Estimating Soil Moisture (Soil Water) Using Synthetic Aperture Radar

Heather McNairn and Eric Gauthier
Research Branch - AAFC
Outline

• What research projects related to EO and soil moisture are we been involved in (AAFC: EO Ottawa Research Branch Team)

• What are our strengths

• What are our challenges

• What are the implications of not having the gaps or deficiencies addressed?
Ottawa Research Branch Activities (EO and Soil Moisture)


**Project Objectives:**

1. Assess the accuracy with which surface roughness and soil moisture can be estimated using multi-polarization and multi-angle satellite SAR data
2. Develop an approach to estimate crop residue cover using optical data
3. Integrate crop type, residue and surface roughness EO-derived estimates into a land management product

**Research Branch Project Team:**
Dr. Heather McNairn  
Eric Gauthier  
Anna Pacheco  
Delmar Holmstrom  
Catherine Champagne  
Dr. Jiali Shang

<table>
<thead>
<tr>
<th>Soil Moisture and Surface Roughness</th>
</tr>
</thead>
</table>
| **Study Sites:**  
Eastern Ontario (2005,2006)  
PEI (2006) |
| **Satellite data:**  
- SAR HH (RADARSAT-1)  
- SAR Dual-Polarizations (Envisat-ASAR, ALOS)  
- Polarimetric SAR (ALOS) |
| **Field data:**  
in situ measurements using Theta Probes  
surface roughness using SRM-200 |
| **Radar Models:**  
- Standard Dubois  
- Modified Dubois  
- Oh  
- IEM  
- Calibrated IEM |
Methodology to Derive Soil Moisture Estimates

\[ \sigma^o = f(\lambda, P, \theta, \text{rms}, m_v) \]

Backscatter versus Soil Roughness

Backscatter versus Soil Moisture

for identical \( \lambda, P, \theta, Mv \)

for identical \( \lambda, P, \theta, \text{rms} \)
Methodology to Derive Soil Moisture Estimates

Multi-Polarization Approach

\[ \sigma^o = f(\lambda, P, \theta, s, m_v) \]
\[ \sigma^o_1 = f(\lambda, P_1, \theta, s, m_v) \]
\[ \sigma^o_2 = f(\lambda, P_2, \theta, s, m_v) \]

Multi-Angle Approach

\[ \sigma^o = f(\lambda, P, \theta, s, m_v) \]
\[ \sigma^o_1 = f(\lambda, P, \theta_1, s, m_v) \]
\[ \sigma^o_2 = f(\lambda, P, \theta_2, s, m_v) \]
Soil Moisture Estimation
- Using Multi-Angle & Multi-Polarization SAR Data -

RMS Error (% Mv)
Modified Dubois Multi-Angle HHHH Model

Smooth = 4.3
Interm. = 4.4
Rough = 6.0

Prince Edward Island

RMS Error (% Mv)
Standard Dubois Multi-Polarization

Smooth = 8.4
Interm. = 11.4
Rough = 9.8

Eastern Ontario
Soil Moisture Estimation
- Using Multi-Angle & Multi-Polarization SAR Data -

- Prince Edward Island - Spring 2006:
  - Modified Dubois model with multi-angle RADARSAT-1 S6 HH and ASAR IS4 HH data have provided promising results. RMS errors range from 4 to 6 percent volumetric moisture (depending on roughness classes).

- Eastern Ontario - Spring 2006:
  - Standard Dubois model with multi-polarization RADARSAT-1 S4 Desc. HH and ASAR IS5 Desc. VV data have provided results with RMS errors ranging from 8 to 11 percent volumetric moisture (depending on roughness classes).

- Results are not consistent with respect to model performance and accuracies; similar conclusions are reported in the literature.

- Research must continue, with due attention to errors in ground data collection (sampling and characterization of surface soil moisture and roughness). Errors are greater for rougher fields, where moisture and roughness are more difficult to characterize.
Project Objectives:

1. Develop methods to quantify soil moisture using active radar data and to flag regions experiencing extreme soil moisture conditions using passive microwave data.

2. Demonstrate the assessment of risk due to extreme soil moisture conditions using integrated active and passive microwave soil moisture, over sites in the Prairies.

Project Team:

- Research Branch (Dr. Heather McNairn, Dr. Jiali Shang, Catherine Champagne, Anna Pacheco, Eric Gauthier, Delmar Holmstrom, PDF)
- PFRA (John Fitzmaurice, Zhirong Yang)
- NLWIS (Allan Howard, Ian Jarvis)
- CCRS (Dr. Touzi, Dr. Brisco, Dr. Hawkins, Dr. Charbonneau)
- Array Systems Inc.

