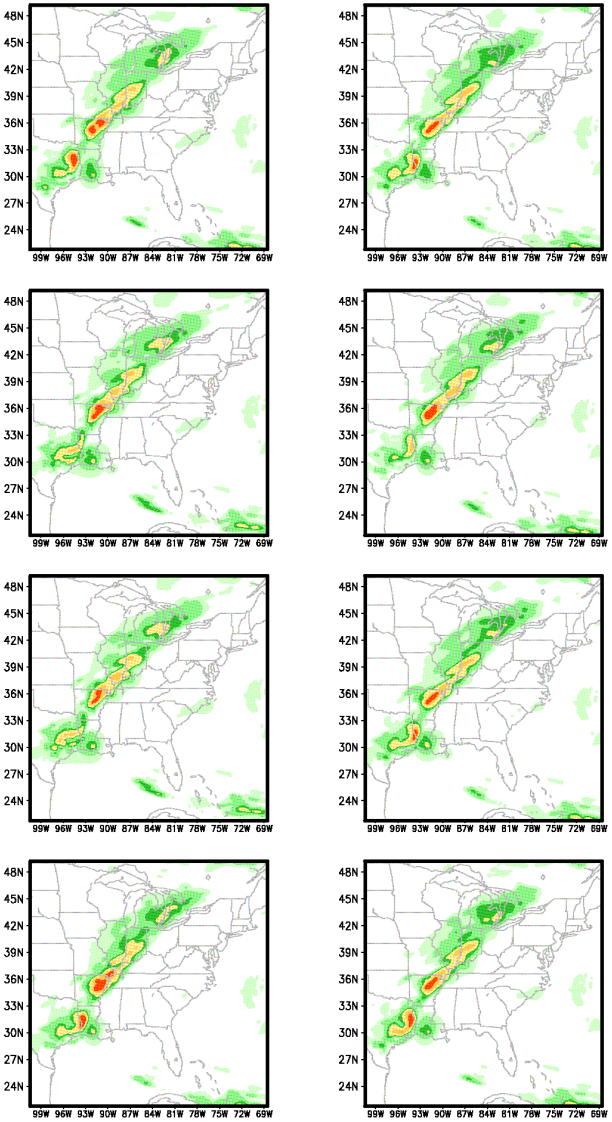
Canadian Precipitation Analysis (CaPA)
Generation of an Ensemble of Precipitation analyses

Perturbed Precipitation Gauge Observations Measurement + Errors of Representativity

Optimum Interpolation Assimilation

Spatially perturbed Model forecasts of precipitation

Ensemble of precipitation analyses

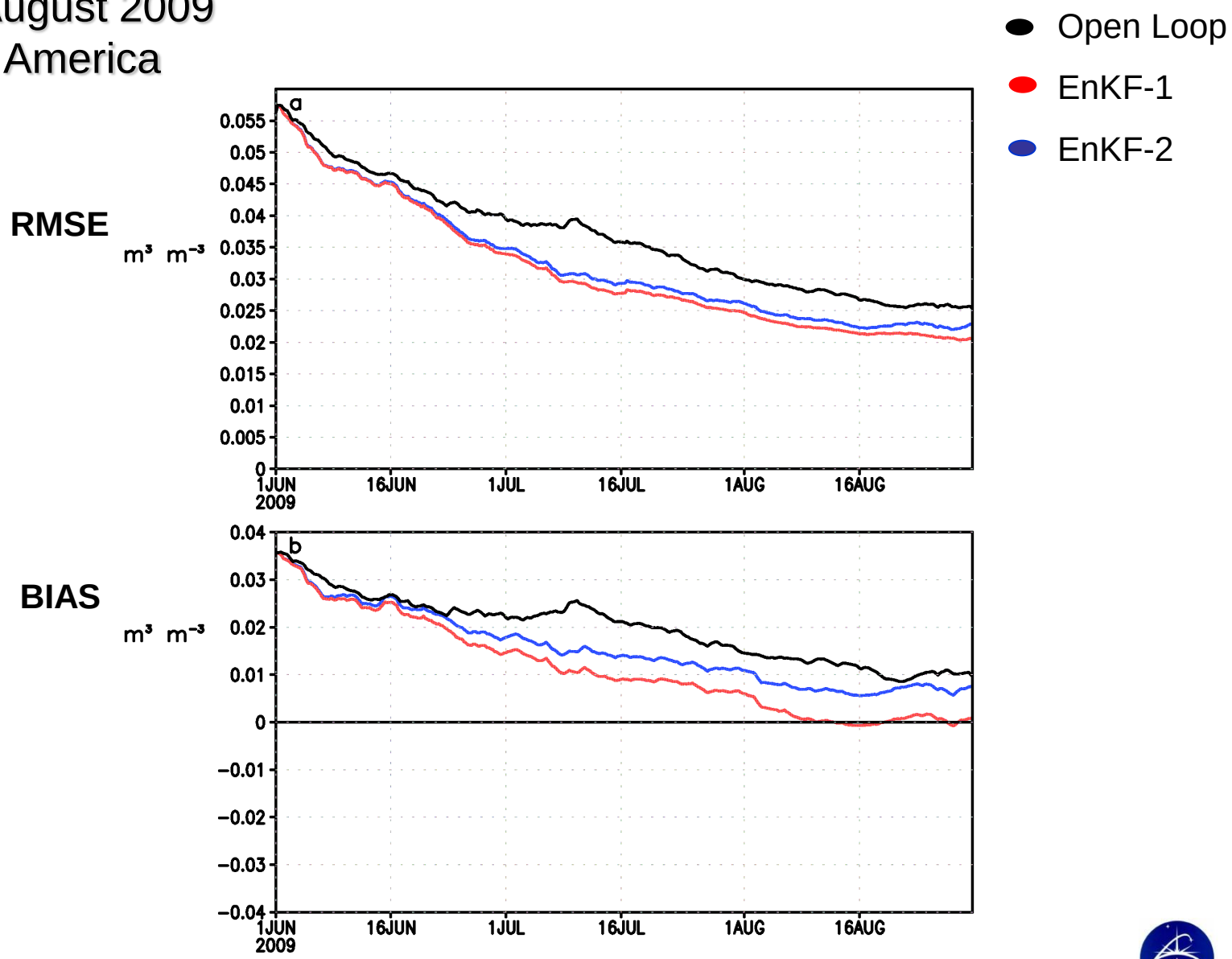


Canada

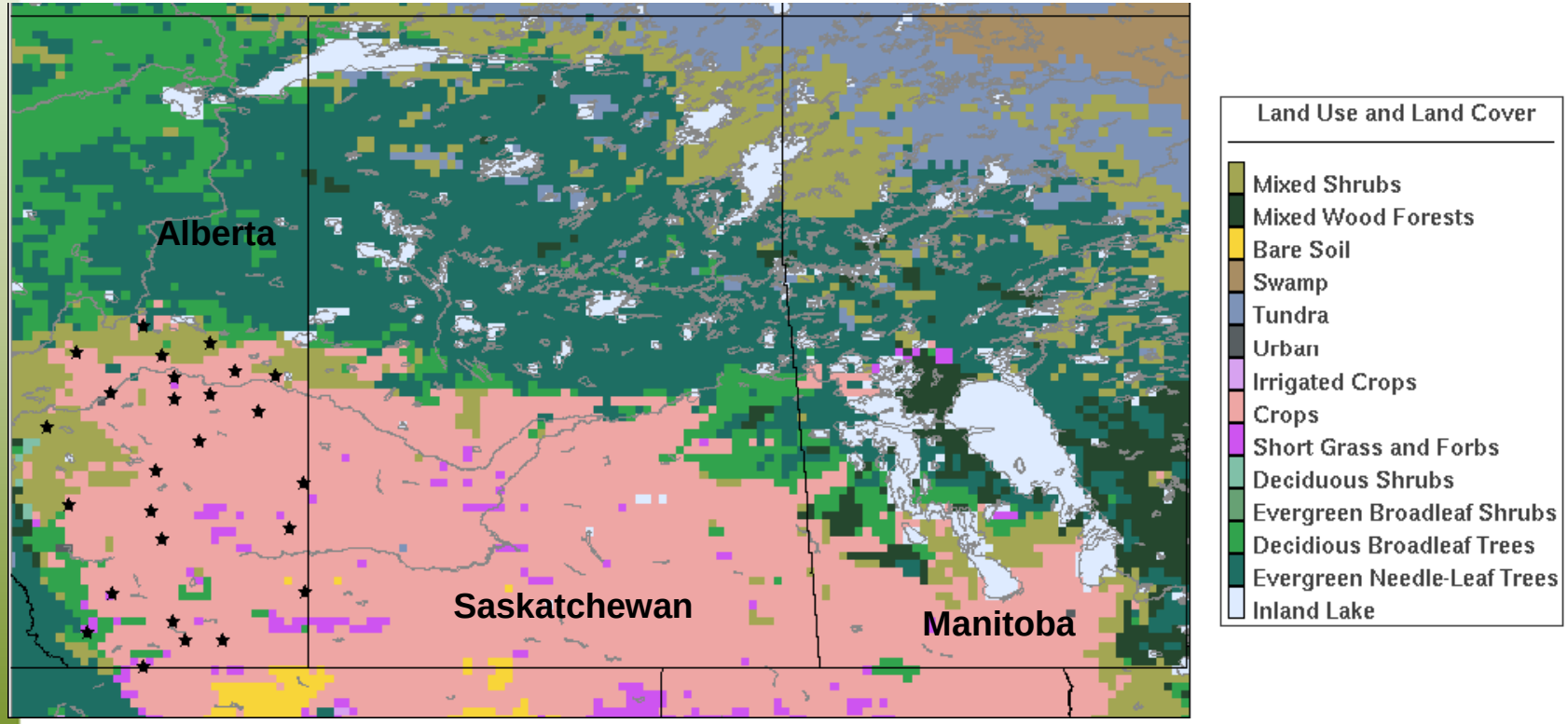
Synthetic Experiments
Assimilation of L-band Brightness Temperatures (TB)

- Synthetically generated L-band TBs from 1km nature/reality run over North America ;
- Average at 40km and perturbed ;
- Assimilated in CaLDAS ;
- Comparison against “reality” ;
- Useful for setting up CaLDAS configurations.

