Agriculture and Agri-Food Canada

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AAFC Research Activities in Soil Moisture

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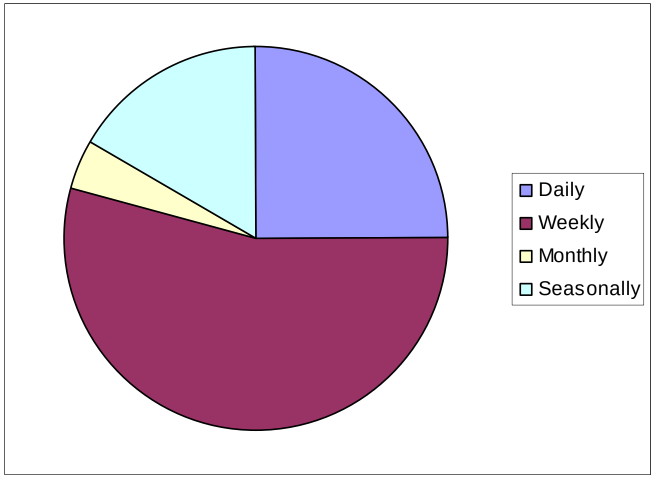
Canada

Need for Soil Moisture Information for Agriculture

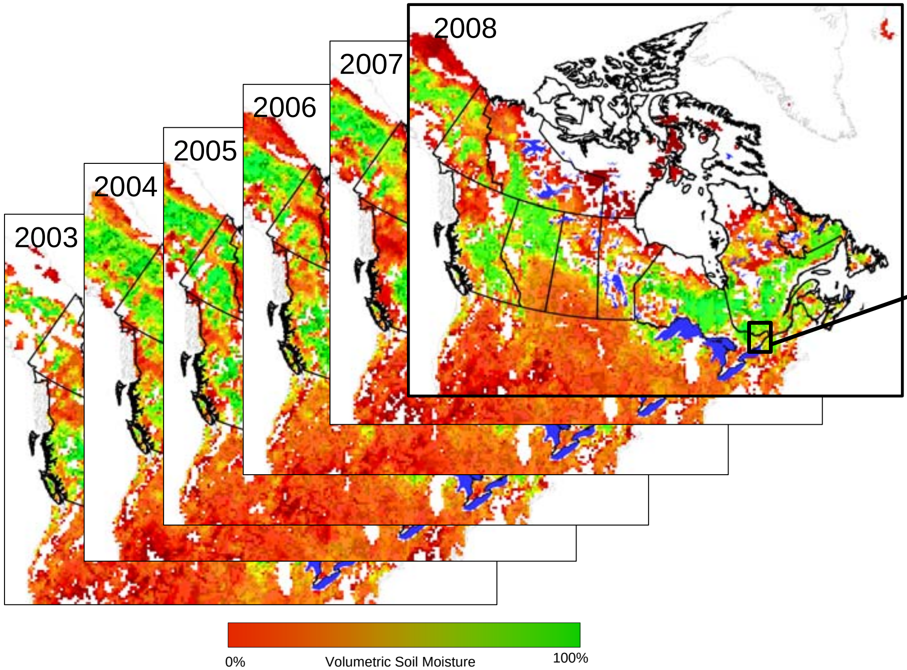
- **Early assessment of emerging risk, due to too much or too little available soil water, will assist the agricultural community to develop appropriate management strategies**
  - ***Erosion risk***
  - ***Prediction of spring flooding***
  - ***Pest assessment***
  - ***Fertilizer, pesticide and seed demand***
  - ***Yield estimation***
  - ***Soil trafficability***



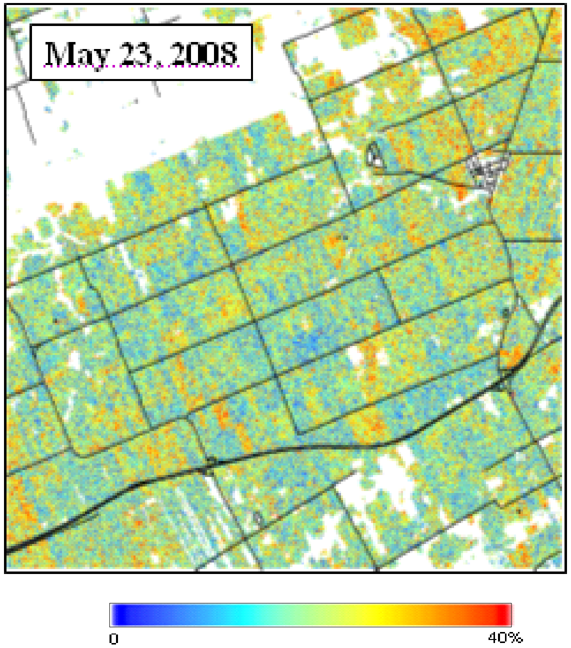
Source: International GEO Workshop on Synthetic Aperture Radar (SAR) to Support Agricultural Monitoring: Report of Pre-workshop Survey Findings

Concept of Integrated Active and Passive System

Week 21



Flag anomalies



Weekly coarse resolution passive microwave derived soil moisture

Use historical record of passive microwave soil moisture to derive anomalies

Derive field-scale information on soil moisture from targeted SAR acquisitions

Overview of progress and plans

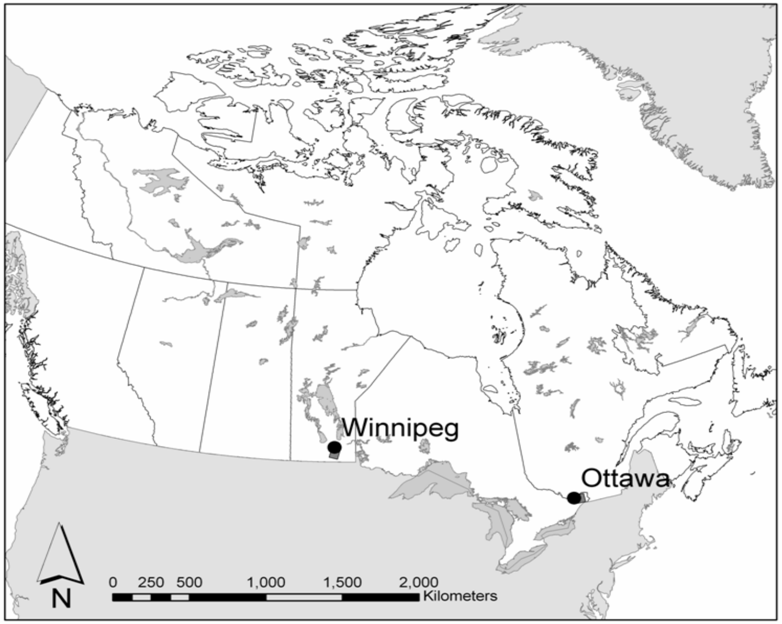
Active SAR (Heather McNairn, Amine Merzouki, Anna Pacheco)

