Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

Integration of Radar and Optical Satellite Imagery to Support Crop Classification

Heather McNairn, Catherine Champagne and Jiali Shang

Agriculture and Agri-Food Canada, Ottawa, Canada
mcnairnh@agr.gc.ca

Canada

Presentation Outline – Crop Classification

- Results using multi-temporal optical (SPOT and Landsat) and C-Band SAR (RADARSAT and ASAR)
- Results using multi-temporal Landsat, C-Band SAR (RADARSAT) and L-Band SAR (ALOS)
- Comparison of results using SPOT, Landsat and AWifs
- Next steps

Supporting Sustainable Agriculture

- Agriculture is an important economic sector
- The federal and provincial governments are working co-operatively to deliver national programs to enable the competitiveness of this sector, and to meet both economic and environmental sustainability goals.
- Land information is needed at a range of detail and temporal scales to
  - assess the status and changing state of agriculture
  - measure the impacts of programs on land use decision-making
  - gauge the environmental and economic benefits of these investments
- National Land and Water Information Service
  - provides internet access to national land, soil, water, air, climatic and biodiversity resource information
  - supports national programs as well as local, regional and national land use decision-making

Project Objectives

- Develop an approach to deliver the crop inventory capacity of a land information hierarchy. Specific research questions:
  - At what level of accuracy and with what consistency can crops be classified across Canada's diverse cropping systems?
  - What satellite data (optical, SAR or both) are needed to accurately classify crop types across Canadian landscapes?
  - When are the critical times during the growing season to collect these data?
  - What is the best classification model?

- Methodology developed for *operational* crop classification must (a) provide **consistent** results, (b) be **robust** across diverse cropping systems, and (c) be **reliable** regardless of data availability.
  - Consistency – tested over multiple years
  - Robustness – tested over multiple sites
  - Reliability – multi-sensor approach (cloud cover, data continuity, sensor failure, acquisition conflicts)

- Set target accuracy of 85%

Study Sites (2004-2006)

2004-2006

Lethbridge , AB
(2006)

2006 AWifs

Swift Current, SK
(2006)

Winnipeg, MB
(2006)

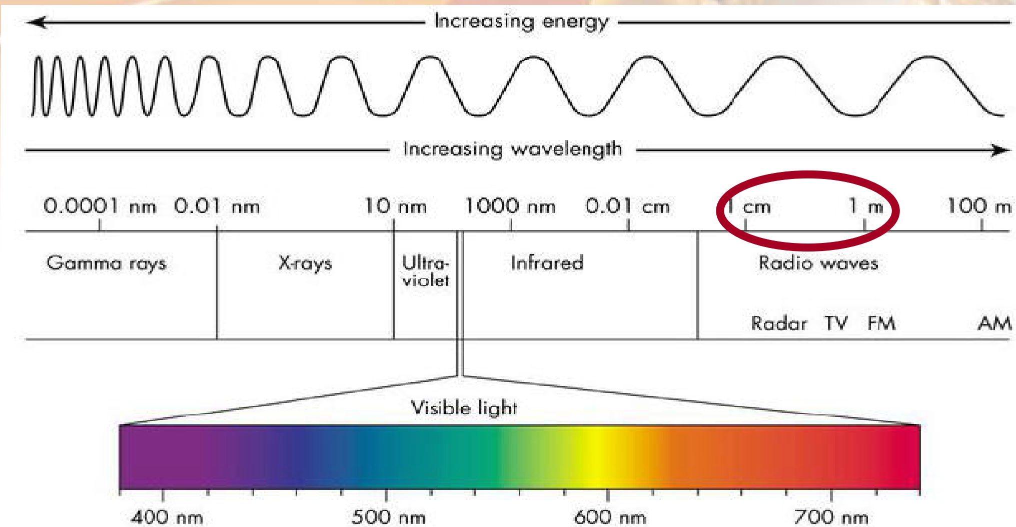
2006 ALOS PALSAR (L-Band)

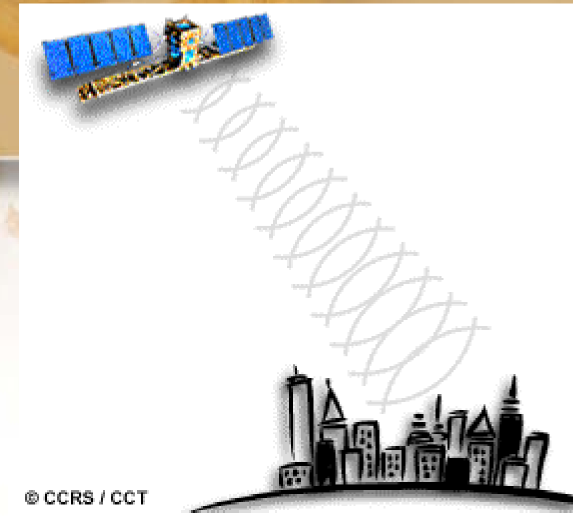
Eastern Ontario
(2004, 2005, 2006)

- **SPOT**
- **Landsat**
- **Landsat**
- **RADARSAT (C-Band)**
- **AWifs(2006)**
- **Envisat ASAR (C-Band)**

- **SPOT**
- **Landsat**
- **Envisat ASAR (C-Band)**
- **RADARSAT (C-Band)**

Synthetic Aperture Radar (SAR)

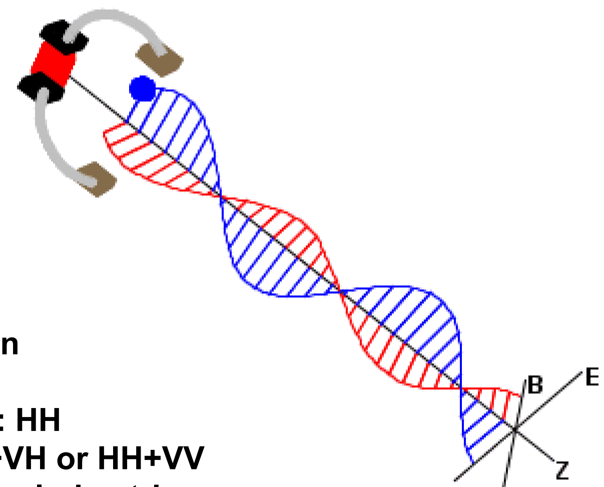




Frequency

C-Band
RADARSAT-1 and ASAR: 5.3GHz (5.6 cm)
RADARSAT-2: 5.405 GHz (5.6 cm)

L-Band
ALOS PALSAR: 1.27 GHz (23.6 cm)