Root-Zone Soil Moisture
June – August 2009
North America



Land Use and Land Cover
Canadian Prairies



★ Alberta Droughtnet Station

EnKF Assimilation Experiment : 2010

- Ensemble Kalman Filter (EnKF) with **48 members** and perturbations to atmospheric forcing, soil moisture model prognostics variables, and the CMEM forward model.
- Horizontal resolution of 15-km covering the Canadian Prairie provinces. Control variables are superficial soil moisture (top 10 cm) and root-zone soil moisture.
- Assimilation of SMOS TBs for the period 1 May 2010 to 31 August 2010.
- SMOS TB observation error of 4 K which is homogeneous in space.
- Forward operator is the CMEM (Community Microwave Emission Modelling Platform) model developed at ECMWF.
- Quality Control : Consider SMOS observations within the exclusive alias free zone of the field of view (FOV). Reject TB values which exceed 350 K (hard-RFI filter).
- A Cumulative Distribution Function (CDF) matching procedure was used to re-scale the SMOS TBs prior to assimilation.

Canadian Experiment for Soil Moisture in 2010 (CanEX-SM10)

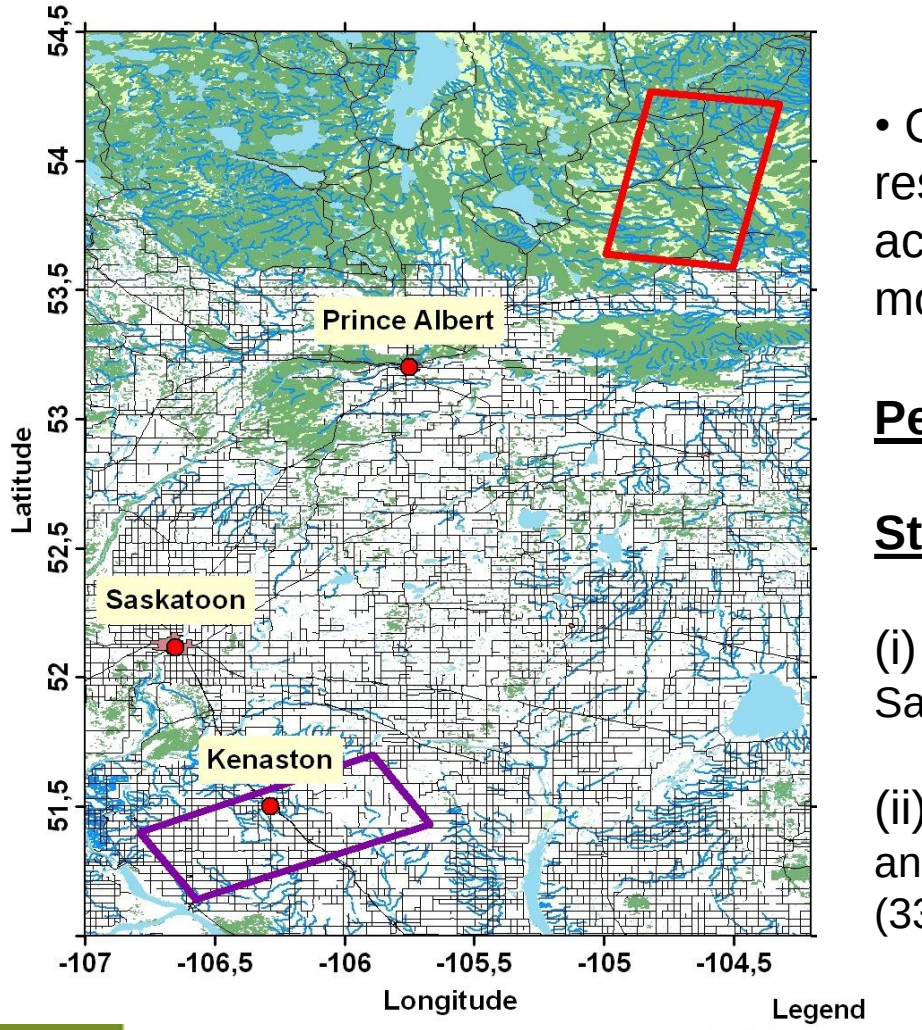


Image courtesy R. Magagi

Legend
BERMS site
Kenaston site

- Originated as an experiment for Canadian researchers to support SMOS Cal/Val activities over land and to develop soil moisture retrieval algorithms.

<u>Period</u> : 31 May – 17 June 2010

<u>Study Sites</u> :

(i) Kenaston agricultural site (~ 80 km south of Saskatoon) (33 km x 71 km).

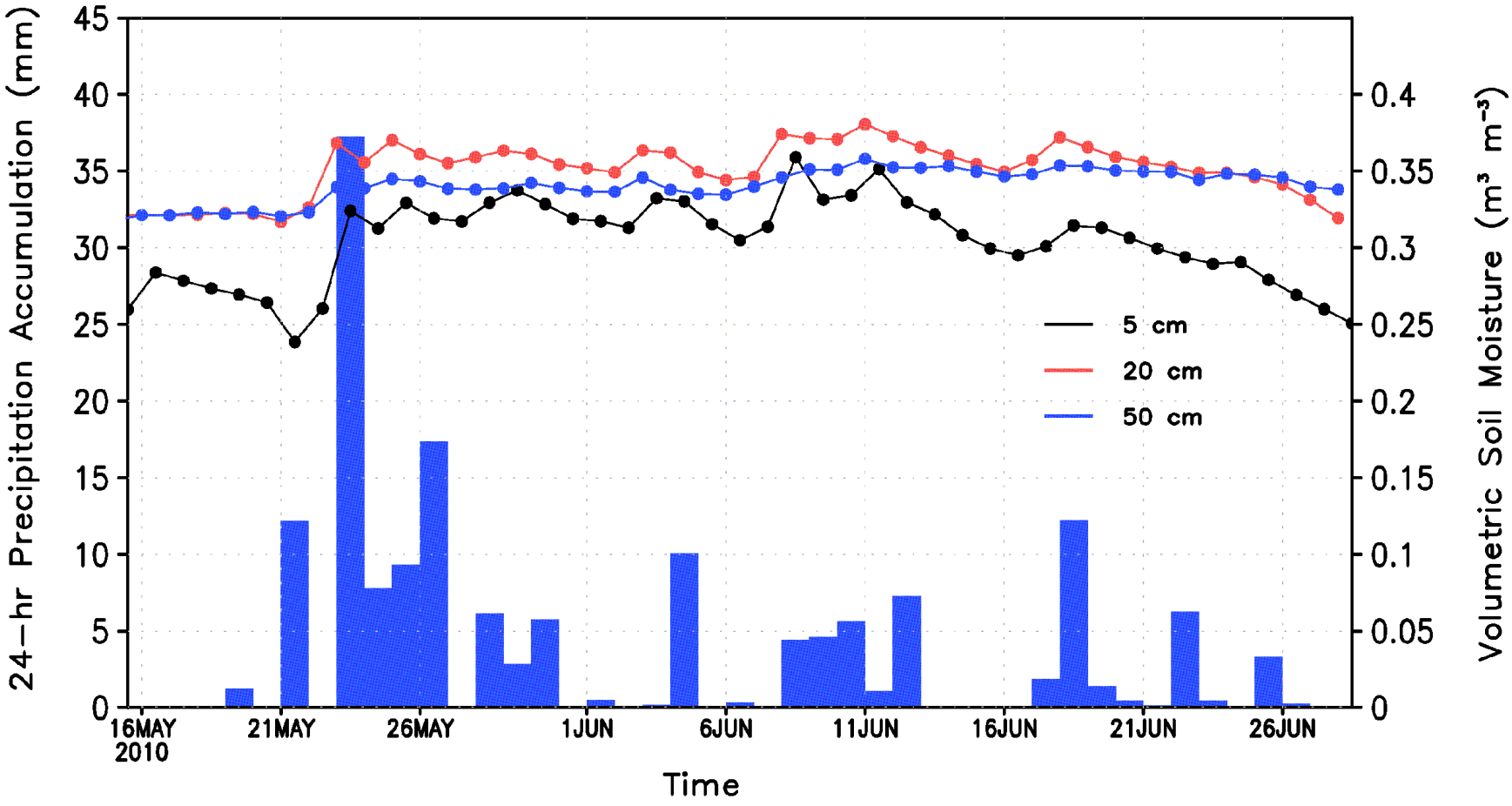
(ii) BERMS (Boreal Ecosystem and Research and Monitoring Sites) in northern Saskatchewan (33 km x 71 km).