- assessing 3 models for estimating surface soil moisture from RADARSAT-2
  - Dubois, Oh and IEM
  - Focusing mostly on IEM and variations of IEM
  - Test sites in Eastern Ontario and Brunkild (2008-2010)
- Will assess these methods with Kenaston UAVSAR and RSAT-2 to determine improvements with L-Band

Passive Microwave (Catherine Champagne, Heather McNairn, Aaron Berg)

- Assessed accuracies of NSIDC (National Snow and Ice Data Centre) X-Band soil moisture products as well as accuracies of the LPRM (Land Parameter Retrieval Model) C- and X-Band soil moisture products
- Developed a soil moisture anomaly approach
- Will assess this anomaly method using SMOS (entire Prairies)

RADARSAT-2 Data Collection



• RADARSAT-2 (C-band 5.3 GHz) data have been acquired over sites in eastern (Casselman) and western (Brunkild) Canada (2008, 2009 and 2010)

• all Quad-Polarization images

• in situ soil moisture measurements with Theta Probes on over 40+ sites for every RSAT acquisition

• 16 sub-sites per site with 3 replicates, providing 2000+ measurements per acquisition

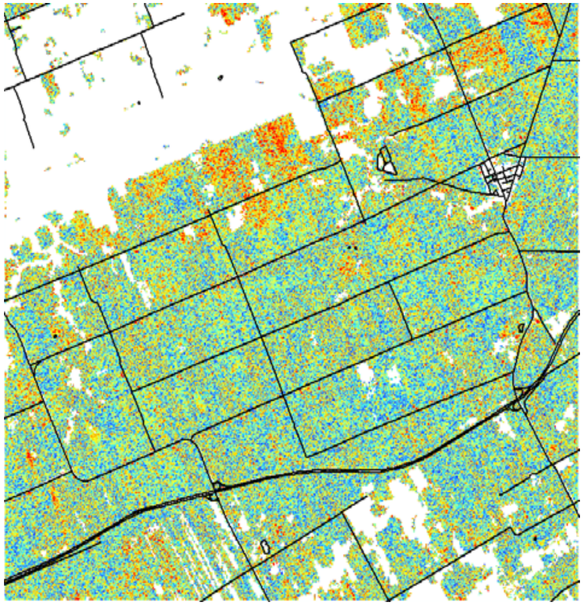
• roughness measured using pin profiler

Results – Oh and Dubois models

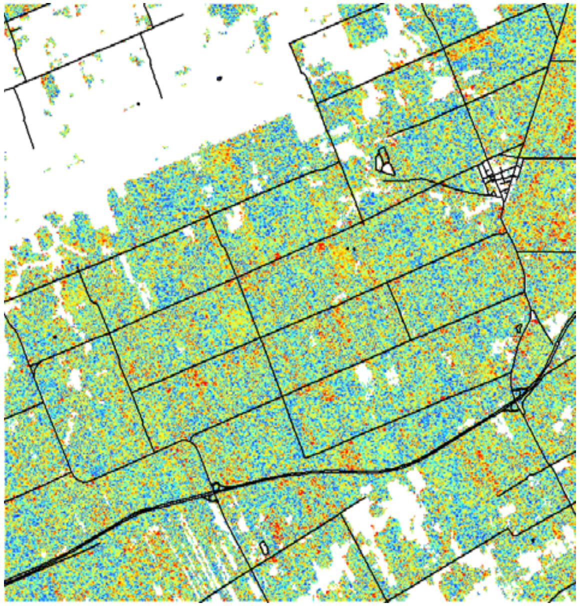
Oh and Dubois semi-empirical models:

- semi-empirical models overestimate the radar response, but correction factors of about 3.5 dB and 2.0 dB were found sufficient to correct the Dubois HH and VV backscatter coefficients, respectively; a correction factor of about 5.0 dB was necessary for Oh model
- soil moisture was estimated by explicitly solving the two backscatter equations of the Dubois model, and using a Look-Up Table (LUT) approach applied to the Oh model
- Validation using 2008 Eastern Ontario data
- the Oh model in a cross-polarization (HH-HV) and Dubois in a co-polarization (HH-VV) inversion scheme provided the best estimates. Soil moisture root mean square errors were found to be 6.21% for the Dubois model and 7.56% for the HH-HV version of the Oh model.
- to expand the range of validity of these soil moisture estimates, the maps produced by the Dubois and Oh models were combined.

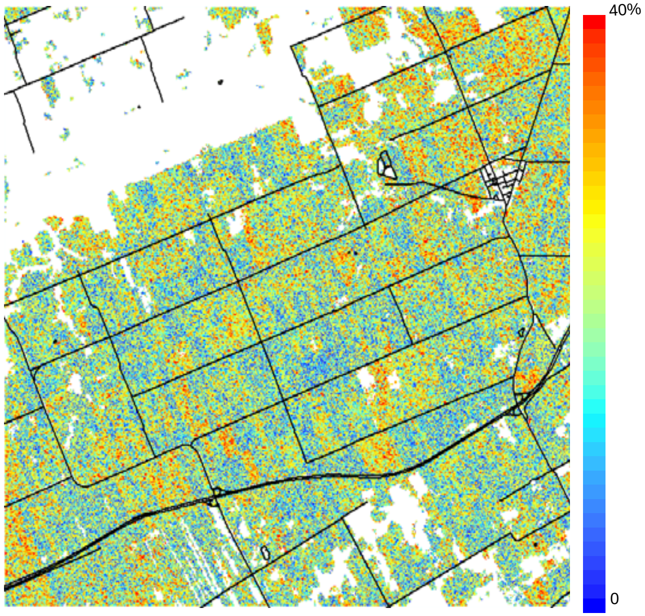
Casselman Spring 2008 Results



5 May 2008
(FQ19)



16 May 2008
(FQ11)



23 May 2008
(FQ16)

Volumetric soil moisture map (in %) obtained by combining Oh and Dubois models over Casselman site using spring 2008 RADARSAT-2 acquisitions.