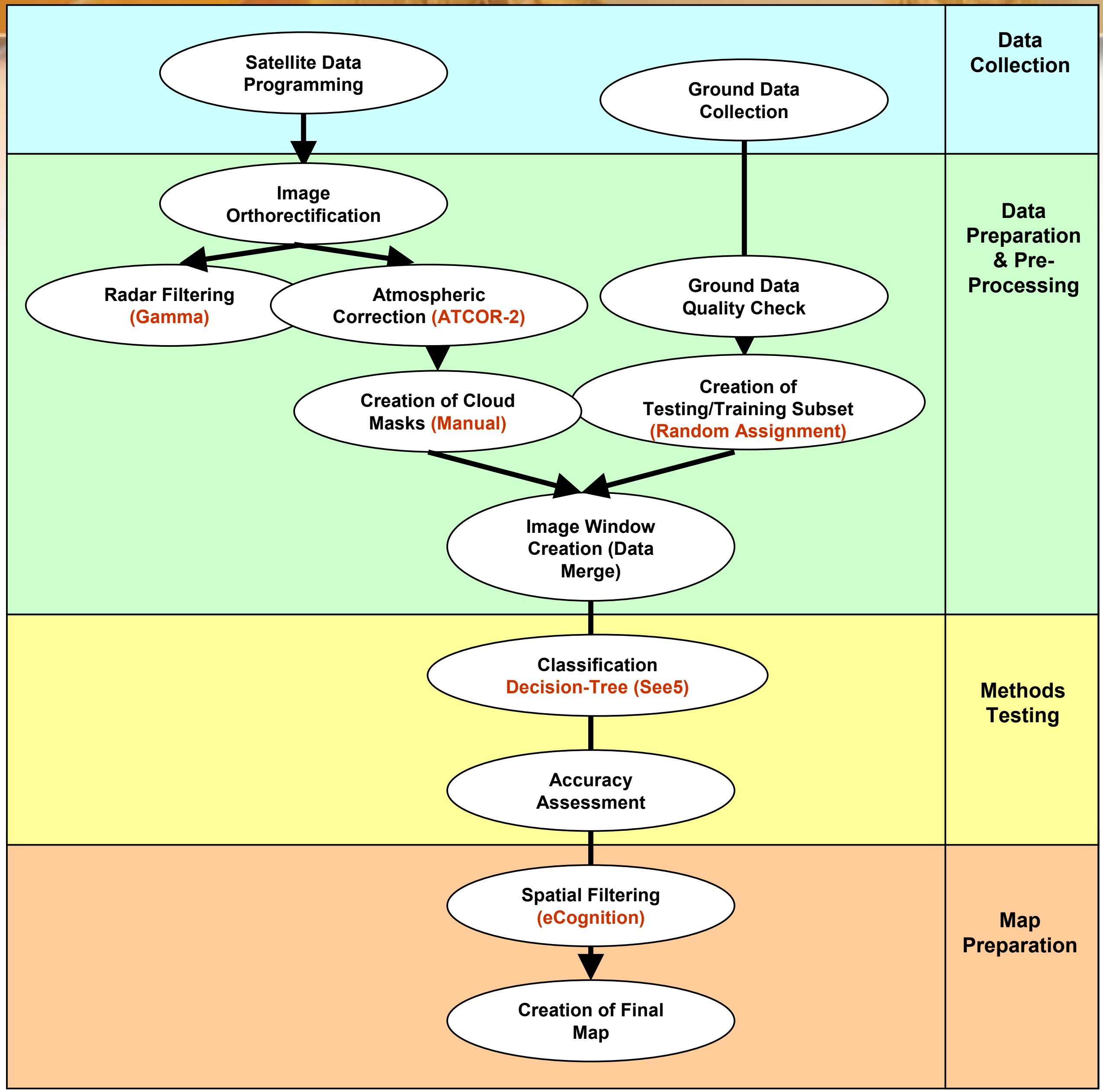
Polarization

RADARSAT-1: HH
ASAR: HH + HV or VV+VH or HH+VV
ALOS PALSAR: fully polarimetric
RADARSAT-2: fully polarimetric

Data Collection (2004-2006)

Site	Number of Satellite Acquisitions						Number of Fields Surveyed
	RADARSAT (HH)	ASAR (VV,VH)	SPOT	Landsat	AWifs	ALOS PALSAR	
2004							
Eastern Ontario	4	4	3	3			459
2005							
Eastern Ontario	12	6	2	3			397
2006							
Eastern Ontario	10 (ALOS – 4)	5	3	3 (ALOS – 3)	1	4	776 (ALOS – 228)
PEI	8	5	3	2			346
Red River	9	4	5	5	3		272
Swift Current	10	5	5	4	2		373
Lethbridge	10	3	4	4			317

Overview of Methodology



Cropping Mix Across Canada

Percentage of Fields Surveyed by Crop Type (2006)					
	PEI	**Eastern Ontario**	**Red River**	**Swift Current**	**Lethbridge**
Buckwheat		1%			
Canola			15%	9%	13%
Cereals (wheat, barley, oats)	20%	9%	39%	43%	30%
Chick peas				7%	1%
Corn		26%	7%		9%
Dry Beans					3%
Fallow				9%	2%
Field peas				13%	8%
Flaxseed			8%	1%	2%
Lentils				9%	2%
Mustard				1%	
Pasture-forage	47%	39%	9%	8%	12%
Potato	19%	1%			9%
Safflower					1%
Sod		1%			
Soybean	14%	23%	16%		
Sugarbeets					8%
Sunflower			6%		

Multi-temporal optical (SPOT and Landsat) and C-Band SAR (RADARSAT and ASAR)

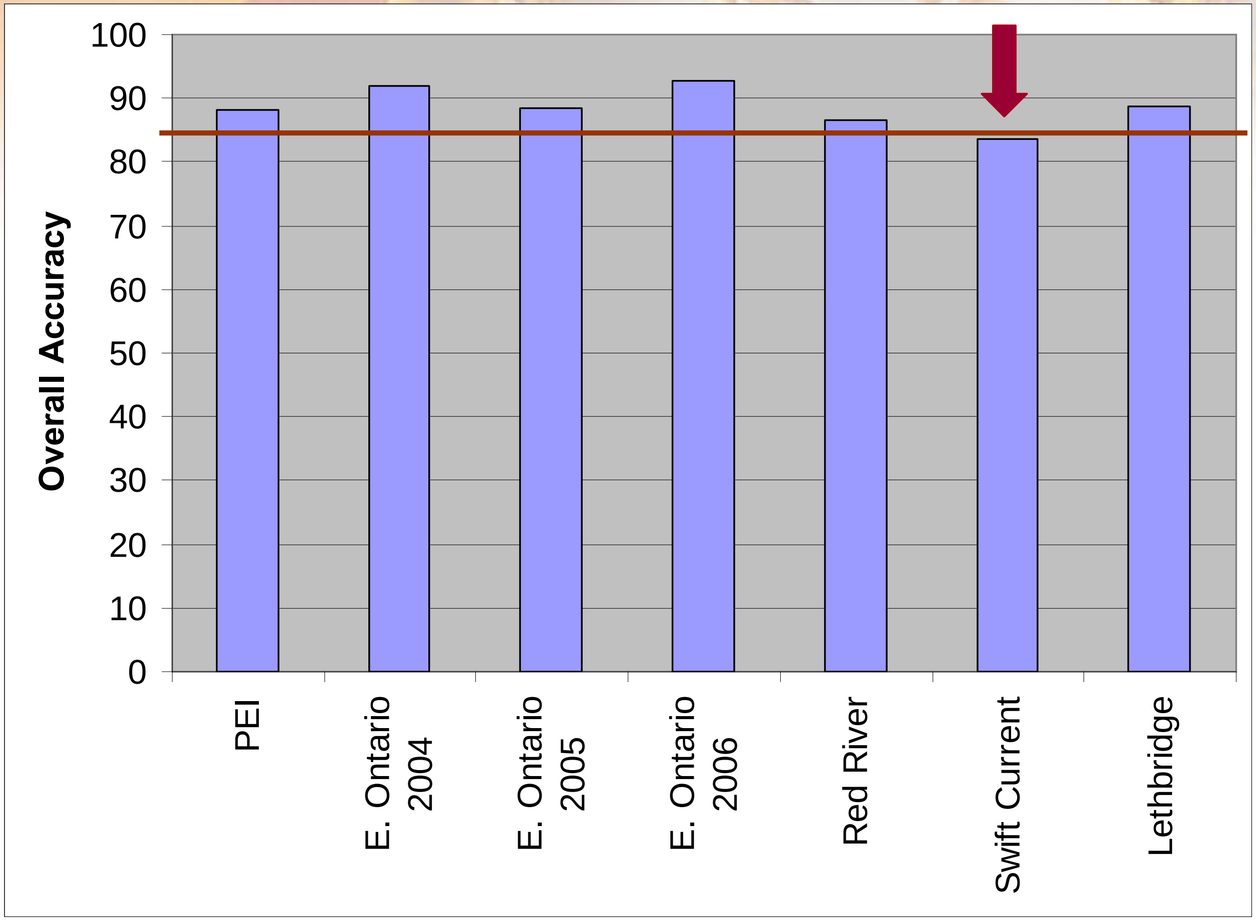
2004-2006

Comparing Multi-Date Optical and SAR Imagery

	Percent Overall Classification Accuracy			
	Optical	All SAR	RADARSAT	ASAR
PEI	87.0	73.5	68.2	65.6
E.Ontario 2004	89.0	83.9	72.9	79.2
E.Ontario 2005	85.9	78.7	62.0	73.9
E.Ontario 2006	92.0	78.6	75.0	60.6
Red River	85.0	74.3	65.8	75.8
Swift Current	78.8	68.1	62.1	58.4
Lethbridge	88.0	78.1	72.9	61.7