Environment Canada Environnement Canada

CSA ASC

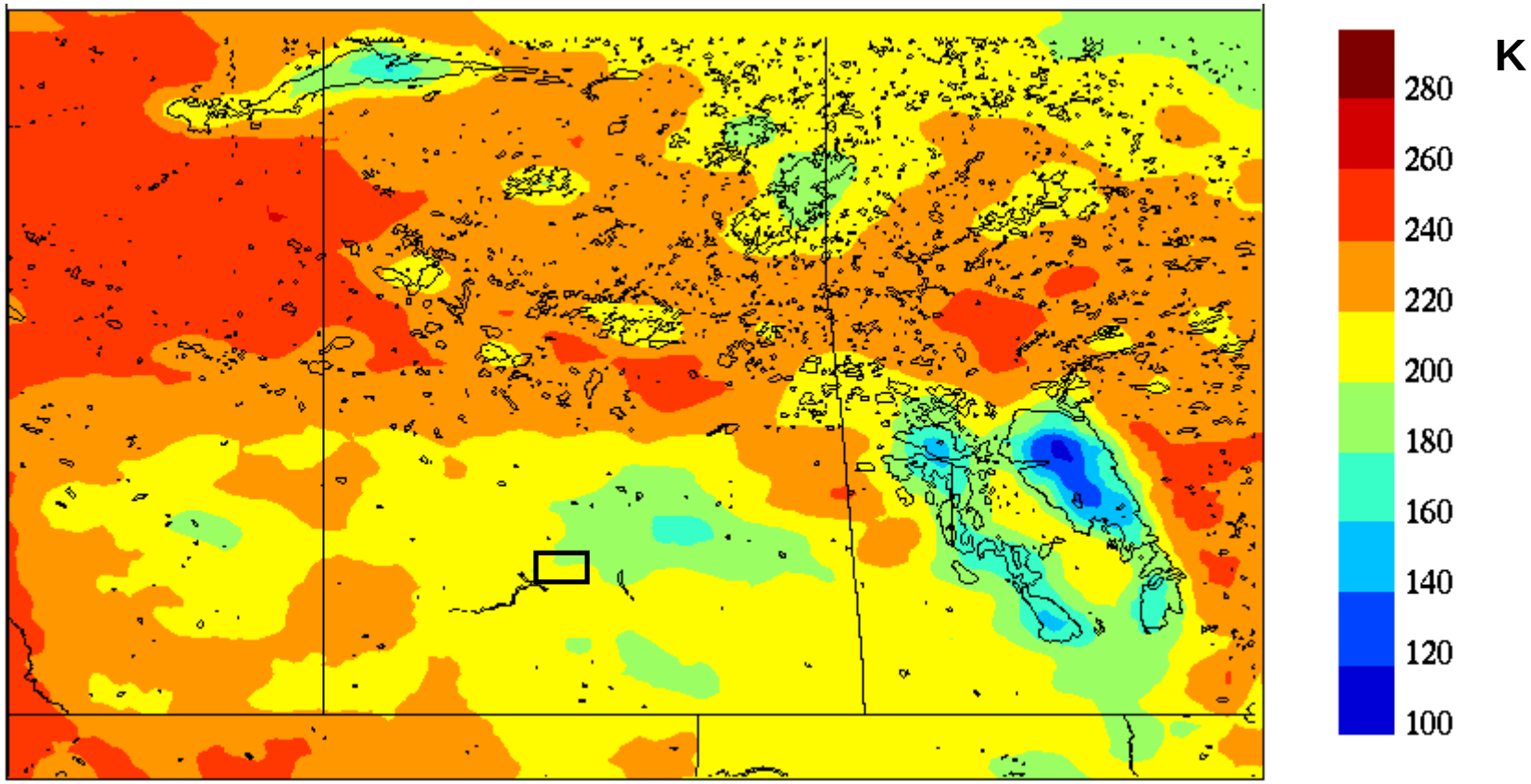
Canada

CanEX-SM10 : Soil Moisture and Precipitation



Significant precipitation prior to CanEx-SM10 period which created very wet soil conditions.

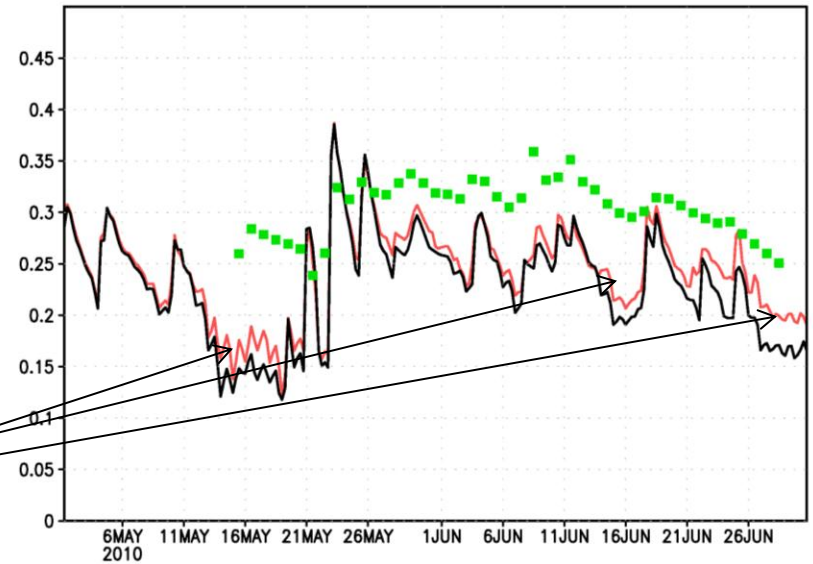
Mean SMOS Brightness Temperatures
Horizontal Polarization (40º)
CanEX-SM10 Period : 31 May – 16 June 2010



SMOS observations are consistent with very wet conditions on ground.

Soil Moisture Simulations : CanEX-SM10 : Kenaston

Superficial Soil Moisture ($m^3\ m^{-3}$)



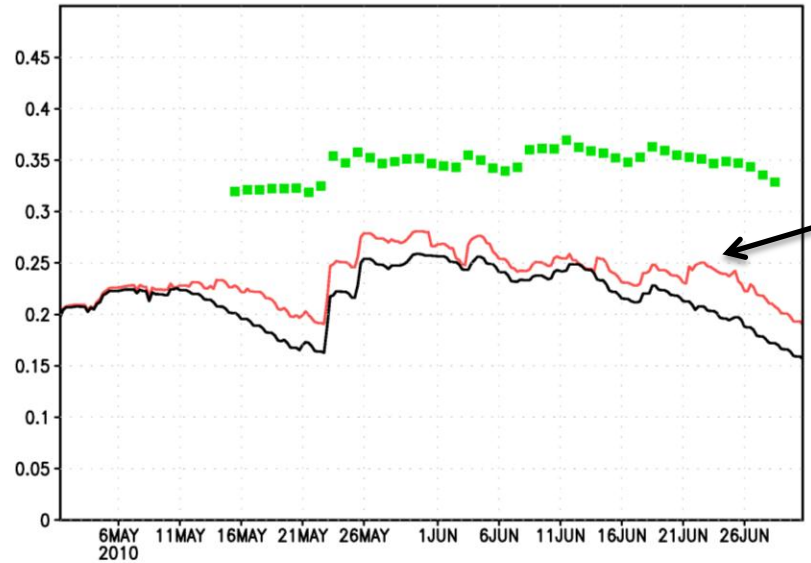
Open Loop

EnKF

Assimilation of SMOS TBs helps mostly with the dry down periods.

5-cm soil moisture

Root Zone Soil Moisture ($m^3\ m^{-3}$)



Assimilation of SMOS TBs leads to a more humid root-zone

Mean soil moisture sfc-50 cm

Forward Model

Community Microwave Emission Modeling (CMEM) Platform

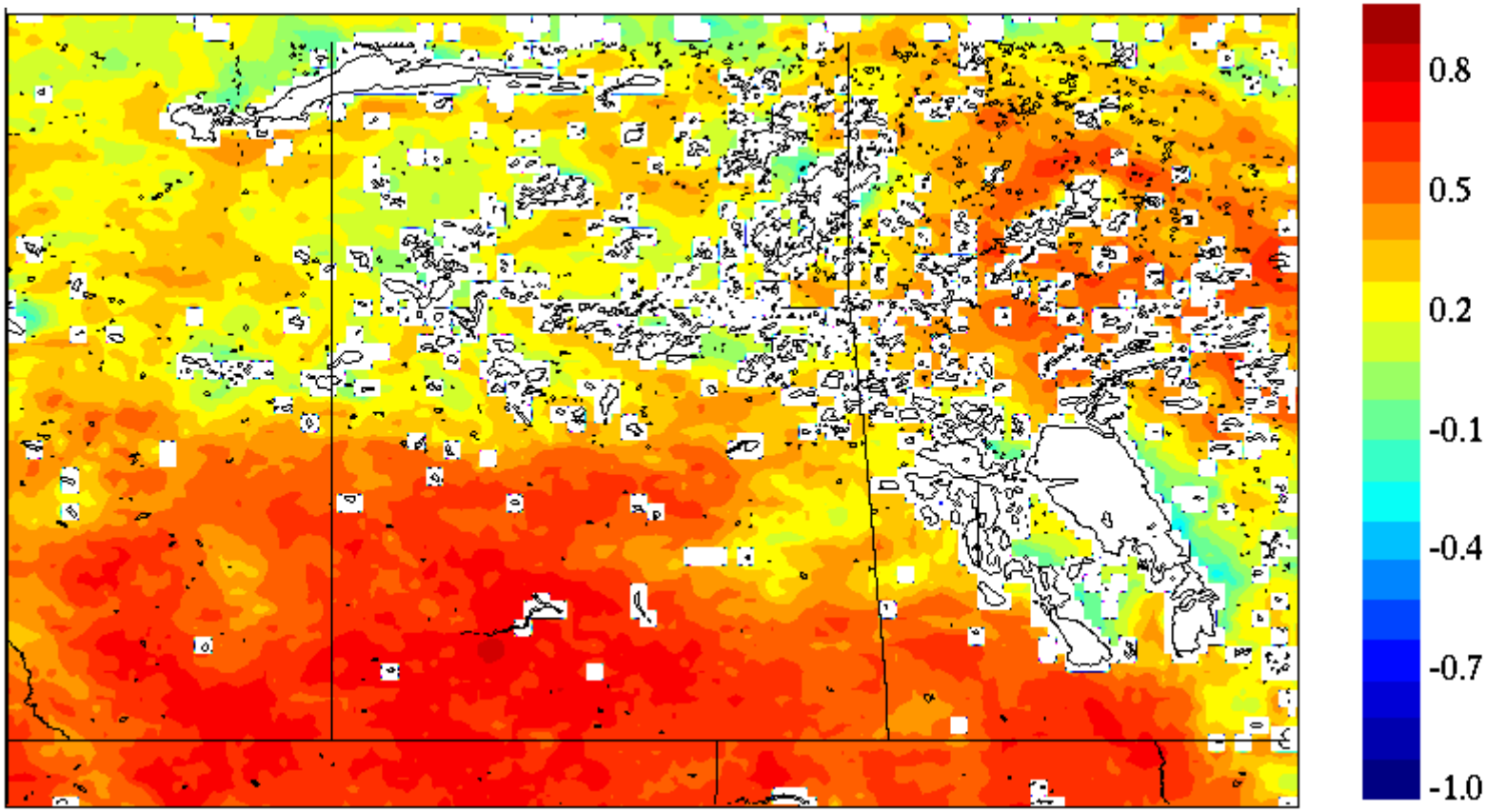
Dielectric Mixing Model	Surface Roughness Model	Smooth Surface Emissivity	Vegetation Opacity Model	TBRH FG Departures [SMOS – FG] [K]	Correlation TBRH [SMOS; FG]
Dobson	Wigneron	Fresnel	Jackson	-7.38 (11.42)	0.41 (0.60)
Dobson	Wigneron	Fresnel	Kirdyashev	0.45 (21.92)	0.39 (0.56)
Dobson	Wigneron	Fresnel	Wigneron	-1.9 (15.91)	0.41 (0.59)
Dobson	Wsimple	Fresnel	Jackson	-21.6 (-21.98)	0.41 (0.59)
Dobson	Wsimple	Fresnel	Kirdyashev	-15.0 (-16.93)	0.40 (0.58)
Dobson	Wsimple	Fresnel	Wigneron	-16.9 (-20.52)	0.41 (0.59)
Dobson	Choudhury	Fresnel	Jackson	-37.2 (-44.11)	0.38 (0.52)
Dobson	Choudhury	Fresnel	Kirdyashev	-35.8 (-42.72)	0.38 (0.52)
Dobson	Choudhury	Fresnel	Wigneron	-35.6 (-44.72)	0.38 (0.53)
Dobson	Wegmueller	Fresnel	Jackson	-24.4 (-25.93)	0.41 (0.59)
Dobson	Wegmueller	Fresnel	Kirdyshev	-18.7 (-21.53)	0.40 (0.58)
Dobson	Wegmueller	Fresnel	Wigneron	-20.2 (-24.84)	0.41 (0.59)