Integral Equation Model (IEM)

- A physically based model applicable to a wide range of conditions present on agricultural fields (from smooth to rough surfaces)
- Three parameters describe roughness in IEM: the correlation function, correlation length and root mean square (rms) height
- Forward modeling was used to compare simulated (from the original IEM) to measured (from RADARSAT-2) backscatter
- Backscatter was simulated using field data (soil moisture and roughness) and the RADARSAT-2 configuration parameters (frequency, polarization, and incidence angle)
- These comparisons between IEM simulated backscatter and measured backscatter yielded considerable discrepancies
- These discrepancies have largely been attributed to inaccuracies in the measurement of the correlation length

Calibrated IEM

- Baghdadi et al. have proposed a calibration of the IEM
  (Baghdadi, N., Holah, N. and Zribi, M. (2006) “Calibration of the Integral Equation Model for SAR data in C-band and HH and VV polarizations”, International Journal of Remote Sensing, 27:4, 805-816)

- calibrated IEM uses an optimum roughness correlation length ℓopt2 obtained by forcing the IEM until a good agreement is reached between simulations and SAR image data. This optimum correlation length is expressed as:

$$\ell_{\mathrm{opt2}} = \delta (\sin\theta)^{\mu}\, rms^{(\eta\theta+\xi)}$$

$$\delta_{\mathrm{VV}} = 3.289$$
$$\delta_{\mathrm{HH}} = 4.026$$
$$\xi_{\mathrm{VV}} = 1.222$$
$$\xi_{\mathrm{HH}} = 1.551$$
$$\eta_{\mathrm{HH}} = \eta_{\mathrm{VV}} = -0.0025$$
$$\mu_{\mathrm{HH}} = \mu_{\mathrm{VV}} = -1.744$$

- ℓopt2 depends on roughness, incidence angle, polarization and frequency
- validation is on-going to compare measured and simulated backscatter coefficients for the calibrated IEM, where ℓ values were replaced by the optimum values ℓopt2, using Baghdadi’s equation (i.e. no site specific calibration)
- results are being assessed on site-by-site basis, and averaged according to broad soil texture classes (heavy clay, sandy soils and silty and clayey loams)

Calibrated IEM

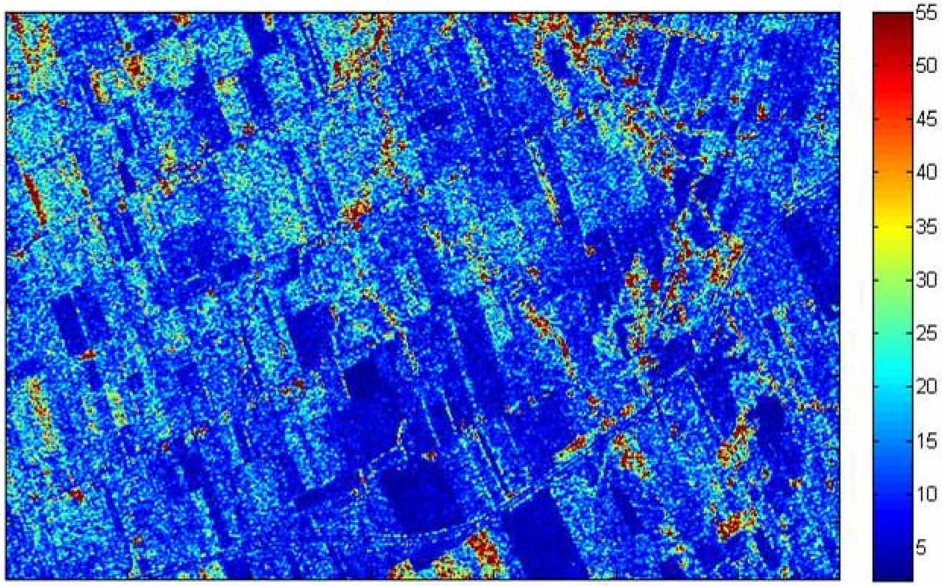
• calibrated IEM inversion was implemented using a LUT approach where LUTs were generated by simulating HH and VV backscatter coefficients using ℓopt2 formulation.

• involves the creation of a table of backscatter values associated with surface soil moisture, roughness rms height, and incidence angle values generated by performing multiple runs of the calibrated IEM model within its validity range.

• a direct search algorithm minimizes a scalar value representing the difference between measured and simulated backscatter coefficients.

• validation to date using only Manitoba 2008 data; validation against other data sets is in progress

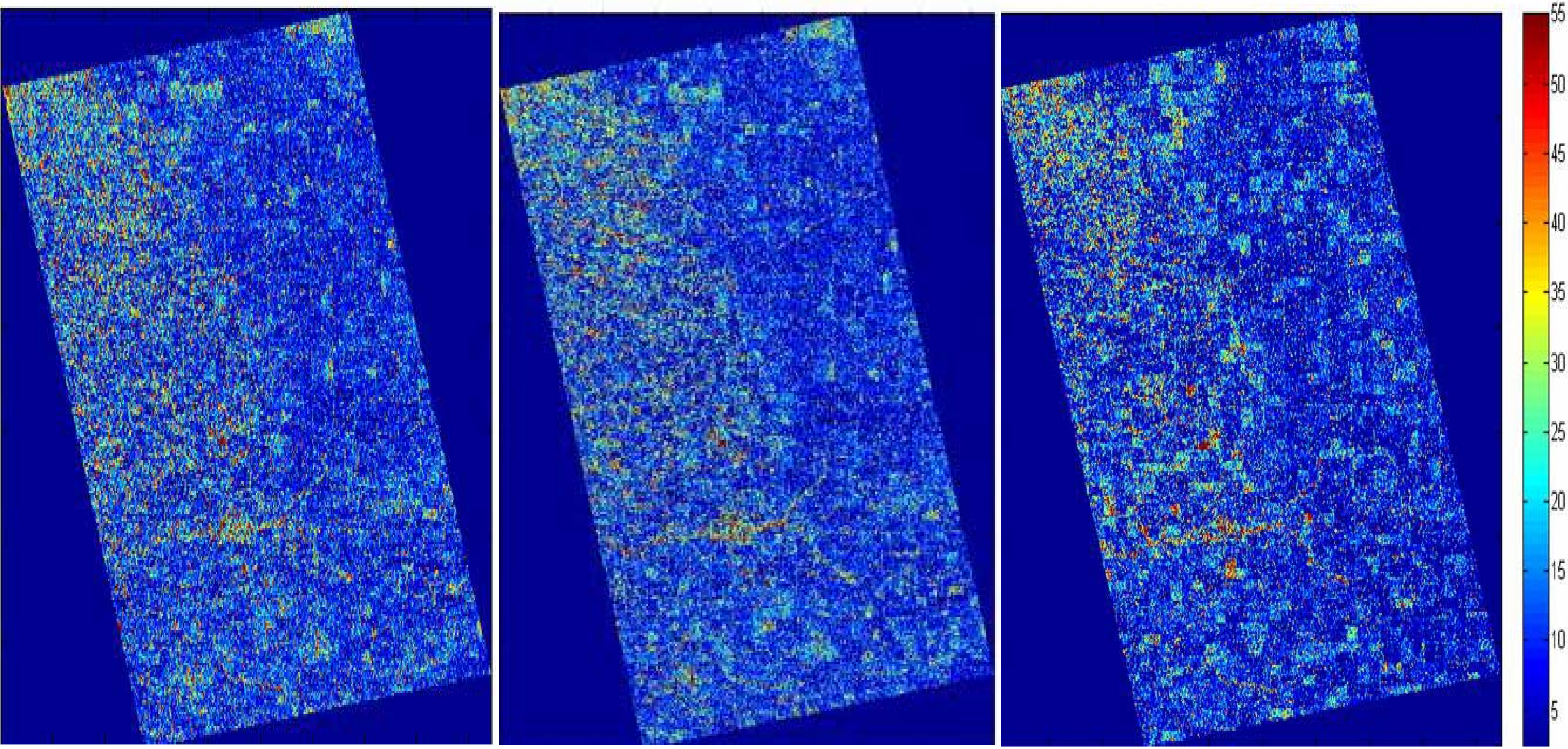
Mapping soil moisture using calibrated IEM