Workplan:

- Processing of historical SAR (ASAR, RADARSAT, polarimetric space-borne and airborne data)
- Begin collection of new SAR data Fall of 2007. Sites include PEI, Eastern Ontario and Manitoba.
- Begin assessment of passive microwave data over Prairies (AMSR-E and then SMOS, once available)
- R&D first 2 years of project; demonstration 2009-2010
What are our strengths?

- extensive experience in the processing and analysis of satellite and airborne synthetic aperture radar (SAR) data – both multi-polarization and polarimetric – for many agriculture applications including soil moisture

- approved 4-year research project to further test and develop models to derive soil moisture estimates from SAR over 3 sites across Canada. RADARSAT-Constellation (a constellation of 3-6 dual polarization satellites) will be well suited for these models; could seek funding for applications development.

- over the course of this project the research, technology and partnerships could result in this application becoming another demonstration of how EO data and products can support the agriculture sector
  - SAR technology is developing rapidly and next generation of SAR satellites (ALOS PALSAR, RADARSAT-2 and RADARSAT-Constellation) will provide the frequencies, polarizations and multiple angles needed to move the model development forward into implementation
  - interest and participation of key Research Branch partners, in particular NLWIS and PFRA
  - a soil moisture monitoring approach, that uses an integration of in situ and satellite data, will clearly support a key AAFC business line - risk management for the agriculture sector
Earth Observation - Ottawa Research Branch Team

• develop methods to derive information from EO to support the mandate of the department
• partner with other branches/services for evaluation and delivery (i.e. NLWIS, PFRA)
• crop inventory is an excellent example of bridging the discovery to delivery continuum
• soil moisture could be the next success
What are our challenges?

The Approach

- Pieces together data from different satellites and at different times/dates, thus introducing error due to changing soil conditions; next-generation of sensors will reduce these errors (multiple polarizations on single sensor; near-coincident multiple angles)

- At C-Band, we are still only detecting surface (<10 cm) soil moisture; L-Band will be of interest

- The crop canopy has a contribution to C- and L-Band backscatter; methods to incorporate or remove canopy influence are in the early stages of research. Other site factors (row direction, residue, topography) are not accounted for in these models; we need to make stronger links with the SAR modelling community

- Soil moisture estimation requires well (absolutely) calibrated SAR data; this is generally not an issue for existing systems, but we need to assess the errors that calibration contributes to soil moisture estimates, and we need to connect with the microwave calibration community with respect to new sensors
What are our challenges?

Model assessment

• To assess the performance of radar models we require independent surface soil moisture measurements

• When comparing SAR estimates and *in situ* measurements of soil moisture, a significant source of error is related to how we are measuring moisture in the field
  – *In situ* soil moisture measurements are required at the same depth as radar penetration (which varies depending on SAR configuration and soil moisture conditions). We either need measurements at multiple depths, or must be able to predict penetration depth.
  – *In situ* data must be coincident with SAR acquisitions (rule of thumb is ± 2 hours). This significantly constrains the amount of data that can be collected during field campaigns.
  – Spatial sampling of soil moisture (and surface roughness) is of significant concern… not just how we measure, but where we measure.

• These are long standing issues, but they have yet to be adequately addressed
What are our challenges?

Passive microwave
• These data are attractive because of their large swath coverage, frequency of observation, and reduced sensitivity to surface roughness
• The spatial resolution would not support field level decision making or some levels of program delivery, but this type of wide-view high-revisit data can provide an important contribution
• Existing satellites are not collecting data at the optimal frequency for soil moisture; are awaiting SMOS
• Current team has very little experience in analysis of passive microwave
• Need to establish collaboration with Canadian or U.S. experts

In situ networks
• Can these networks be a source of data for model assessment, or assist in constraining radar models
• What networks are available and what do they measure; are they in the right locations
• What is the compatibility of instrumentation within and among these networks; are these sensors inter-calibrated
• How do we get access to these data and is there a cost
What are the implications of not having the gaps or deficiencies addressed?

• Research with respect to the estimation of surface soil moisture from SAR has been on-going for more than 30 years. The relationship between soil moisture and SAR has been empirically demonstrated. But we have been unable to consistently reproduce accurate soil moisture estimates across varied agri-ecosystems.

• Until recently, availability of the appropriate satellite SAR configurations was a factor in testing and implementation. But this constraint is quickly disappearing.

• Questions around field measurement approaches and protocols is long standing. How do we move forward?

• There are many research avenues still to pursue with respect to model development and new sensor approaches (i.e. polarimetric SAR). But we can make significant progress using existing models if we could improve the data used for model comparisons.

• Simply put, if we are unable to develop an approach that is robust and can consistently deliver accurate soil moisture estimates, we will never develop the bridge between research and operations.