Values in red are over cropland and short grass vegetation types

Information Content : Brightness Temperature Correlation (First Guess : SMOS)

Horizontal Polarization : 40º Incidence Angle

May – August 2010



Surface Roughness Model : Wsimple (Wigneron et al. 2001)
Vegetation Opacity : Jackson and Schmugge (1991)
Dielectric Mixing Model : Dobson

Evaluation against Soil Moisture Measurements from the Alberta Droughtnet Network (26 stations)

May – August 2010

Correlation Coefficient

$R(w_g)$ EnKF	$R(w_g)$ Open Loop	$R(w_2)$ EnkF	$R(w_2)$ Open Loop
0.50	0.45	0.53	0.52

Improved Correlations

RMSE (Unbiased) ($m^3\ m^{-3}$)

w_g EnKF	w_g Open Loop	w_2 EnKF	w_2 Open Loop
0.058	0.064	0.030	0.029

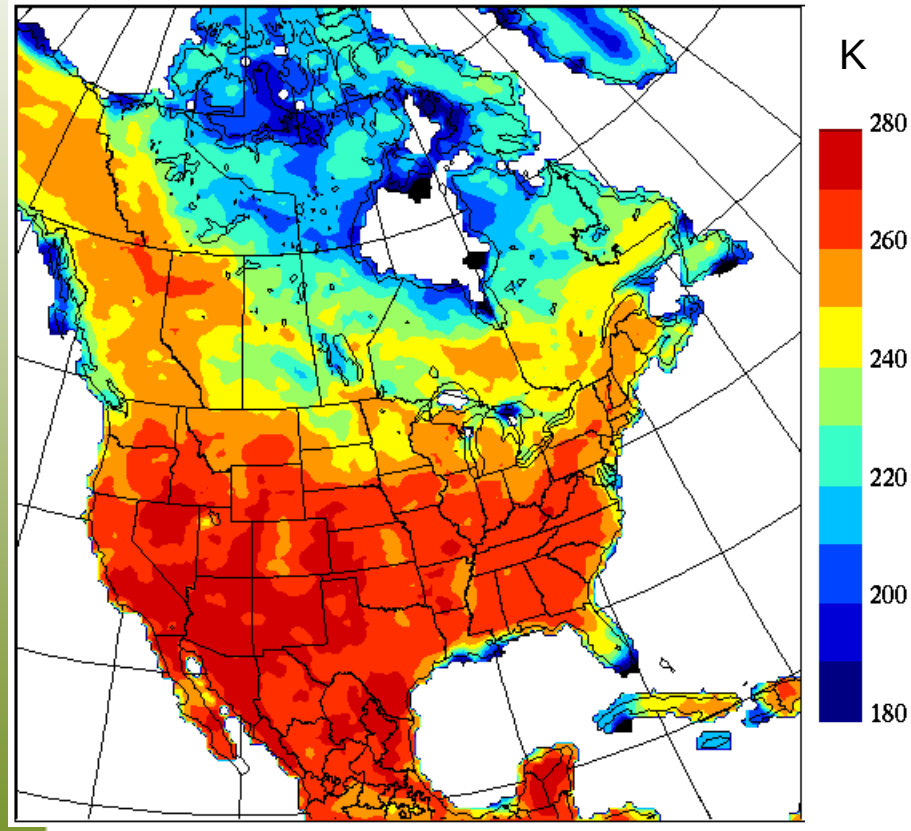
Reduction in unbiased RMSE

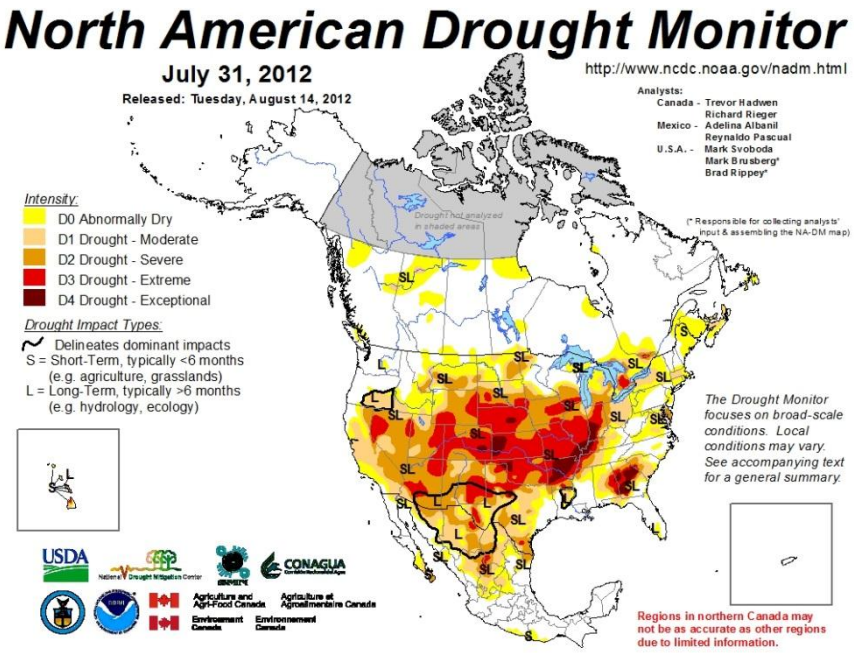
EnKF Assimilation Experiment : 2012

- Ensemble Kalman Filter (EnKF) with **48 members** and perturbations to atmospheric forcing, soil moisture model prognostics variables, and the CMEM forward model.
- Horizontal resolution of 40-km covering North America. Control variables are superficial soil moisture (top 10 cm) and root-zone soil moisture.
- Assimilation of SMOS TBs for the period 1 May 2012 to 30 September 2012 with an update frequency of 3 hours.
- SMOS TB observation error of 4 K which is homogeneous in space.
- Forward operator is the CMEM (Community Microwave Emission Modelling Platform) model developed at ECMWF.
- Quality Control : Consider SMOS observations within the exclusive alias free zone of the field of view (FOV). Reject TB values which exceed 350 K and **make use of the RFI flags provided with the data.**
- A Cumulative Distribution Function (CDF) matching procedure was used to re-scale the SMOS TBs prior to assimilation.