Volumetric soil moisture map (in %) retrieved by inverting the calibrated IEM

- Reduced incidence angle effect is within the SAR antenna calibration errors (< 0.5dB)
- Final soil moisture map appear less noisy compared to the original IEM product
- Manitoba 2008: comparing the in situ soil moisture measurements to the estimates from the calibrated IEM pixel level rmse for soil moisture remains high (15.29%)
- Manitoba 2008: averaged over soil texture, the rmse of the soil moisture estimate was 5.37%

Mapping soil moisture using calibrated IEM: Manitoba 2008



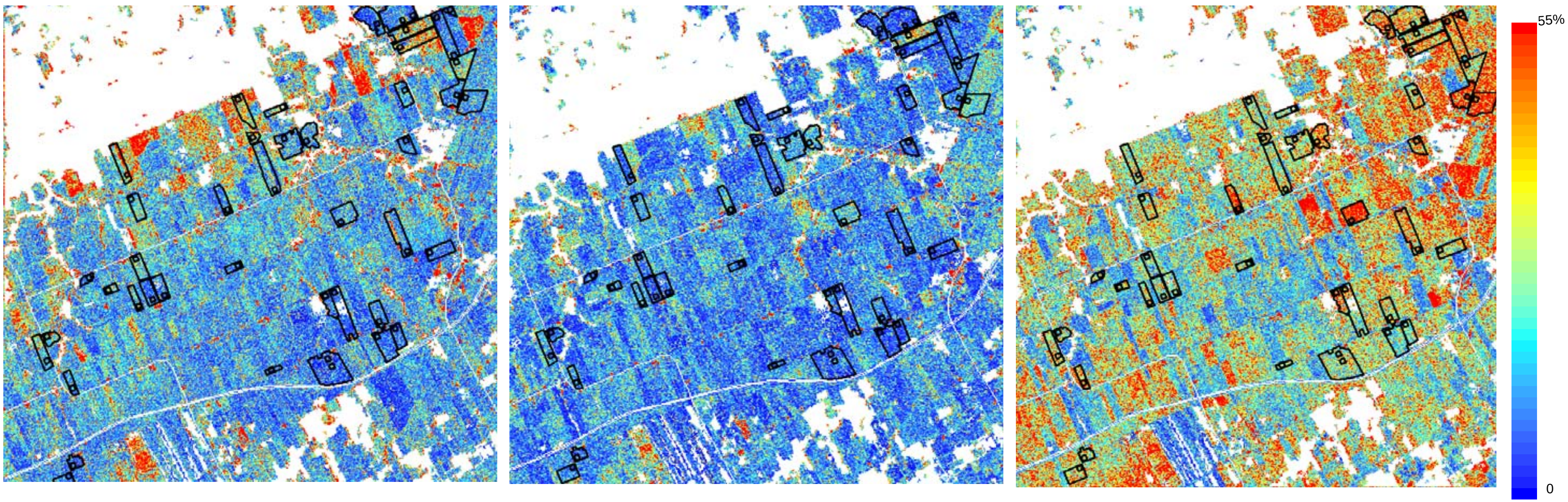
24 April 2008
(FQ11)

10 May 2008
(FQ15)

17 May 2008
(FQ11)

Volumetric soil moisture map (in %) obtained by inverting the calibrated IEM over Carman site.
This area was selected as it's covered by two RADARSAT-2 FQ acquisitions.