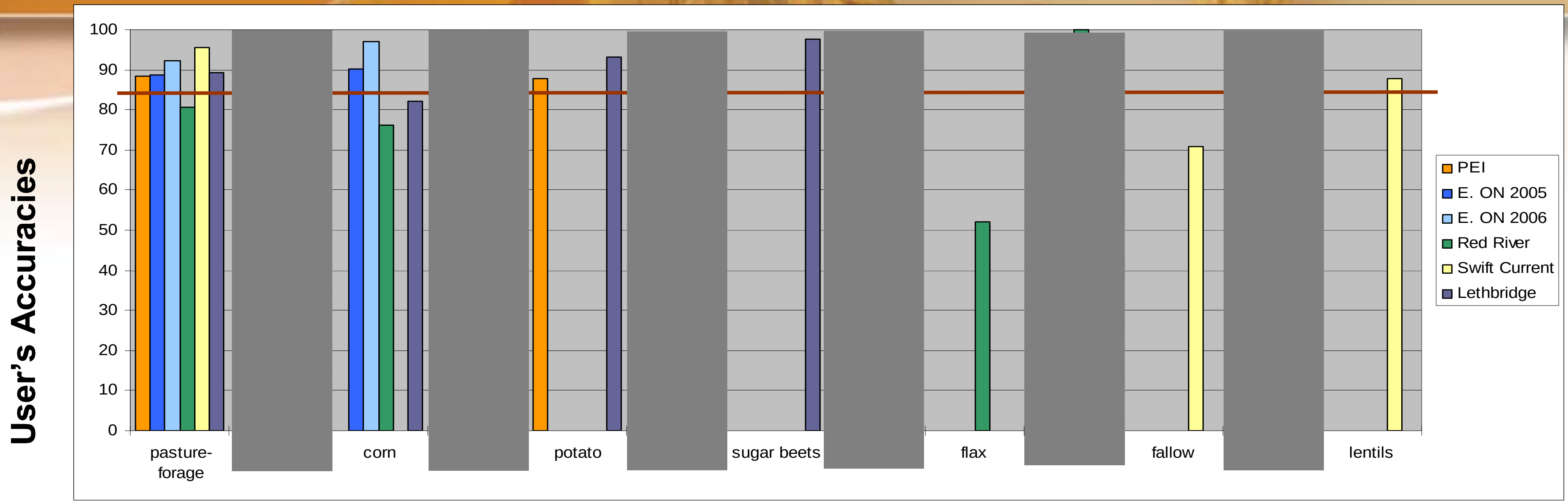
- accuracies above 85% were achieved using multiple dates of optical imagery
- increases in accuracies when HH and VV/VH were combined
- higher accuracies (7-14%) using multi-date optical compared with multi-date SAR
- data acquired later in the season were critical in classification

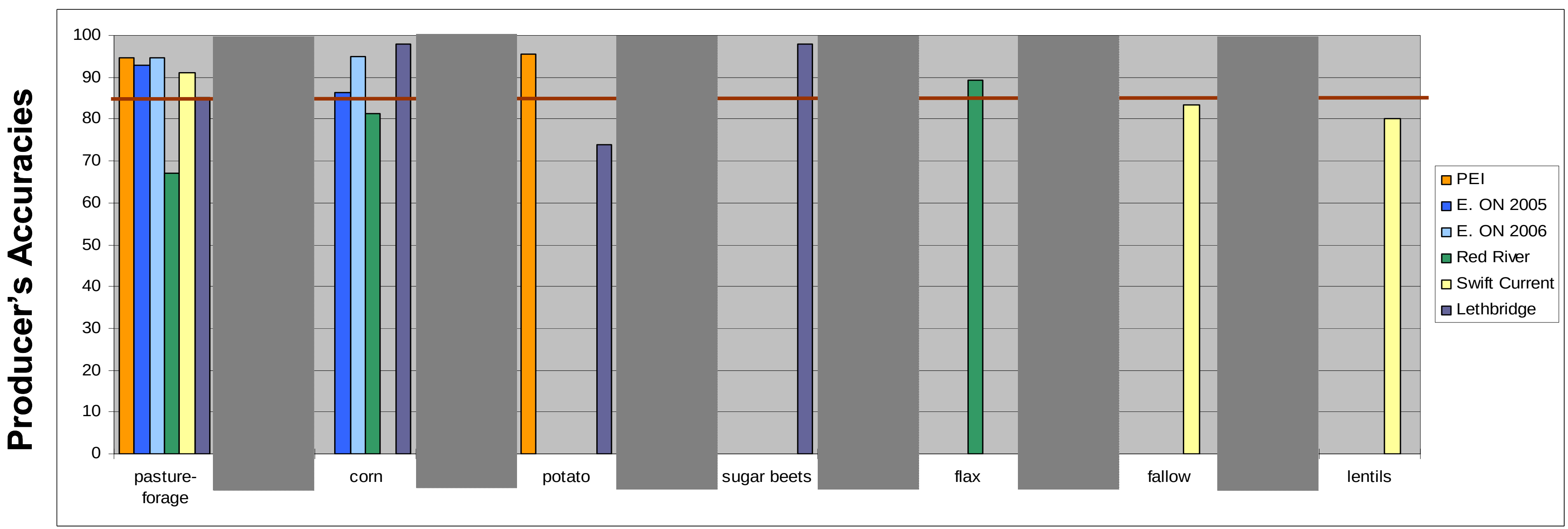
Overall Accuracies Using All Available Imagery



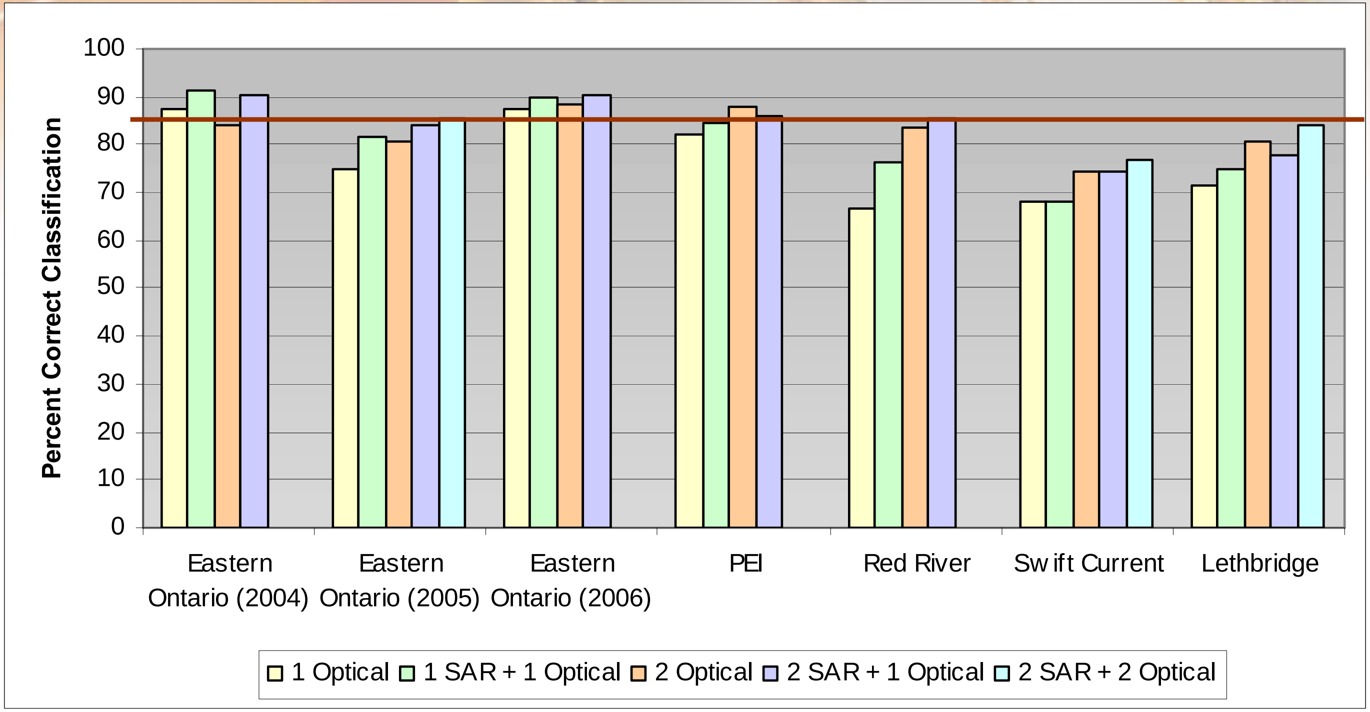
Small incremental increases in overall classification accuracies were observed when SAR data were added to optical data (~1-5%)