Dry Conditions : North America 2012

Mean SMOS TBs : Horizontal Polarization (40º)
May – August 2012





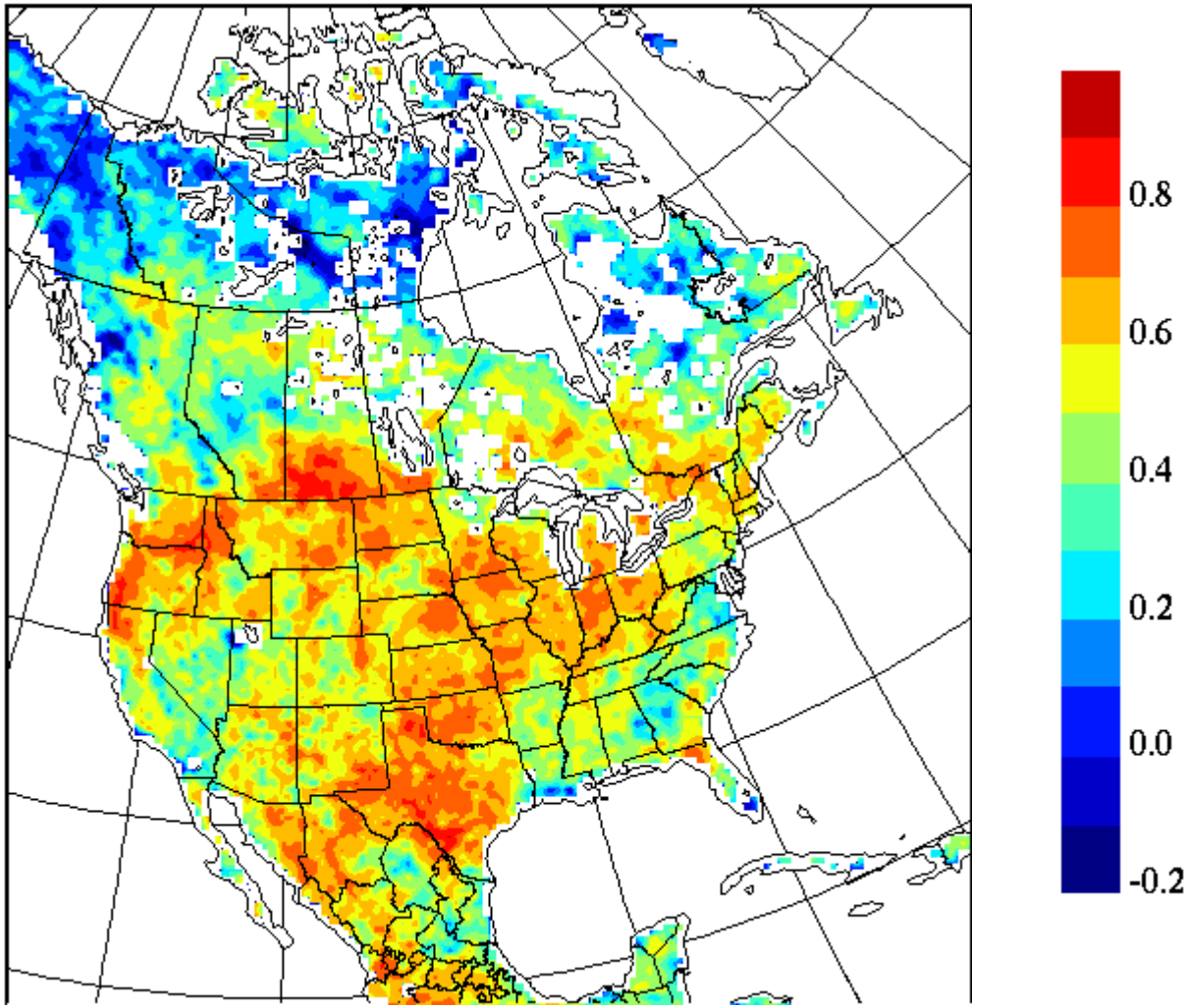
Forward Model
Community Microwave Emission Modeling (CMEM) Platform

Dielectric Mixing Model	Surface Roughness Model	Smooth Surface Emissivity	Vegetation Opacity Model	TBRH FG Departures [SMOS – FG] [K]	Correlation TBRH [SMOS; FG]
Dobson	Wigneron	Fresnel	Jackson	2.85	0.42
Dobson	Wigneron	Fresnel	Kirdyashev	7.86	0.41
Dobson	Wigneron	Fresnel	Wigneron	6.33	0.43
Dobson	Wsimple	Fresnel	Jackson	-0.51	0.44
Dobson	Wsimple	Fresnel	Kirdyashev	4.5	0.44
Dobson	Wsimple	Fresnel	Wigneron	2.96	0.45
Dobson	Choudhury	Fresnel	Jackson	-18.3	0.44
Dobson	Choudhury	Fresnel	Kirdyashev	-17.3	0.45
Dobson	Choudhury	Fresnel	Wigneron	-17.0	0.45
Dobson	Wegmueller	Fresnel	Jackson	-3.70	0.45
Dobson	Wegmueller	Fresnel	Kirdyshev	0.62	0.44
Dobson	Wegmueller	Fresnel	Wigneron	-0.61	0.45

Information Content : Brightness Temperature Correlation (First Guess : SMOS)

Horizontal Polarization : 40º Incidence Angle

May – August 2012

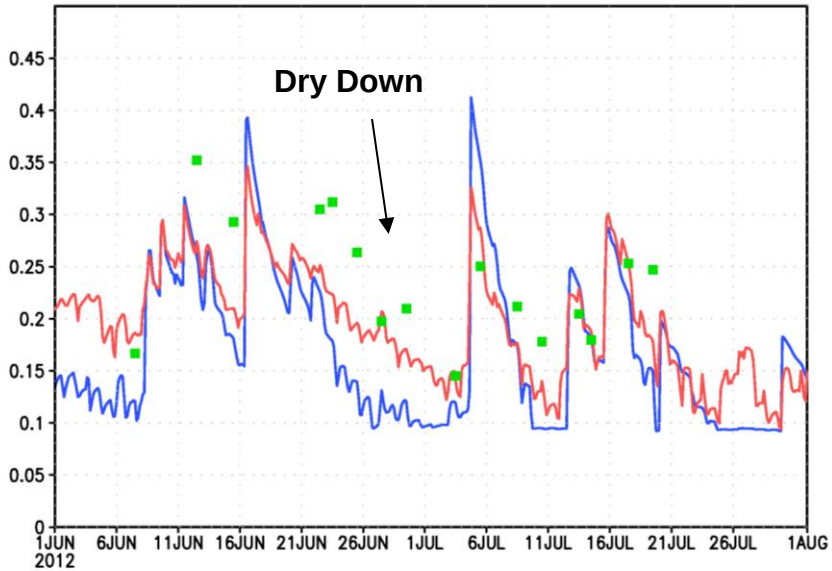


Correlation

Mean = 0.44

SMAPVEX12 Region

Superficial Soil Moisture ($m^3\ m^{-3}$)

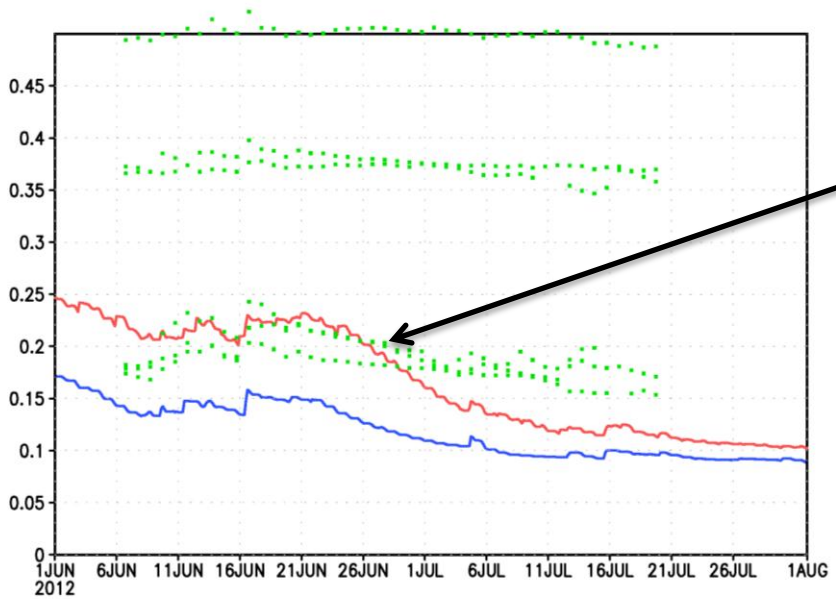


Open Loop

EnKF

5-cm soil moisture 55 fields

Root Zone Soil Moisture ($m^3\ m^{-3}$)



Assimilation of SMOS TBs leads to a more humid root-zone

AAFC SAGES mean (5, 20 and 50 cm).

(Will need to re-examine with the corrected data.)

Evaluation against Soil Moisture Measurements from the Alberta Droughtnet Network (30 stations)

May – September 2012

Correlation Coefficient

$R(w_g)$ EnKF	$R(w_g)$ Open Loop	$R(w_2)$ EnkF	$R(w_2)$ Open Loop
0.48	0.45	0.69	0.71

Improved Correlations

RMSE (Unbiased) ($m^3\ m^{-3}$)

w_g EnKF	w_g Open Loop	w_2 EnKF	w_2 Open Loop
0.061	0.068	0.024	0.021

Reduction in unbiased RMSE

Summary

- **CanEX-SM10** : The assimilation of SMOS brightness temperatures were beneficial in reducing the rapid surface soil moisture drydowns. Additionally a signal was seen at deeper layers where positive moisture increments led to moistening of the root zone layer in better agreement with observations.

- **SMAPVEX12** : A similar improvement of the surface soil moisture during the dry down periods for the assimilation of SMOS is seen for SMAPVEX12. More importantly a significant signal is seen in the root zone layer with a positive moisture increments leading to a more humid layer.

- **Alberta Droughtnet** : The assimilation of SMOS TBs leads to superior correlation and bias scores for the surface layer for both 2010 and 2012. For the root zone layer the results are more neutral.