Mapping soil moisture using calibrated IEM: Eastern Ontario 2008



5 May 2008 (FQ19) | **16 May 2008 (FQ11)** | **23 May 2008 (FQ16)**

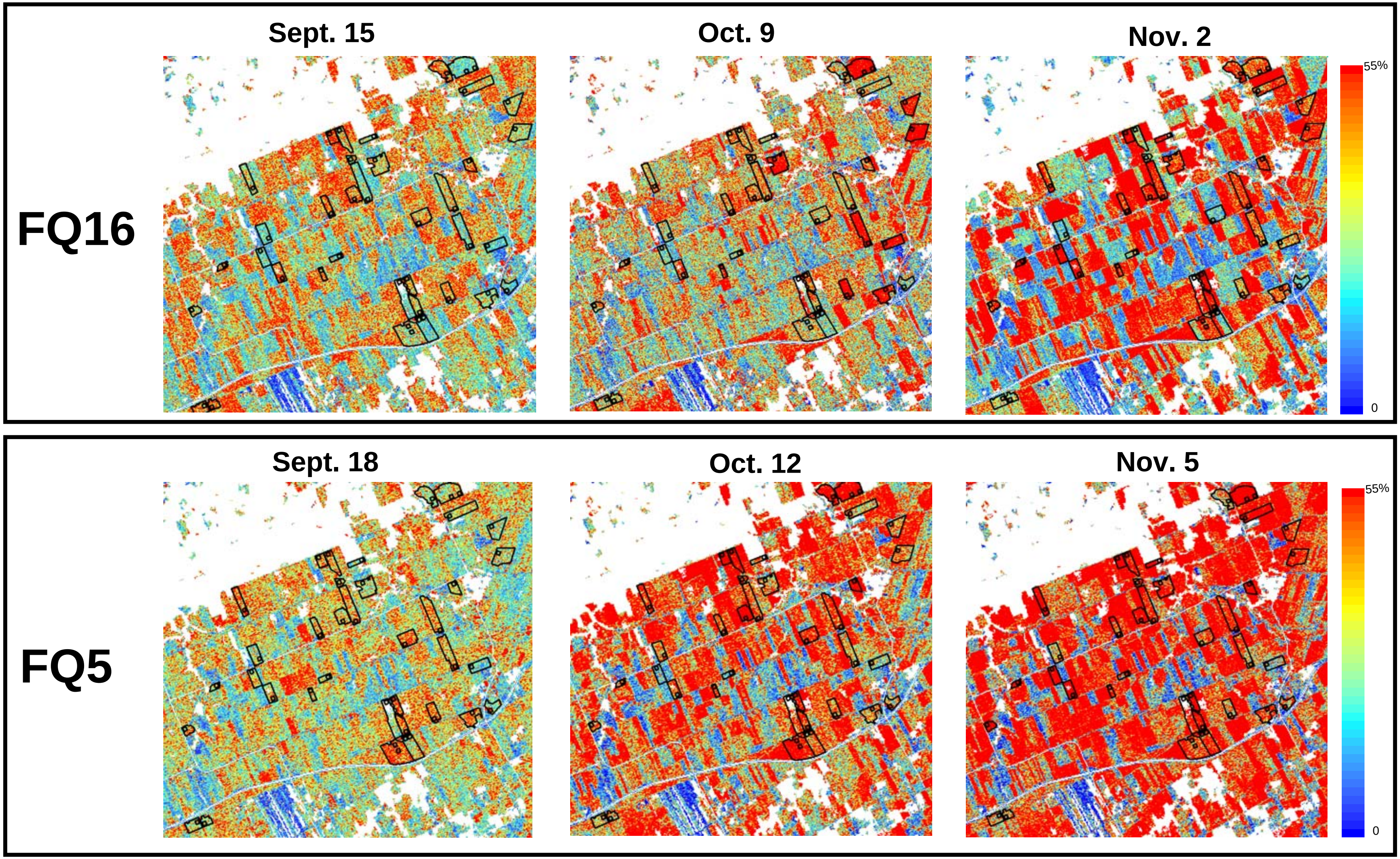
Volumetric soil moisture map (in %) obtained by inverting the calibrated IEM over Casselman site using spring 2008 RADARSAT-2 acquisitions.

Improving IEM

- Pool all results from 2008-2010 for comprehensive error assessment (on-going)
- Assess relative soil moisture estimates using repeat RSAT-2 passes (on-going)
- Multi-angle/multi-polarization model implementation (on-going)

- Isolate surface soil moisture scattering using image decomposition (done for Oh, IEM is next step)
- Assess UAVSAR L-Band data using same models and model formulations (next step)
- Site specific optimal correlation length (future)

Relative Soil Moisture Retrieval using Calibrated IEM: Casselman Fall 2009 Results



Multi-angle/multi-polarization implementation of Calibrated IEM: Brunkild Spring 2010

Image Date	Start Time (Local)	Pass Type	Beam Mode	Incidence Angle	Ordering
Apr. 26	8:44 AM	DES	FQ16	35.4 - 37.0	Received
Apr. 26	8:07 PM	ASC	FQ2	20.0 - 21.8	Received
Apr. 29	8:57 AM	DES	FQ3	20.9 - 22.9	Received
May. 6	8:15 PM	ASC	FQ11	30.2 - 32.0	Received
May. 20	8:44 AM	DES	FQ16	35.4 - 37.0	Received
May. 20	8:07 PM	ASC	FQ2	20.0 - 21.8	Received
May. 23	8:57 AM	DES	FQ3	20.9 - 22.9	Received
May. 30	8:15 PM	ASC	FQ11	30.2 - 32.0	Received

Table. Spring 2010 RADARSAT-2 acquisitions over Brunkild site.

- in preparation for RADARSAT-Constellation
- Ground truth data available only for April 26 and May 20 AM and PM acquisitions.
- The pre-processing of the data is completed.