Individual Crop Classification Accuracies Using All Data



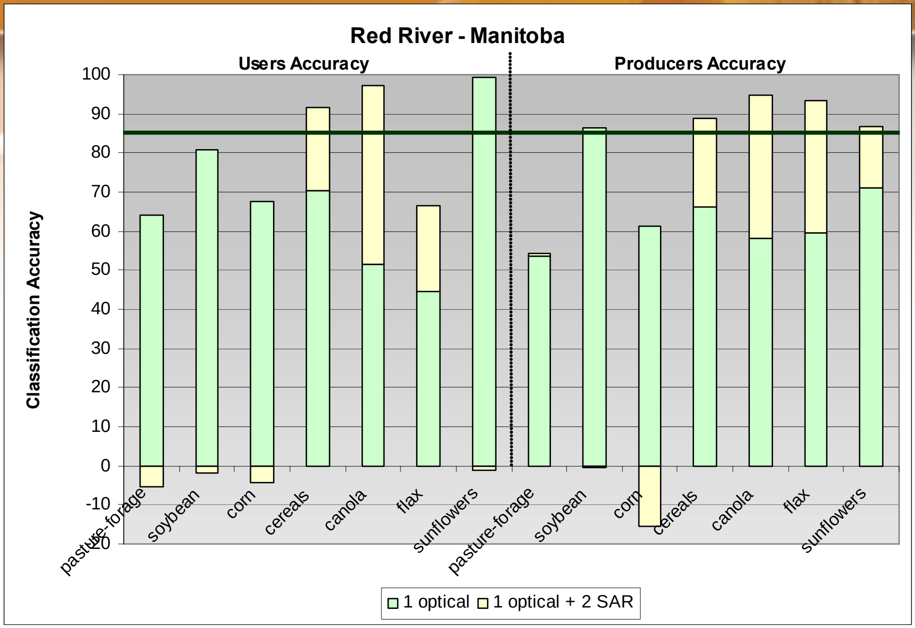


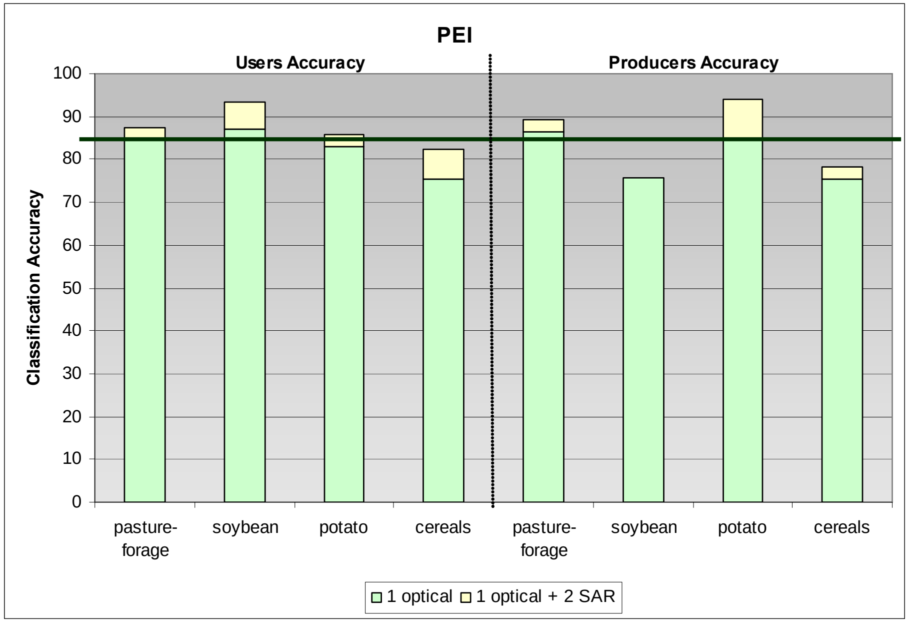
Why Include SAR?
Integrating a Reduced Number of Optical and SAR Images



- integration of 2 ASAR images with 1 optical image can produce overall accuracies of 75-90%
- overall accuracy improved 3-18% when 2 SAR images were added to a single optical image
- Swift Current: using all available optical images (9), accuracies of only 79% are reached; 2 SAR and 2 optical provide accuracies of 77%; all optical and SAR accuracies of 84%

Why Include SAR?
Individual Class Accuracies

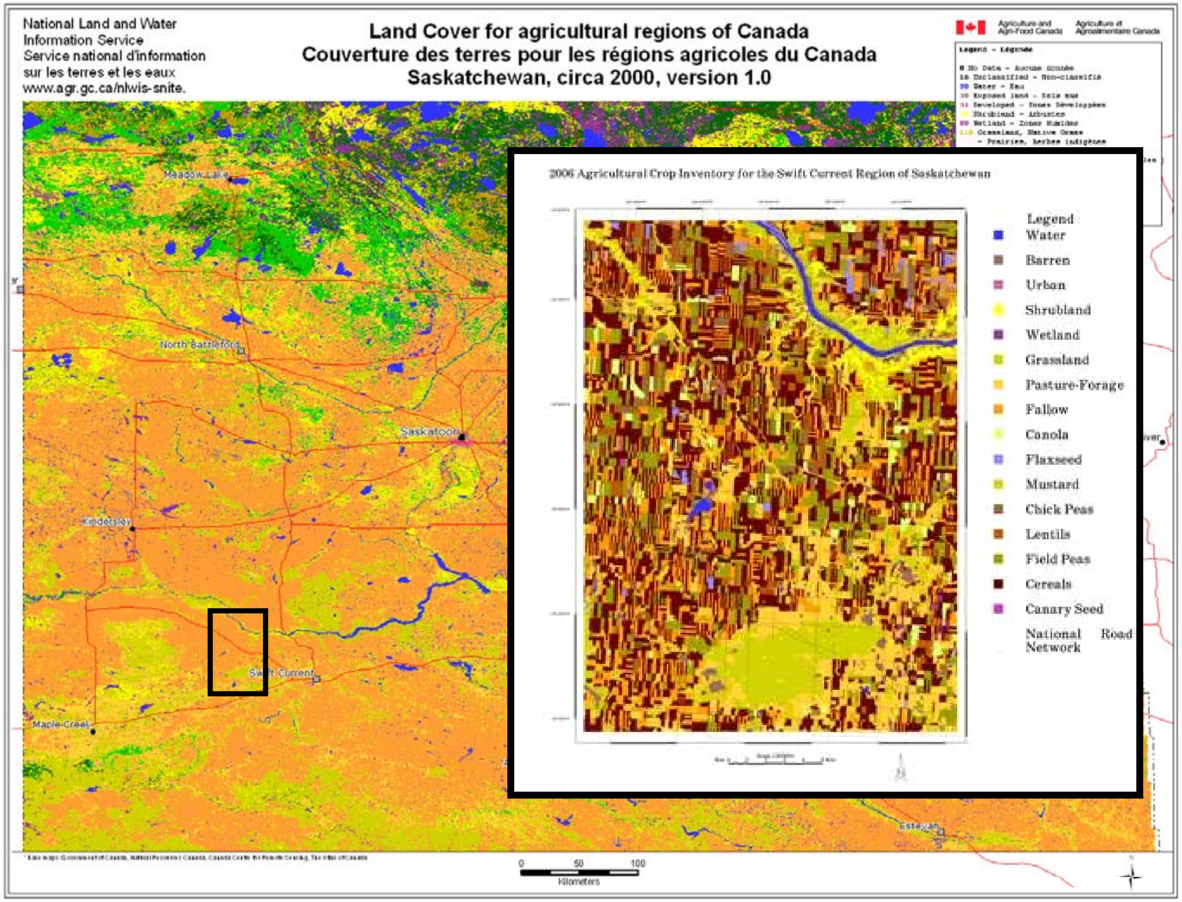




- integration of SAR often increased accuracies such that the 85% threshold was met; in other cases increases of 5% or more were observed

- SAR boosted accuracies most significantly for pasture-forage and broad-leaf crops (potato, sugar beets, canola and sunflowers)

- for the important grain growing regions of western Canada, SAR helped to push accuracies close to or above 85%. This was also the case for potatoes in PEI and soybeans in Ontario.