Future Work

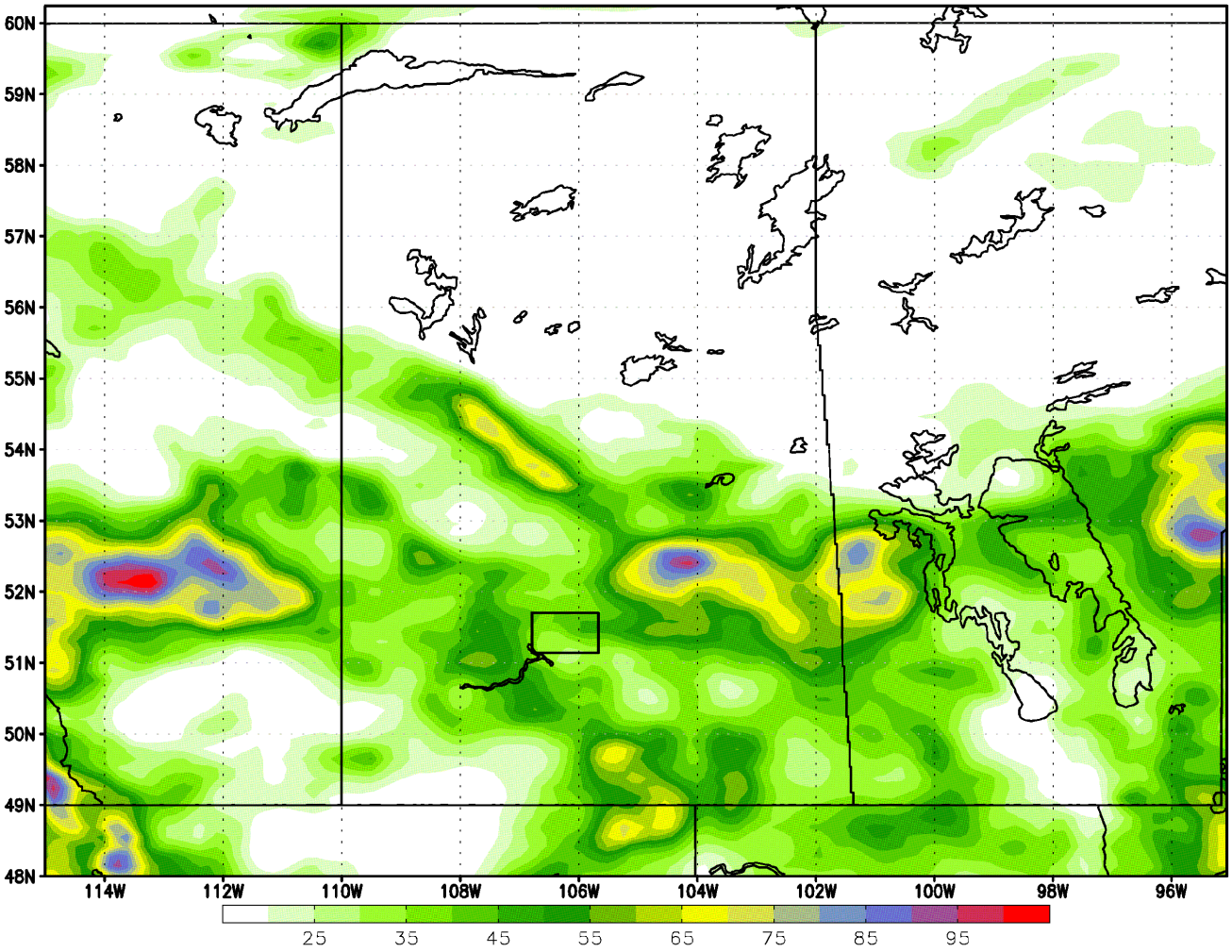
- <u>Higher-resolution soil moisture analyses</u>
  - Downscaling of the lower-resolution SMOS observations to produce higher-resolution (2.5 – 10 km) soil moisture analyses. Downscaling will be performed with the EnKF.

- <u>Combination of screen-level parameters with satellite observations</u>
  - Combine traditional higher temporal frequency assimilation of screen-level parameters with lower temporal frequency SMOS/SMAP observations to generate improved soil moisture analyses.

Thank You
For your attention !

Extra Slides

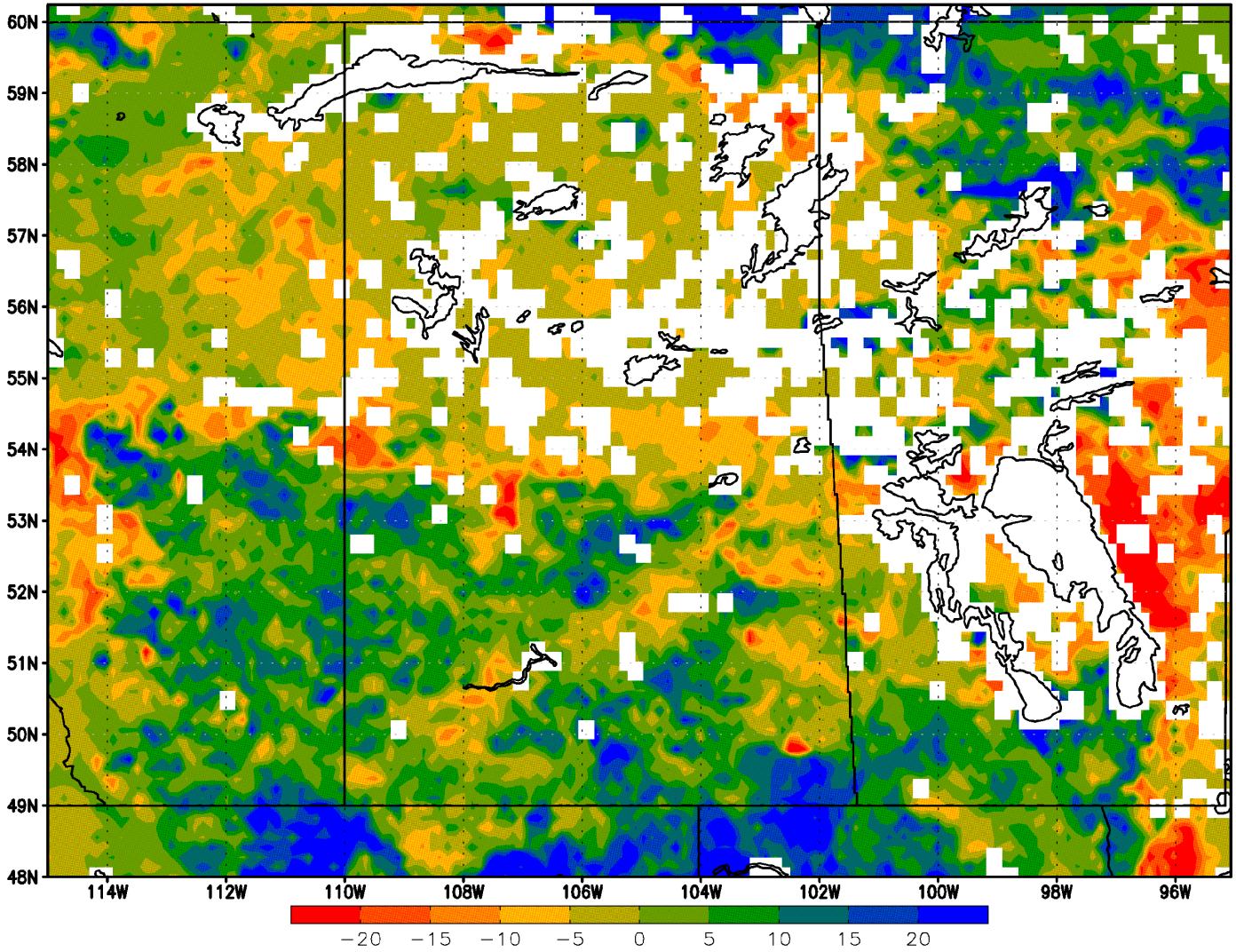
CanEX-SM10 Precipitation : Canadian Precipitation Analysis



~ 40 mm of precipitation over Kenaston region during CanEx-SM10 period.

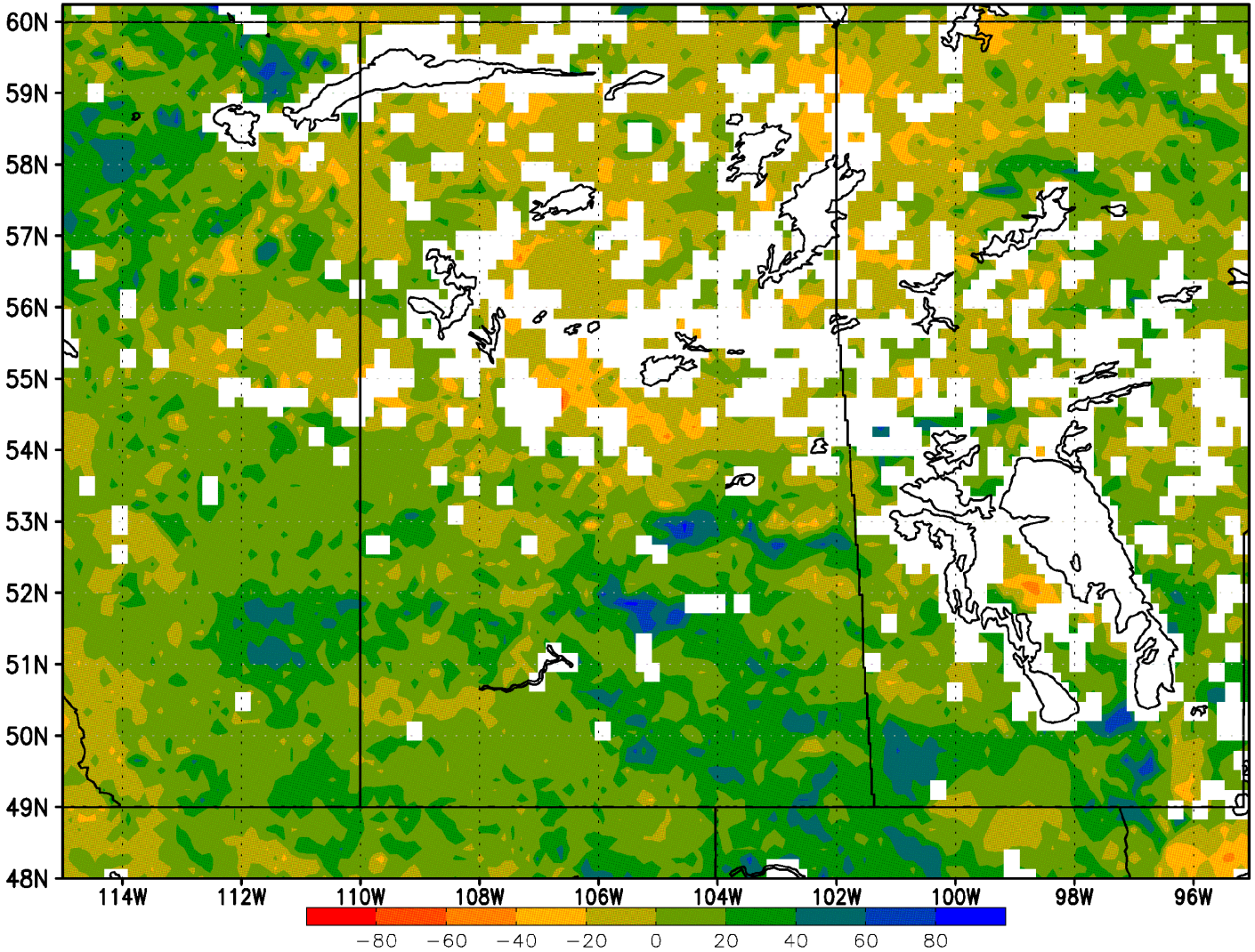
Accumulated Mean Superficial Soil Moisture Increments (mm)