Brunkild Spring 2010 PM-AM Comparisons

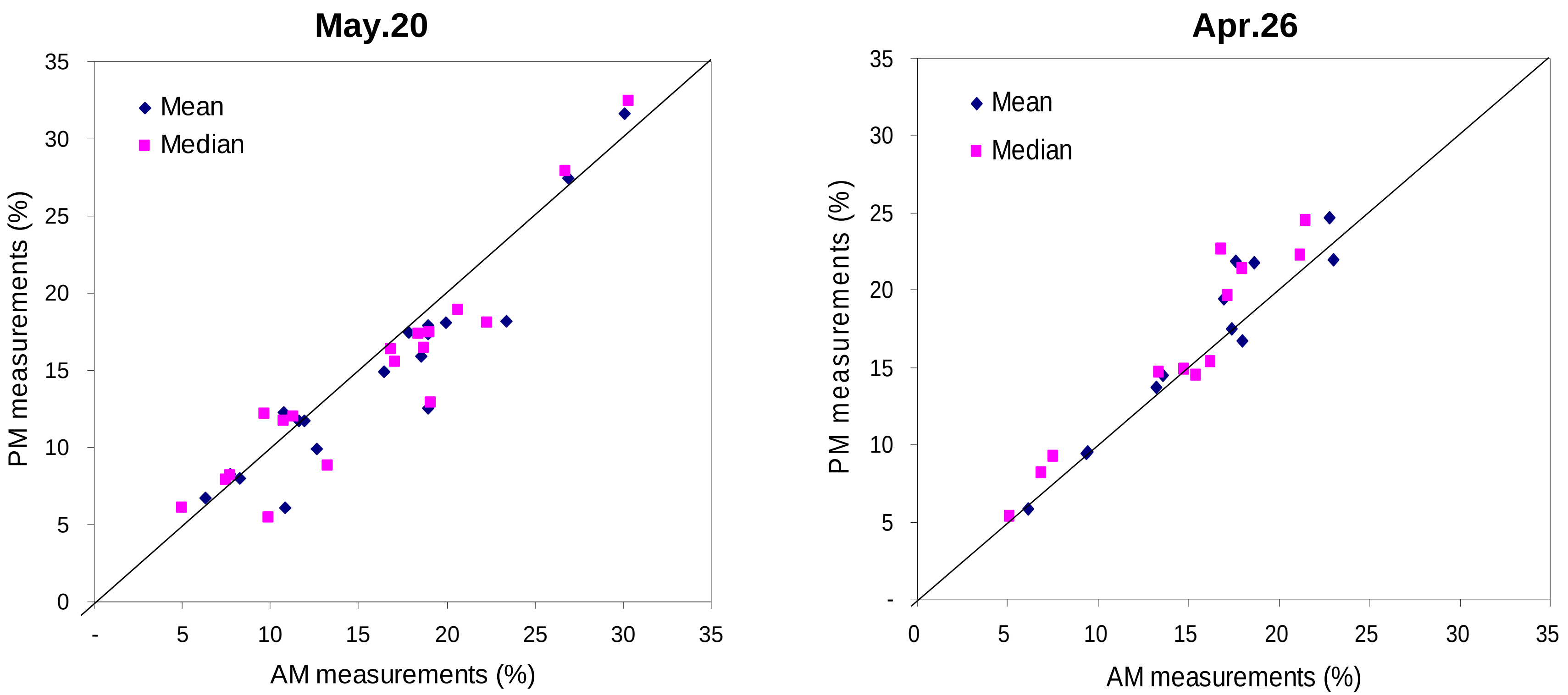


Figure. Soil moisture variability between AM and PM ground measurements.

- Low variation of soil moisture mean that AM and PM acquisitions can be combined in an inversion scheme.

Brunkild Spring 2010 (cont.)

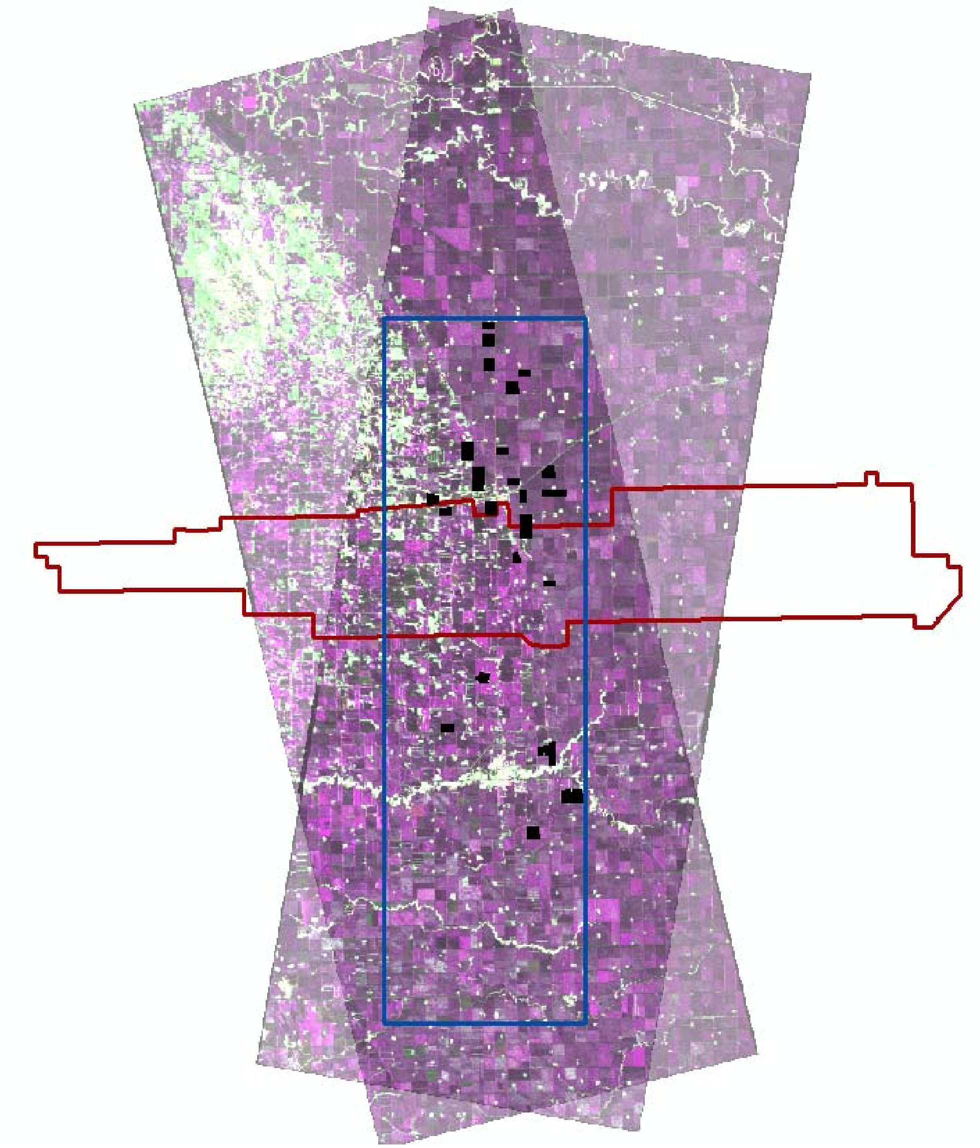
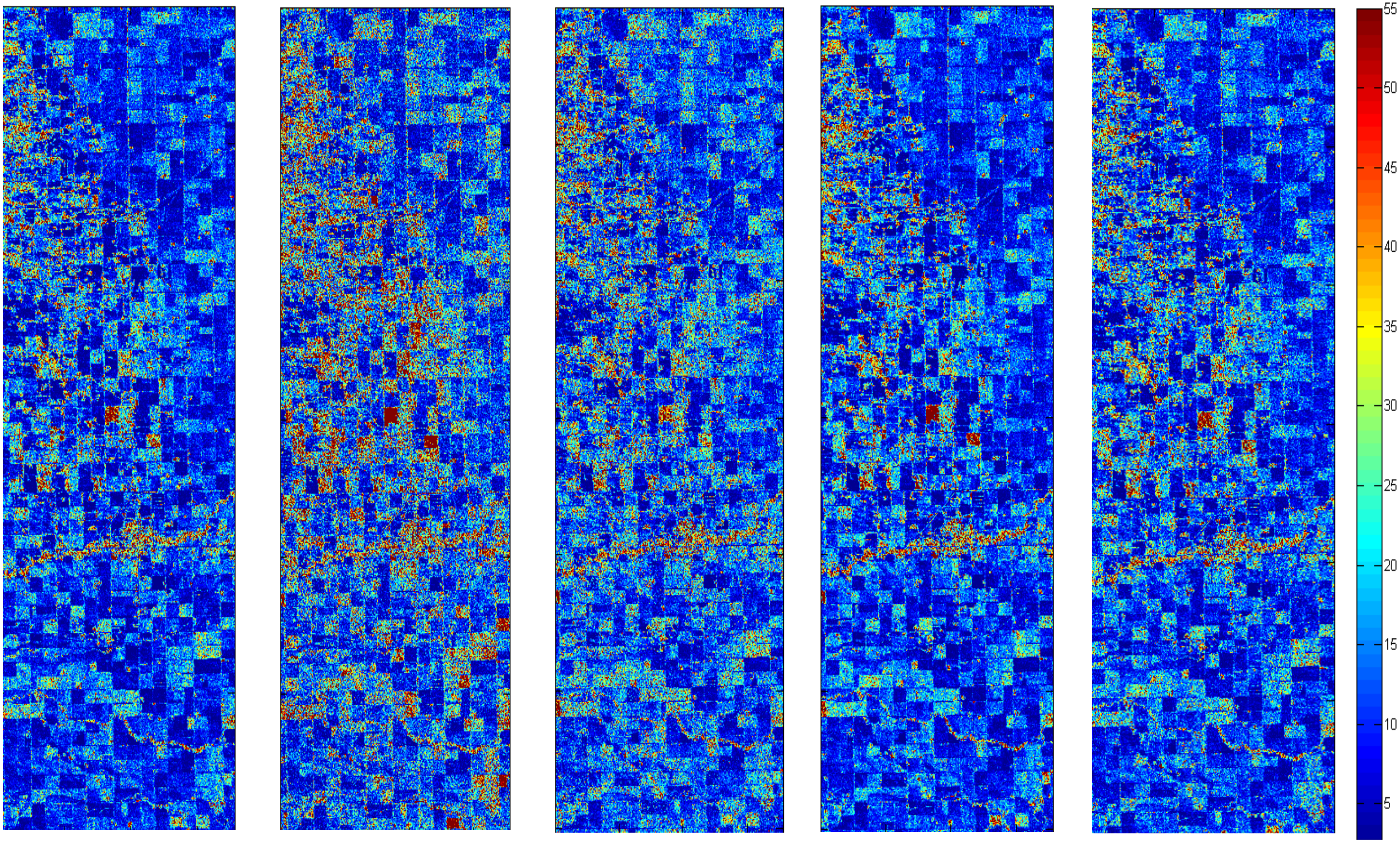