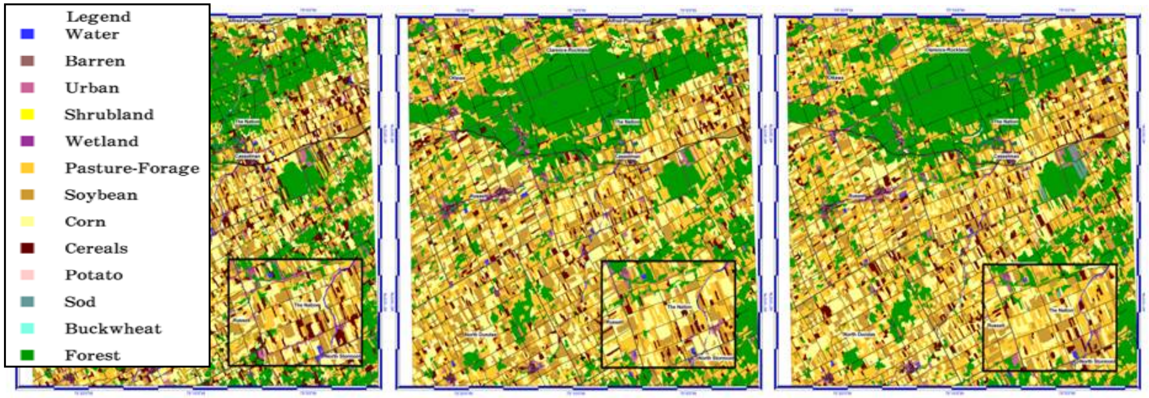


Integrated Land Cover and Land Use

Swift Current, SK

Tracking Land Use Change

Eastern Ontario



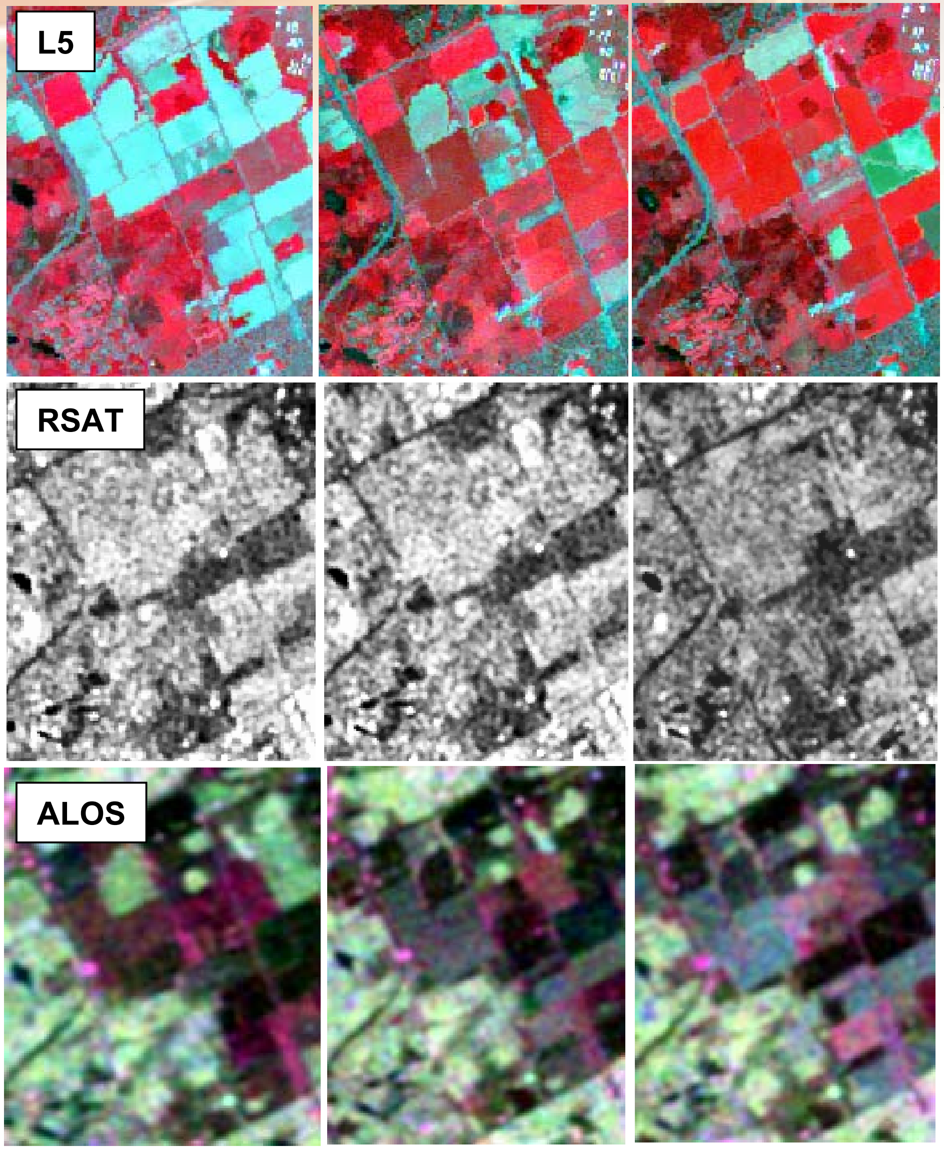
2004 2005 2006

Multi-temporal Landsat, C-Band SAR (RADARSAT) and L-Band SAR (ALOS)

Ottawa 2006

Multi-temporal ALOS and RADARSAT data

Early Season | Mid Season | Late Season



June 5
July 7
August 8

- RSAT and ALOS are near-coincident
- L-Band provides greater penetration into vegetation canopy
- ALOS PALSAR data were fully polarimetric

May 18	(S1 – 20-27°; Asc 18h43 LT)
July 5	(S1 – 20-27°; Asc 18h43 LT)
August 22	(S1 – 20-27°; Asc 18h43 LT)

May 19	level 1.5 (12.5 m resolution)
July 4	level 1.5 (12.5 m resolution)
August 19	level 1.5 (12.5 m resolution)

Comparing Frequency and Polarization

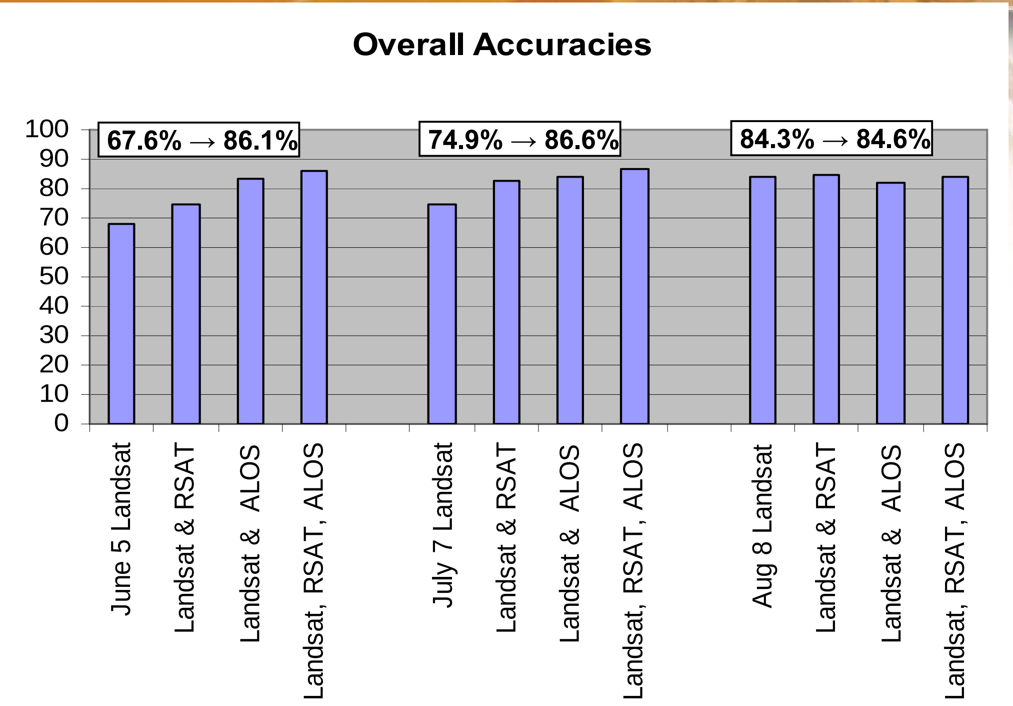
CFIA and Surrounding area (2006)

User's accuracies Producer's accuracies	Overall	Kappa
3 ALOS + 3 RSAT	76.5	0.68
3 ALOS – all linear polarizations	70.1	0.59
3 ALOS VV	61.4	0.47
3 ALOS VH	67.4	0.56
3 ALOS HV	68.5	0.57
3 ALOS L-band HH	62.5	0.49
3 RSAT C-band HH	56.3	0.40

- Comparing L- and C-Band at the same polarization (HH), L-Band slightly outperforms; L-Band is better for classifying large biomass crops (corn); C-Band is better for low biomass crops (hay-pasture)
- X-pol L-Band provides highest overall and crop-level accuracies; consistent with C-Band results
- Benefit of integrating multi-temporal ALOS (multi-pol) and RSAT are clear (76.5%)