May – August 2010



Accumulated Mean Root-Zone Soil Moisture Increments (mm)

May – August 2010



Evaluation against Soil Moisture Measurements from the Alberta Droughtnet Network (26 stations)

May – August 2010

Superficial Soil Moisture

$R(w_g)$ EnKF	$R(w_g)$ Open Loop	$Bias(w_g)$ EnKF (F-O) ($m^3\ m^{-3}$)	Bias (w_g) Open Loop (F-O) ($m^3\ m^{-3}$)
0.50	0.45	-0.067	-0.071

Root Zone Soil Moisture

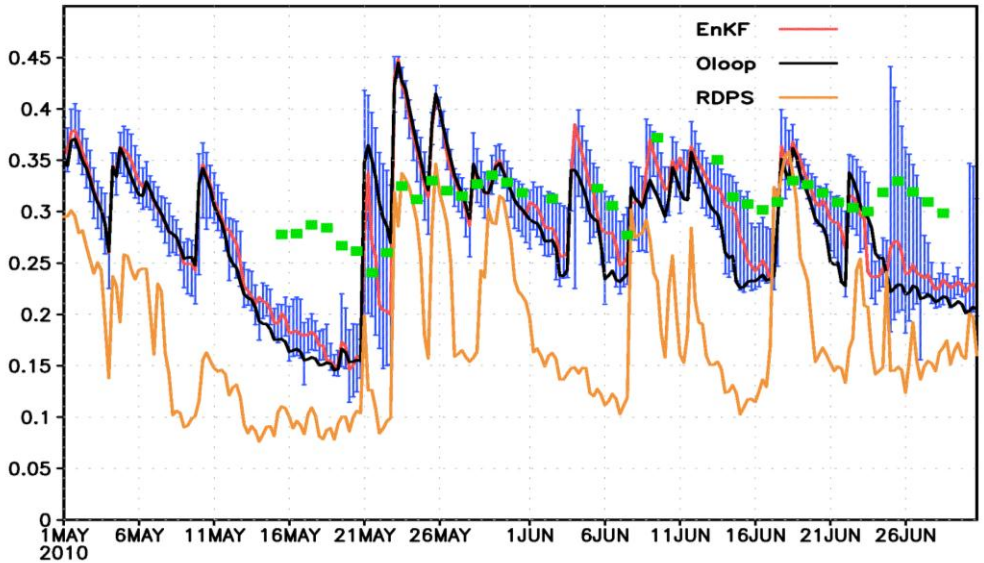
$R(w_2)$ EnkF	$R(w_2)$ Open Loop	Bias (w_2) EnKF (F-O) ($m^3\ m^{-3}$)	Bias (w_2) Open Loop (F-O) ($m^3\ m^{-3}$)
0.53	0.52	-0.134	-0.142

RMSE (Unbiased) ($m^3\ m^{-3}$)

w_g EnKF	w_g Open Loop	w_2 EnKF	w_2 Open Loop
0.058	0.064	0.030	0.029

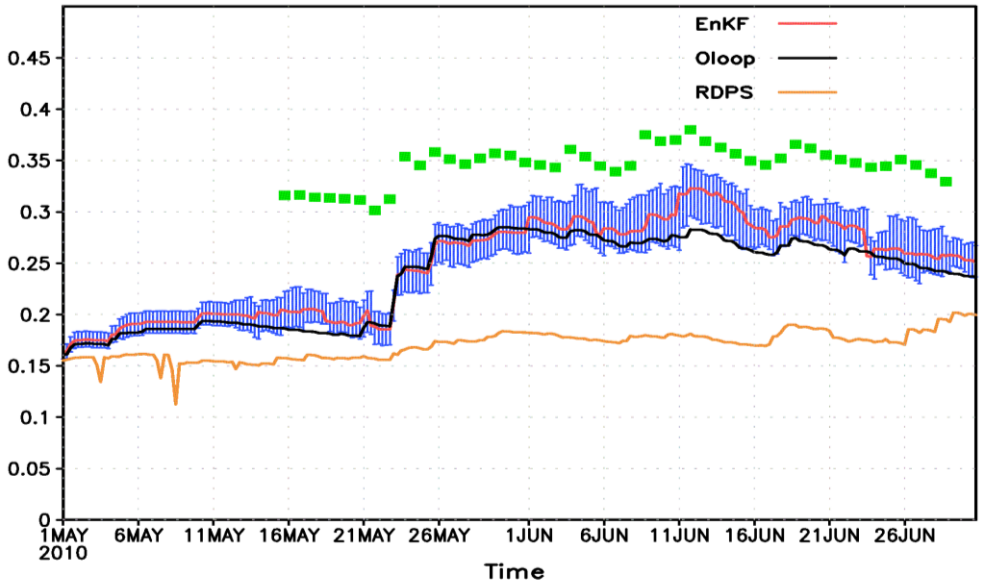
Soil Moisture Simulations : CanEX-SM10 : Kenaston

Superficial Soil Moisture ($m^3\ m^{-3}$)



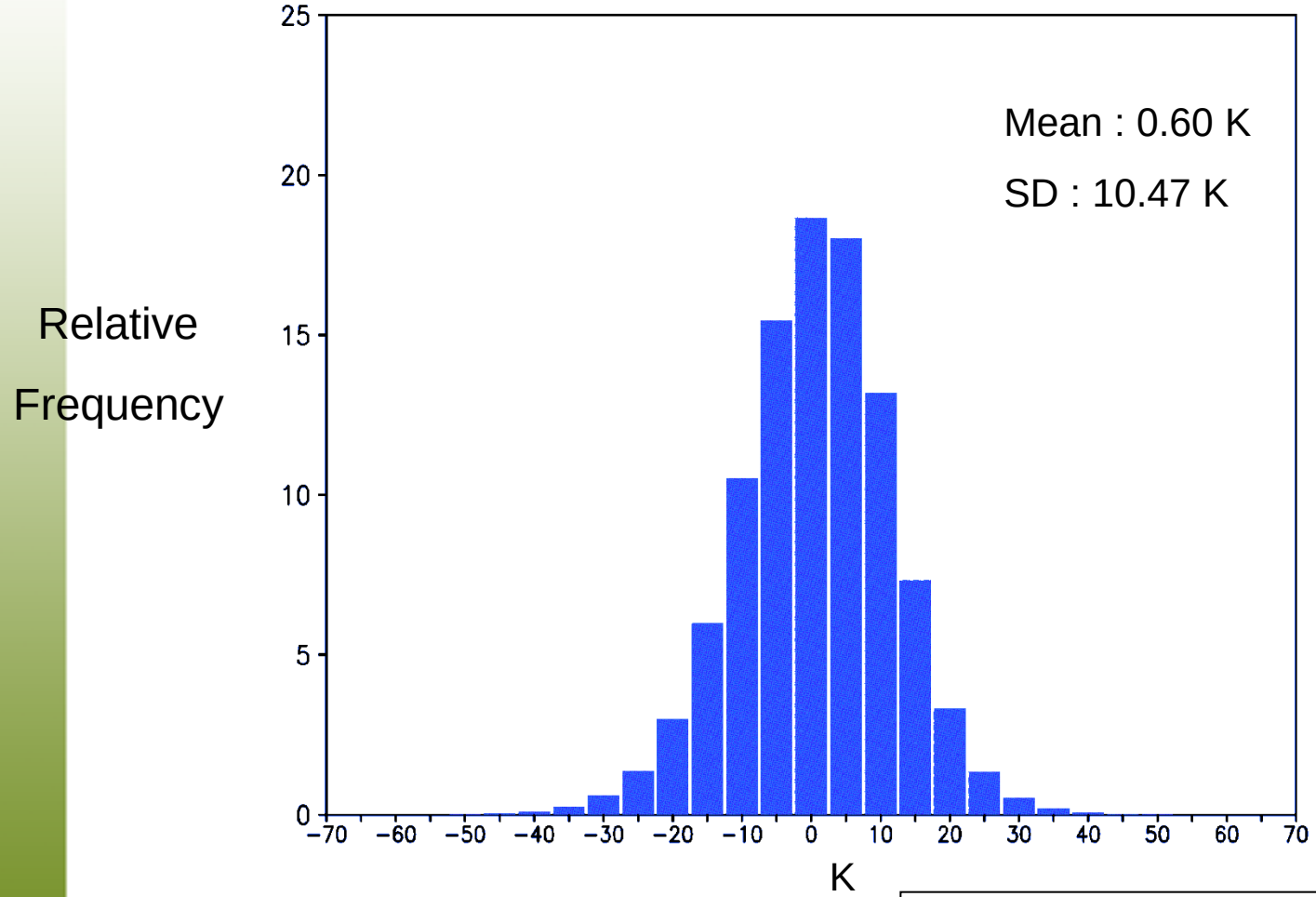
5-cm soil moisture

Root Zone Soil Moisture ($m^3\ m^{-3}$)



Mean soil moisture sfc-50 cm

Histogram : TBRH Innovations : May – August 2010 (SMOS (BC) – First Guess)



Normalized Innovations :

Mean = 0.17 K, SD = 1.86 K

SMOS-Level 1C NRT BUFR

- SMOS data are from the L1C Near-Real-Time (NRT) BUFR product. The first experiments over the CanEX-SM10 region were performed with the Level 1C data which were not reprocessed (Comissionning phase baseline algorithm V300).