Figure. Multi-angle acquisition configuration

Multi-angle and hybrid inversion algorithms can only be applied to the overlap zone which cover a small portion of the watershed.

Brunkild Spring 2010 / Hybrid inversion

HH1-HH2-VV1 | HH1-HH2-VV2 | HH1-VV1-VV2 | HH2-VV1-VV2 | HH1-HH2-VV1-VV2



Soil moisture maps corresponding to the second image pair

AMSR-E Passive Microwave Analysis

- compared two AMSR-E soil moisture data sets, one from the National Snow and Ice Data Centre (NSIDC) and one from the University of Amsterdam (LPRM)
- soil moisture estimates from each passive microwave data set were compared to in situ soil moisture data available from two sensor networks installed by the University of Guelph
- at a daily scale, the LPRM provided a better estimate of surface soil moisture conditions than the NSIDC data set, with root mean squared errors ranging from 5 to 10 % for LPRM and 12 to 18% for NSIDC soil moisture when a temporal smoothing was applied
- both data sets provided better estimates of soil moisture over the Elora, Ontario than the site at Davidson, Saskatchewan. The LPRM data set tended to overestimate soil moisture conditions at both sites, where the NSIDC data set tended to underestimate absolute soil moisture.
- at weekly scales, the LPRM data set provided a better relative estimate of wetness conditions when compared to the NSIDC.

Calculating Soil Moisture Anomalies

- Using the LPRM soil moisture averaged at weekly and monthly scales, a soil moisture anomaly (SMA) index was calculated.

- Due to the short temporal record of the AMSR-E LPRM soil moisture data set, several methods to calculate a baseline were evaluated. These used the concept of defining areas of homogeneity in the soil moisture data to create a larger pool of data points from which to calculate a baseline
  - compared soil landcapes of Canada (SLC), EcoDistrict polygons and two data driven segmentations (based on satellite soil moisture estimates)

- evaluated against the Alberta Ground Drought Monitoring Network (ADGMN), meteorological drought indices (PDSI, SPI) and the North American Drought Monitor

$$SMA_{i(t)} = \left(\frac{m_{v\,i(t)} - m_{v\min i(t)}}{m_{v\max i(t)} - m_{v\min i(t)}} \right) 100$$

m_v = LPRM soil moisture at location *i* and time *t*

m_{vmin} = minimum soil moisture from baseline

m_{vmax} = maximum soil moisture from baseline

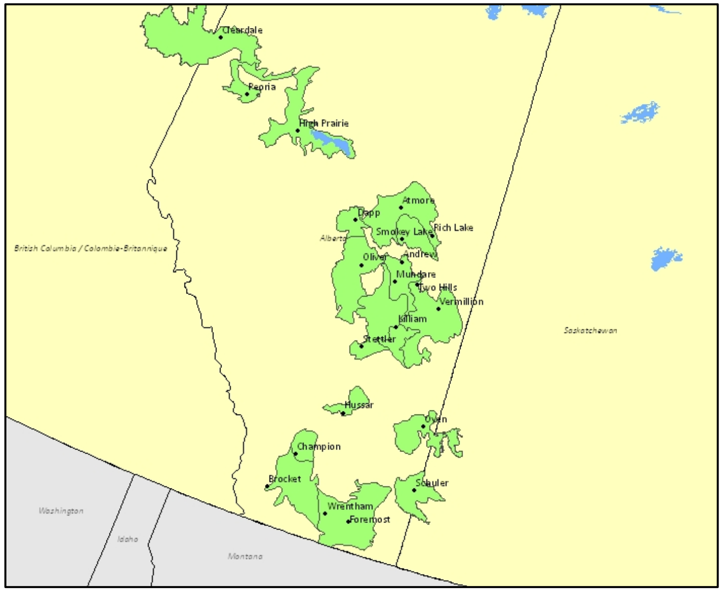
Evaluation of Soil Moisture Anomalies

- A comparison with in-situ, drought indicators and the North American drought monitor showed better agreement between the spatial segmentation of the satellite soil moisture data (Object size of 3) and EcoDistrict baseline SMA and local conditions.