Contribution of SAR to Crop Classification

CFIA and Surrounding area (2006)

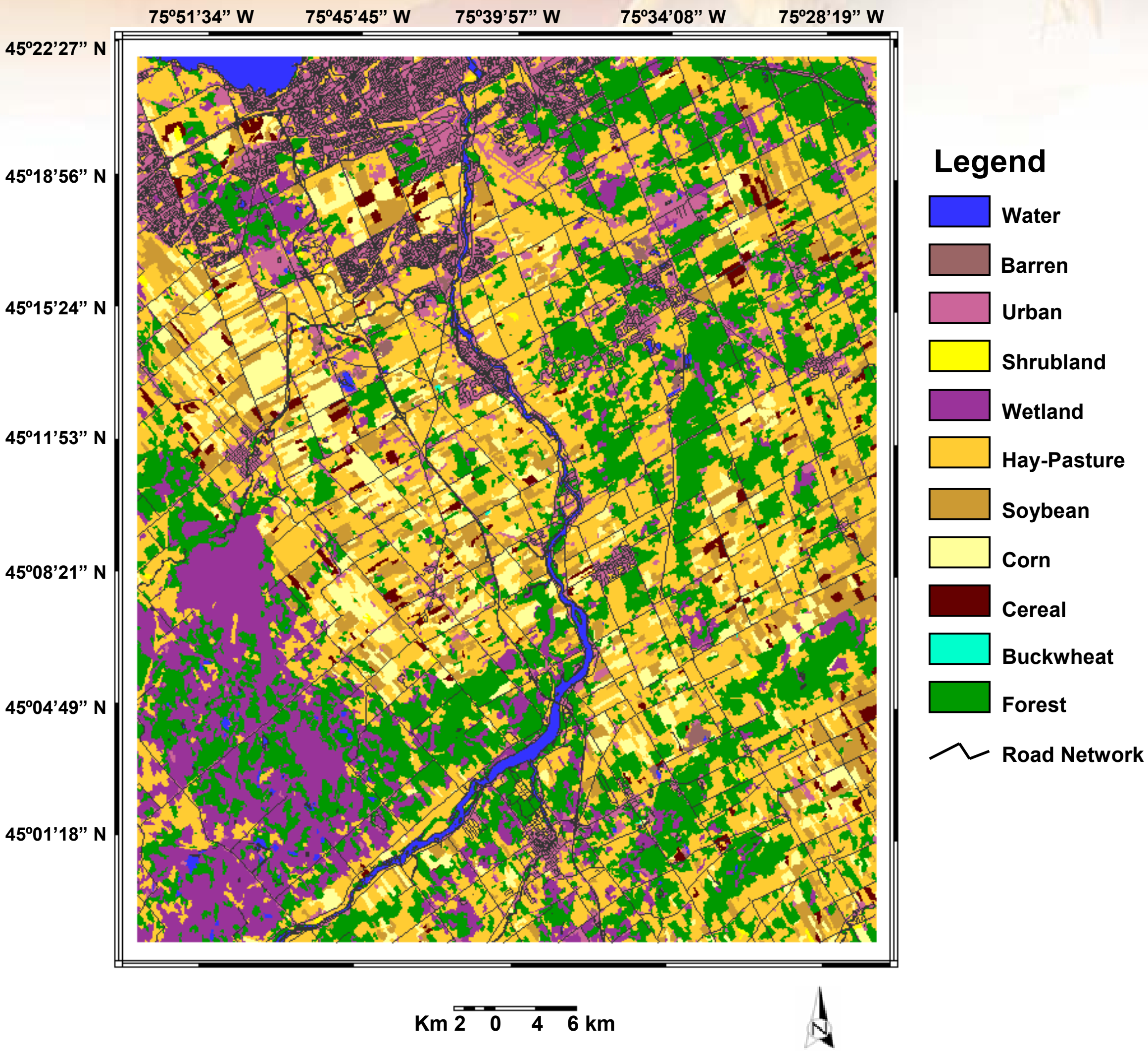


User's accuracies **Producer's accuracies**	**Hay-Pasture**	**Soybean**	**Corn**	**Cereal**
June 5 Landsat	51.6 66.5	78.3 60.1	69.3 80.4	75.7 58.7
June 5 Landsat, 3 ALOS, 3 RSAT	72.2 88.4	91.9 86.0	92.2 95.5	84.2 67.7
July 7 Landsat	69.7 43.4	82.3 76.5	67.0 89.5	88.7 80.3
July 7 Landsat, 3 ALOS, 3 RSAT	83.9 84.8	94.0 78.8	85.0 97.7	83.9 80.9

Post-classification Filtering – Final Map Products

CFIA and Surrounding area (2006)

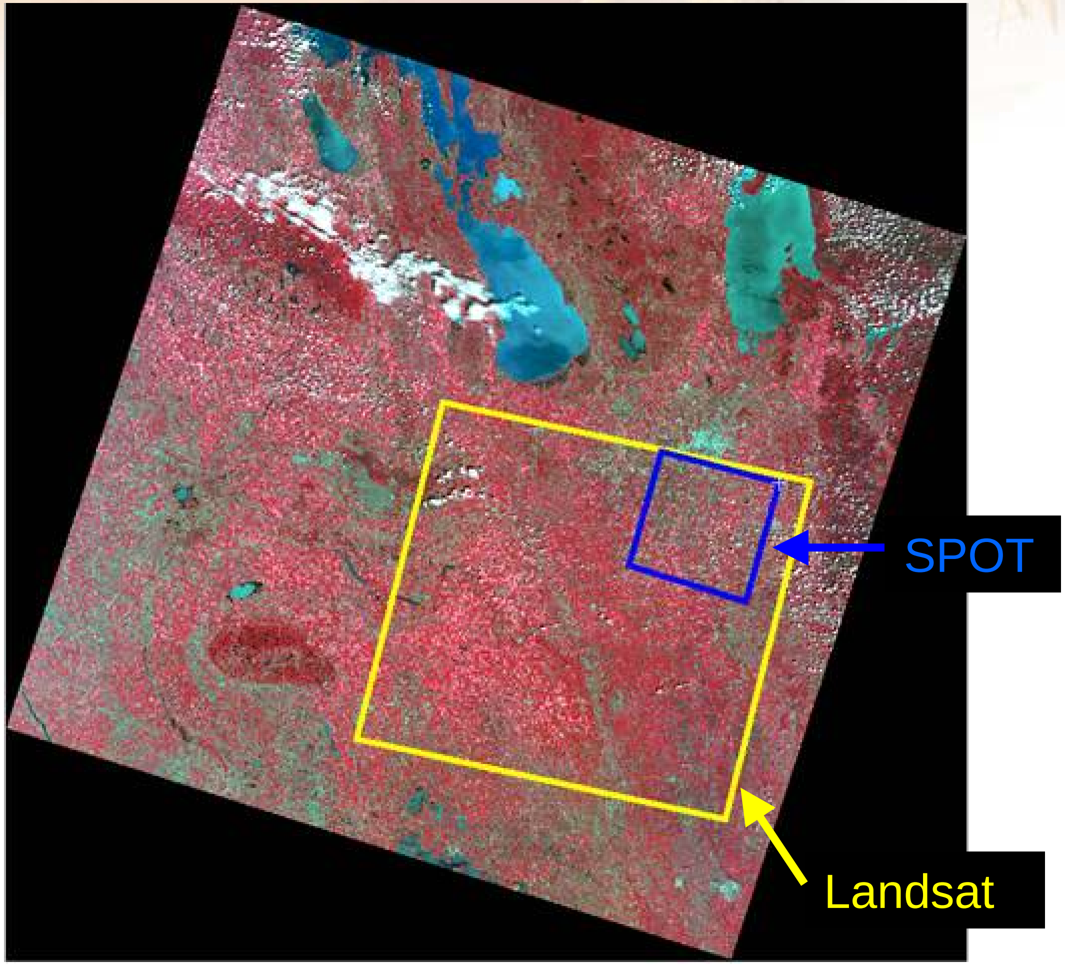
2006 Crop Inventory Results for CFIA and Surrounding Area



- Post-classification filtering (using segmentation and majority assignment) improved accuracies from 4-6%
- 3 Landsat images (June 5, July 7 & August 8): 88.0%
- Early season Landsat, 3 ALOS & 3 RSAT: 90.5%
- *Mid season Landsat, 3 ALOS & 3 RSAT: 91.7%*