- Subsequently re-processed L1C data were obtained from ESA (V500) which were used for the assimilation experiments over the Canadian Prairies region.

- The SMOS data are restricted to the exclusive alias free zone region of the swath and only the 40° incidence angle is considered for the assimilation experiments. A hard-RFI filter is applied to reject brightness temperatures which exceed 350 K.

- For the assimilation experiment the SMOS data were re-scaled using CDF matching following the work of Reichle and Koster 2005.

Canadian Experiment for Soil Moisture in 2010 (CanEX-SM10)

- Originated as an experiment for Canadian researchers to support SMOS Cal/Val activities over land and to develop soil moisture retrieval algorithms.
- Experiment was expanded to include pre-launch validation and algorithm development for SMAP through a collaboration with US scientists.

- **Period** : 31 May – 17 June 2010

- **Study Sites** :

- (i) **Kenaston agricultural site (~ 80 km south of Saskatoon) (33 km x 71 km).**

- (ii) **BERMS (Boreal Ecosystem and Research and Monitoring Sites) in northern Saskatchewan (33 km x 71 km).**

Canadian Experiment for Soil Moisture in 2010 (CanEX-SM10)

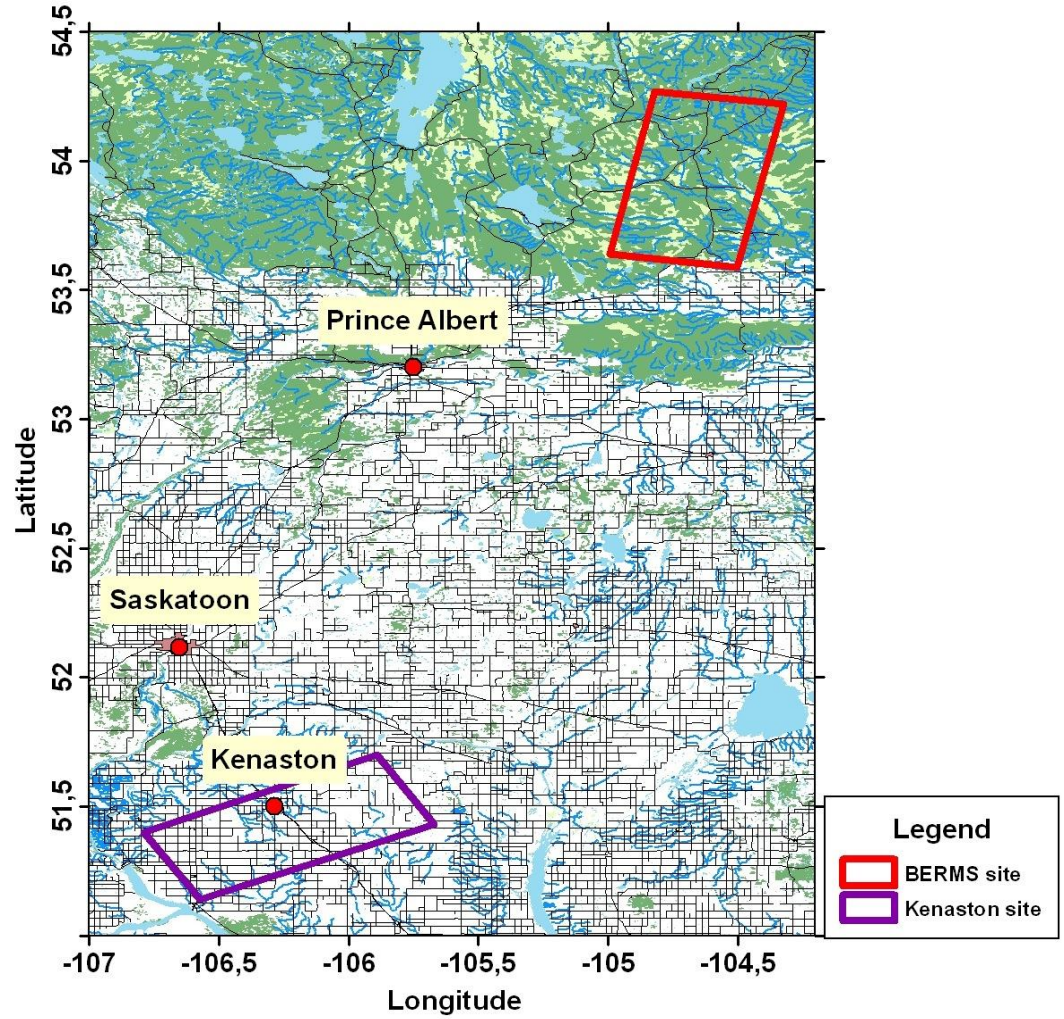


Image courtesy R. Magagi

Kenaston Site :

- High-density network : 24 permanent Environment Canada monitoring sites with measurements of soil moisture at depths of 5, 20 and 50 cm.
- Low-density network : 16 sites operated by the University of Guelph recording soil moisture at depths of 5, 20 and 50 cm.
- Additional 20 manual survey sites were added for CanEX-SM10 which record soil moisture at a depth of 6 cm.
- National Research Council Twin Otter aircraft equipped with a passive microwave radiometer measuring emission in L-band at 40° incidence angle.

EnKF Assimilation Experiment Set-up

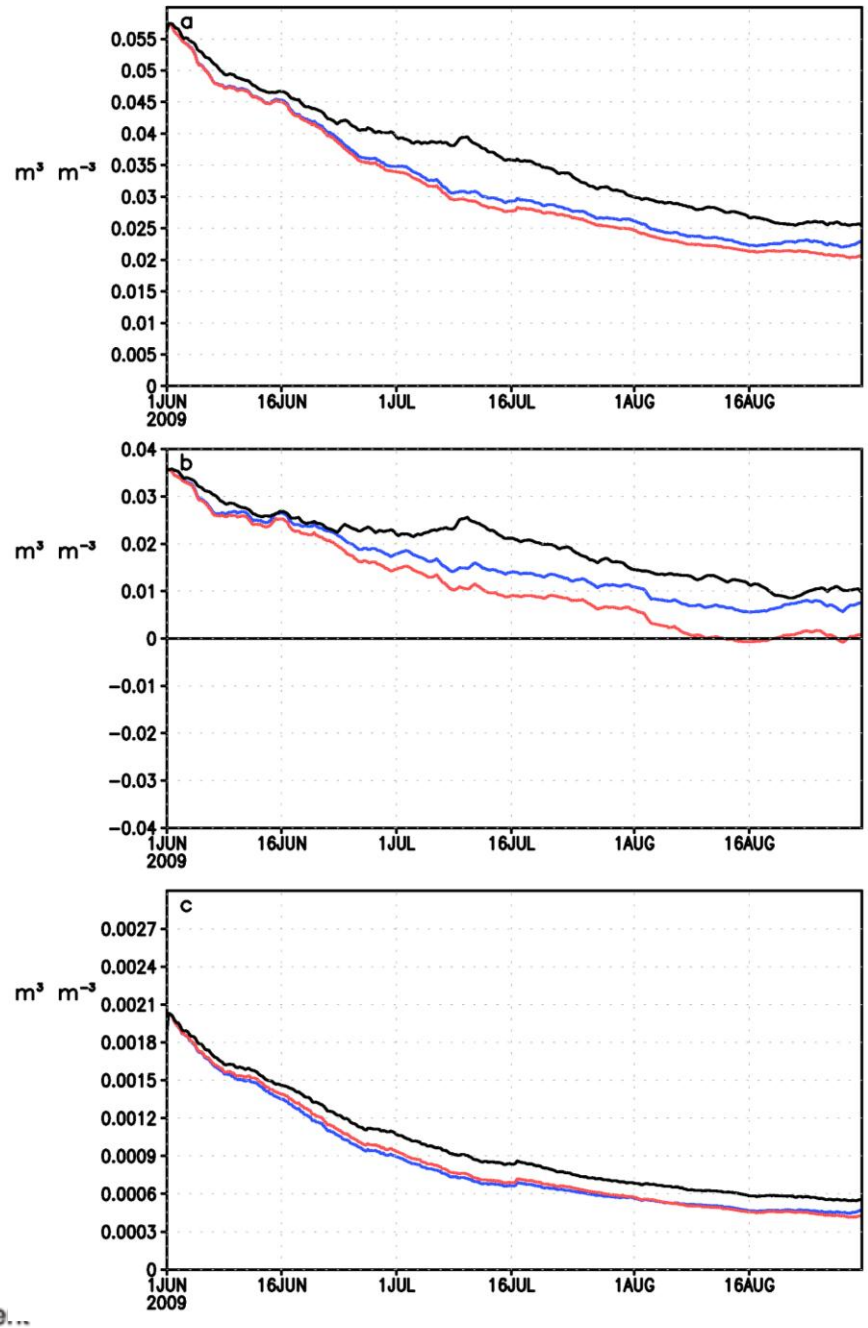
- Ensemble Kalman Filter (EnKF) with **48 members** with perturbations to atmospheric forcing, soil moisture model prognostics variables, and the CMEM forward model.
- Land-surface model ISBA run at 15-km horizontal resolution over the Canadian Prairies region.
- SMOS TBs for the period 1 May 2010 to 31 August 2010. Consider both ascending and descending paths and assimilate data every 6 hours where available.
- Overpass times are roughly 0130Z and 1300Z and we considered these observations valid at 00Z and 12Z respectively.
- SMOS TB observation error of 4 K which is homogeneous in space.
- Forward operator is the CMEM (Community Microwave Emission Modelling Platform) model developed at ECMWF.
- Control variables are superficial soil moisture (top 10 cm) and root-zone soil moisture.

Root-Zone Soil Moisture
June – August 2009
North America

RMSE

BIAS

Spatial Standard Deviation



- Open Loop
- EnKF-1
- EnKF-2