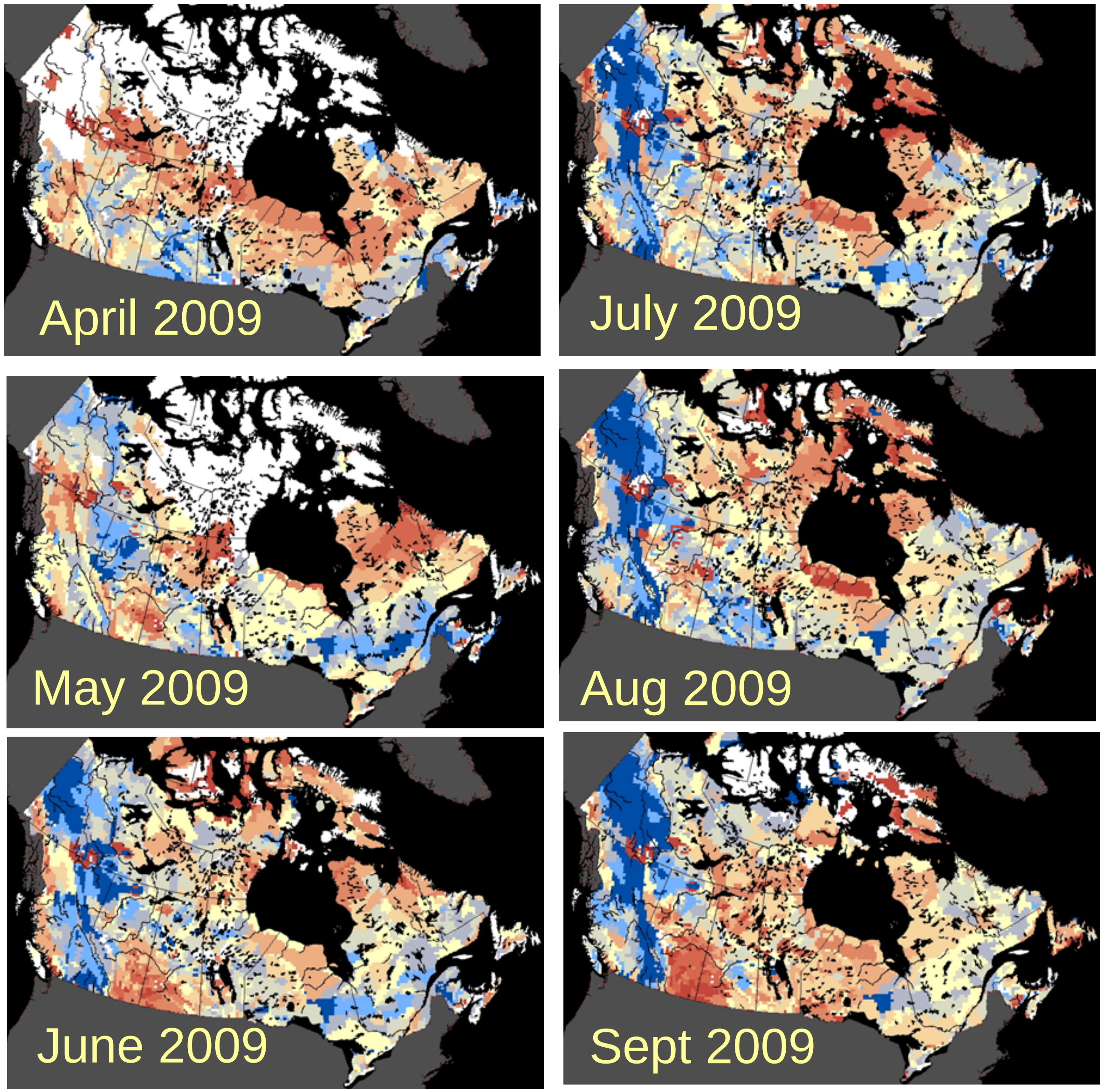
- Based on the desire for minimum error with maximum local representative-ness, the EcoDistrict framework was selected as the method to use for calculating an anomaly baseline

- Future work will link soil moisture anomalies to SAR soil moisture data sets over pilot site

- Integration of SMOS L-Band soil moisture into anomaly calculation will be examined.



Monthly Soil Moisture Anomalies for 2009



- Monthly soil moisture anomalies from monthly averaged AMSR-E LPRM soil moisture (based on the EcoDistrict for baseline calculation)

LPRM-SMA

- 0 - 10 % **(Extreme Dry)**
- 10 - 20 %
- 20 - 30 %
- 30 - 40 %
- 40 - 50 %
- 50 - 60 % **(Average)**
- 60 - 70 %
- 70 - 80 %
- 80 - 90 %
- 90 - 100 % **(Extreme Wet)**
- No Data

Publications

Merzouki, A., McNairn, H., and Pacheco, A. (2010, in press) "Evaluation of Radar Backscatter Models Dubois, Oh, and IEM over Agricultural Fields Using C-band RADARSAT-2 SAR Image Data " Canadian J. of Remote Sensing.

Merzouki, A., McNairn, H., and Pacheco, A. (2010, in press) “Mapping Soil Moisture Using RADARSAT-2 Data and Local Autocorrelation Statistics” IEEE J. of Selected Topics in Earth Observations and Remote Sensing.

Champagne, C., Berg, A., Belanger, J., McNairn, H., and deJeu, R. 2010. “Evaluation of Soil Moisture Derived from Passive Microwave Remote Sensing Over Agricultural Sites in Canada Using Ground-based Soil Moisture Monitoring Networks” International J. of Remote Sensing, 31 (14): 3669-3690.

C. Champagne, H. McNairn and A.A Berg. “Monitoring Agricultural Soil Moisture Extremes in Canada Using Passive Microwave Remote Sensing”, in preparation