Results with SPOT, Landsat and AWifs

Image Swath Comparison

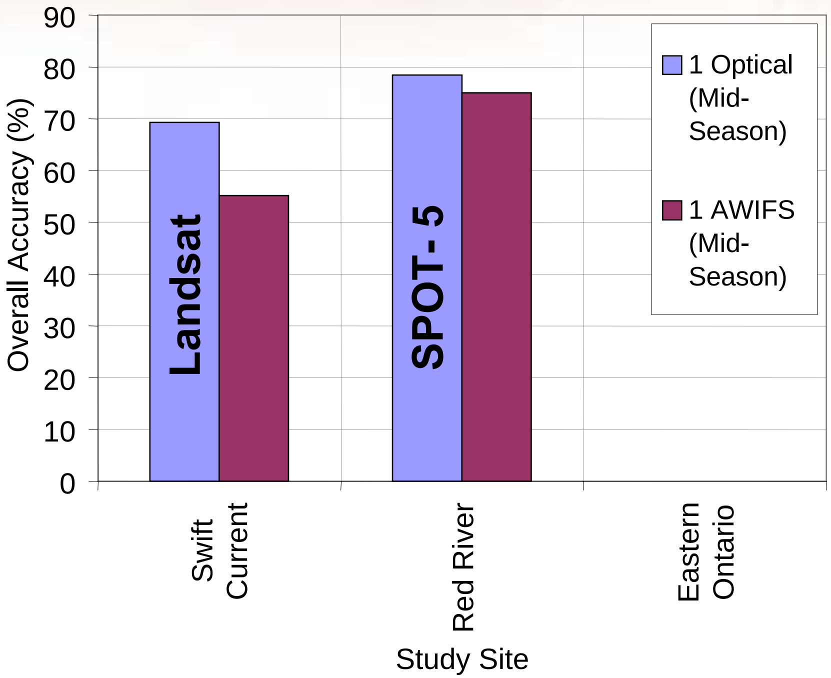


- AWiFS: 370 km / quadrat
  - 5 day repeat cycle
- Landsat: 185 km
  - 16 day repeat cycle
- SPOT: 60 km
  - 26 days (off-nadir 1 – 3 days)
- AWiFS Data
  - GeoEye
  - USDA Foreign Agriculture Service (Robert Tetrault)
- All images were re-sampled to AWiFS nominal resolution of 56m

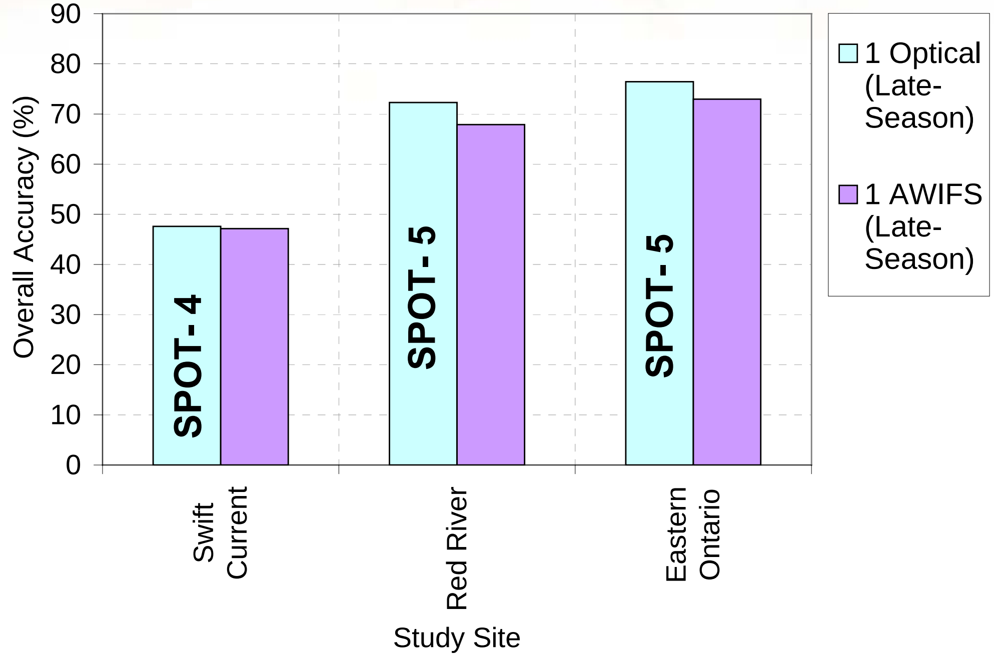
Single Date Optical Comparisons

- For comparison, images are less than 1 week apart

Single-Date Mid-Season

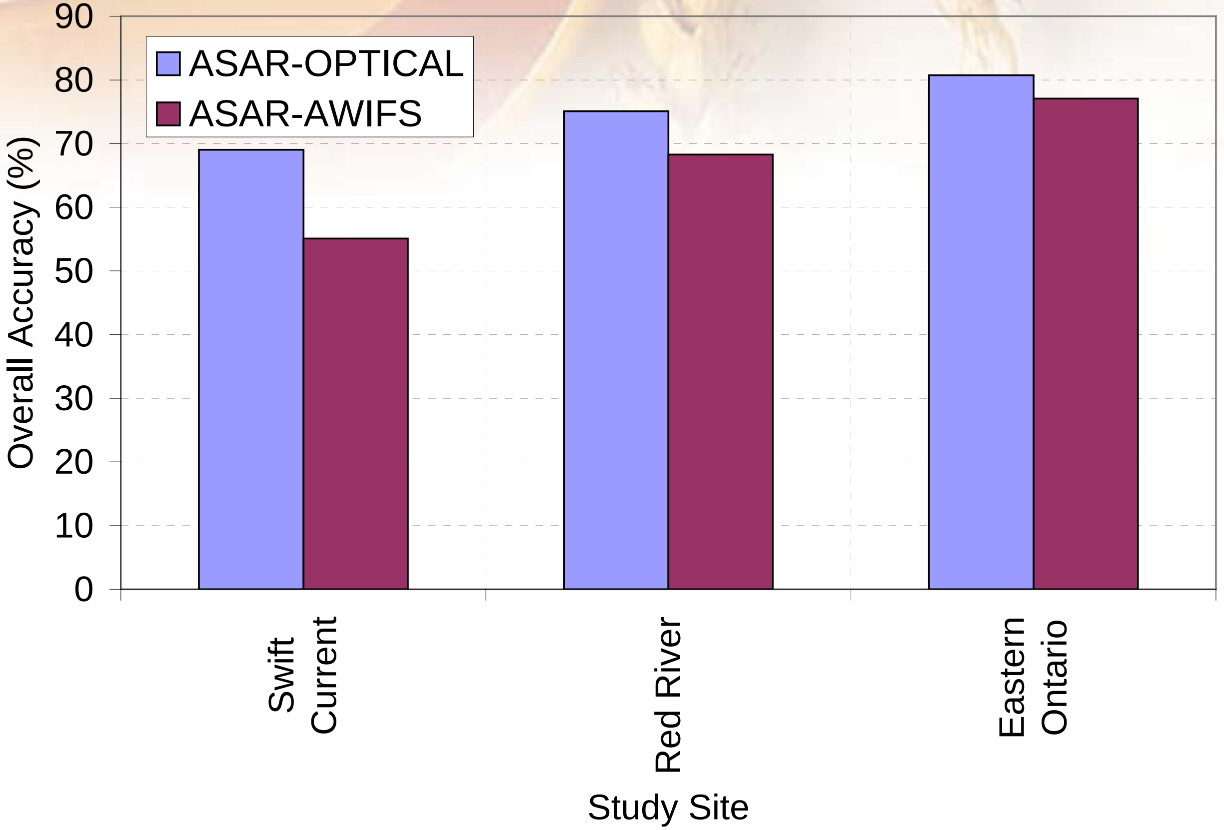


Single-Date Late Season



Red River (MB)
3 Dates of AWiFS: 80.8% (K = 0.74)
3 Dates of SPOT: 83.2% (K = 0.78)

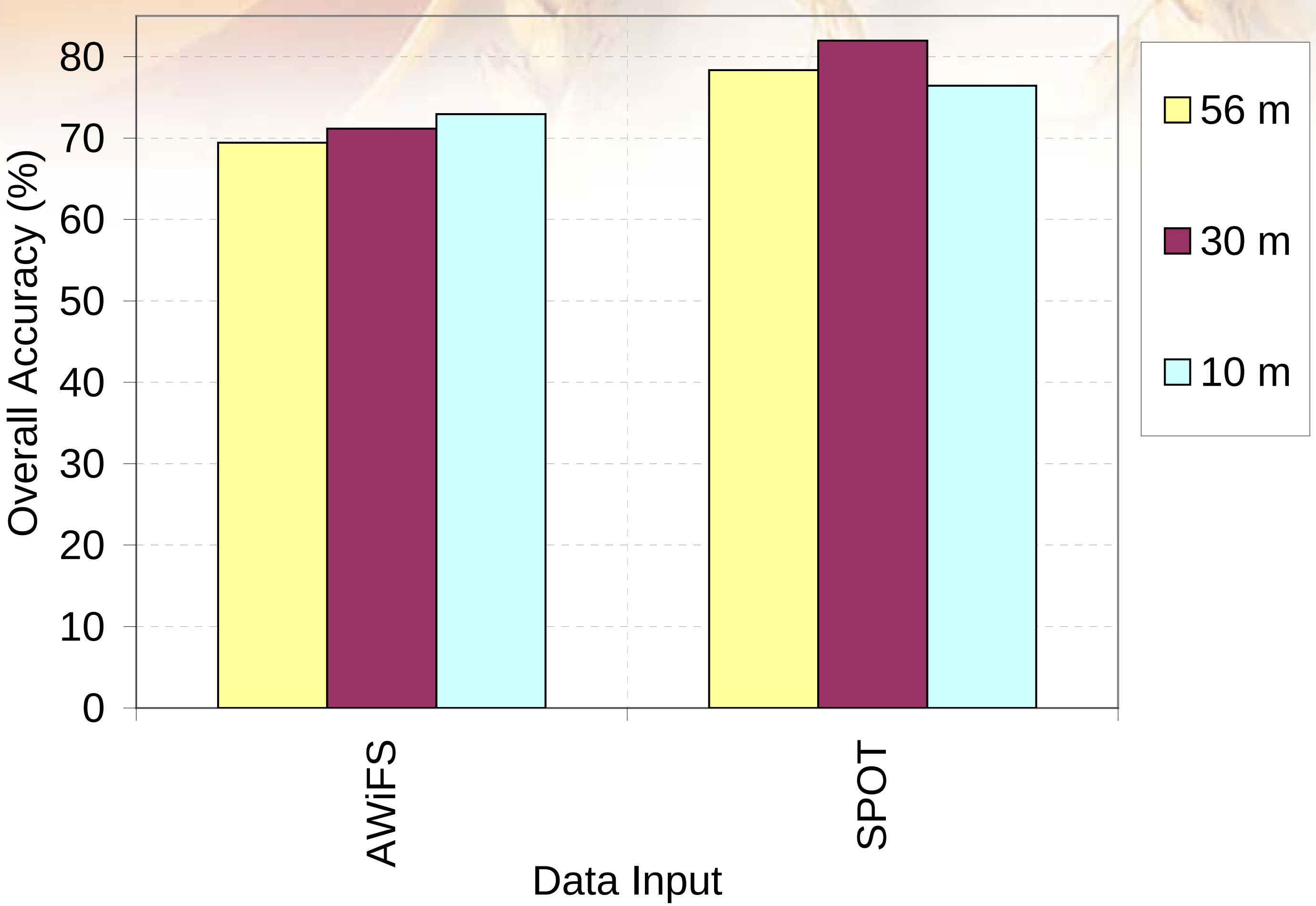
SAR-Optical Synergy



1 date of optical with 1 date of ASAR (mid-season)

- for western sites addition of ASAR to AWiFS was not helpful to overall accuracy; for Eastern Ontario accuracies increased 4%
- ASAR did assist in improving accuracies for AWiFS classification for pasture-forage, sunflowers, soybeans and fallow (> 5%)
- for Landsat and SPOT, ASAR adds 2-3% to accuracy to overall accuracy

Effect of Reduced Spatial Resolution



Summary of Three Research Activities

- Multi-temporal optical imagery can consistently classifying crops at accuracies of 85% or above, for a wide range of cropping systems
- Multi-temporal AWiFS data can produce an adequate crop classification over sites in Canada. Accuracies are slightly reduced in comparison with SPOT and Landsat data
- The wide swath coverage of AWiFS makes these data attractive for operational crop mapping, in areas where field sizes are large. This resolution will be problematic for eastern Canada.
- Integrating SAR with optical data slightly improves overall accuracy, and also improves individual crop classification accuracies, significantly in some cases.
- Integrating a limited number of SAR and optical data will provide an attractive option to mitigate risk and will boost some accuracies.
- Multi-frequency (C- and L-Band) data with a cross-polarization capability are most suited for crop classification. Multi-temporal ALOS and RSAT data with a single early/mid season optical image improved accuracies by 12-18% (to better than 90%)

- McNairn, H., C. Champagne, and J. Shang (2007). The value of SAR multi-polarization data in delivering annual crop inventories, *Proceedings of the International Geoscience and Remote Sensing Symposium*, Barcelona, Spain, CD-ROM.

Next Steps

- Methodology and results have been documented and submitted to the National Land and Water Information Service (NLWIS) of Agriculture and Agri-Food Canada for further assessment.

- Integration of RADARSAT-2 dual-pol data is planned.

- Future research will include assessment of data from advanced sensors, such as C- and L-Band polarimetric data, to assist in crop classification. Early results are promising using polarimetric decomposition.

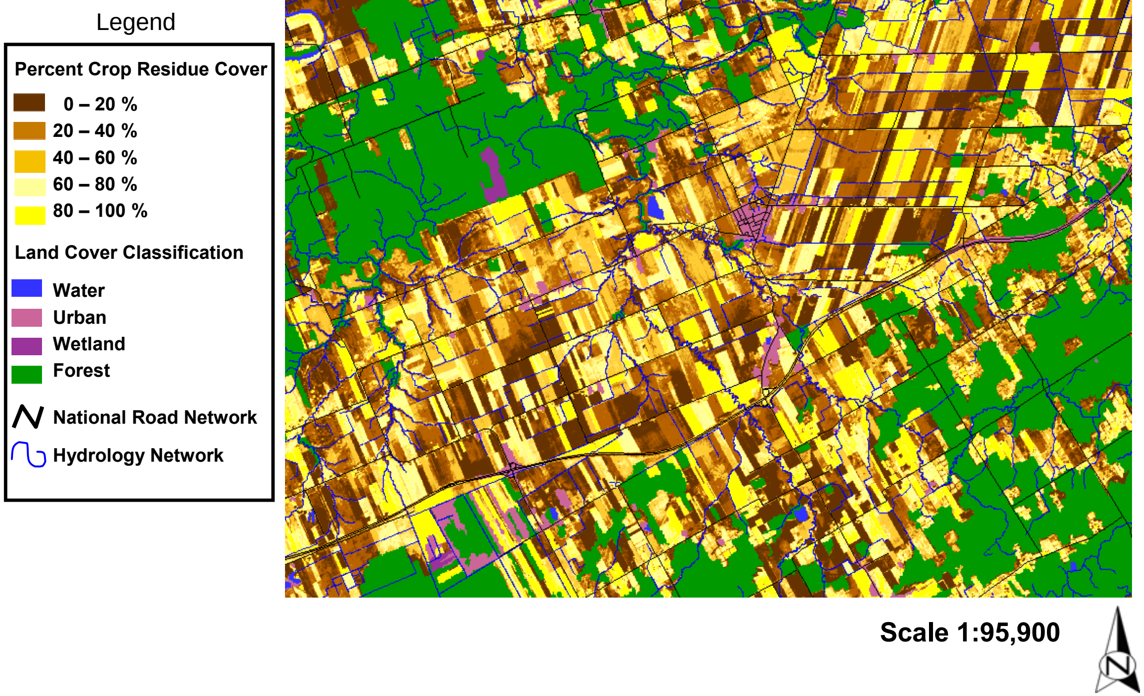
AWiFS – Next Steps

- AAFC is evaluating methods to derive percent crop residue from SPOT data. These maps are useful for erosion modeling, agri-environmental indicators, carbon modeling and evaluation of best management practice policies

- Results are promising; want to evaluate same method with AWiFS

- Questions concerning satellite tasking, acquisition confirmation and near-real time data delivery

Percent Crop Residue Map Derived from Spot-5 Data Acquired on November 9 2007 over Eastern Ontario



Canada