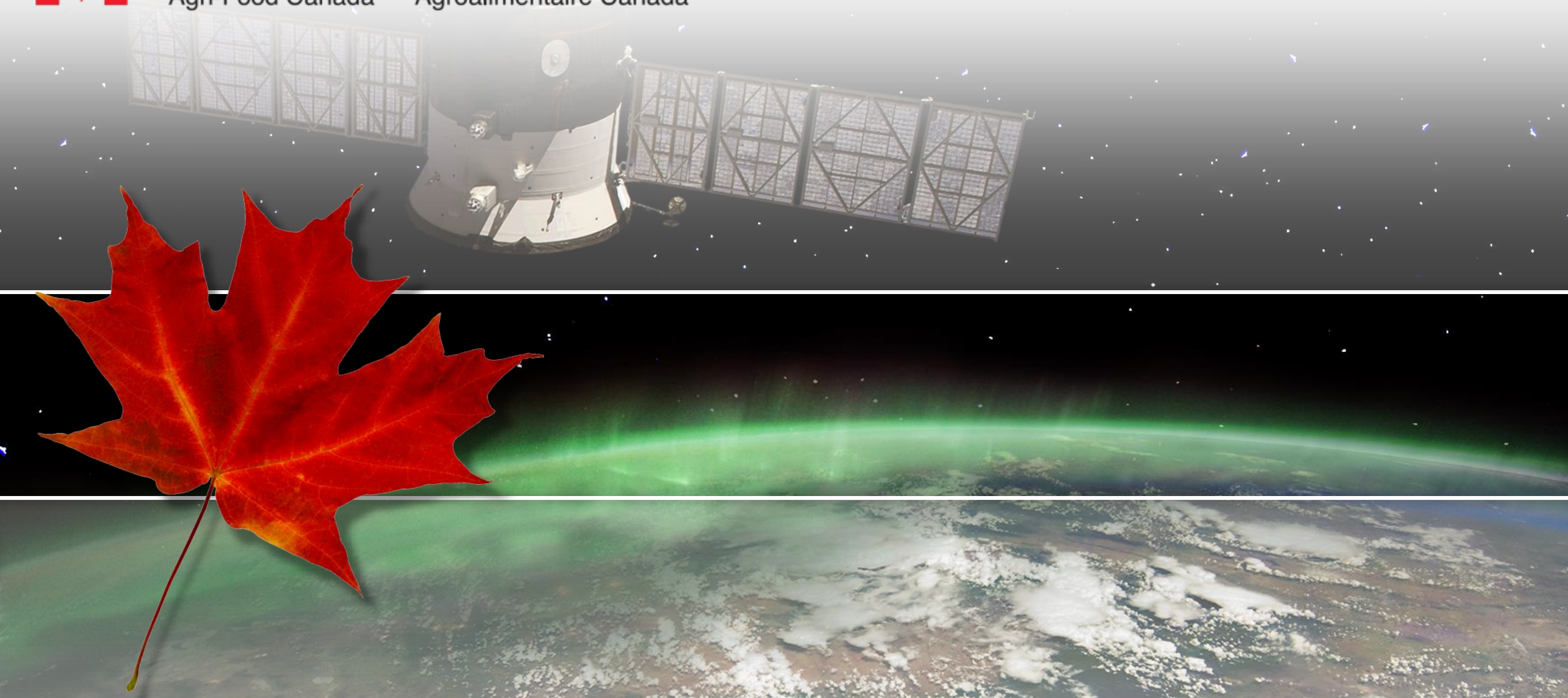
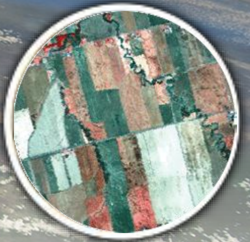
Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada





SAR FOR AGRICULTURE- Research and Development at AAFC

Heather McNairn*, Jarrett Powers, Jiali Shang, Amine Merzouki, Anna Pacheco, Thierry Fisette, Grant Wiseman, Saeid Homayouni and Mehdi Hosseini

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Canada

SAR Applications at Agriculture and Agri-Food Canada

- SAR is playing an increasing role in agriculture monitoring

- Decades of research using airborne systems and ground based scatterometers are now paying dividends, coupled with unprecedented engineering advancements in space-borne SAR

- Annual Crop Inventory
  Status: operational

- Crop Condition Assessment and Phenology Determination
  Status: research

- Soil Moisture Monitoring
  Status: pilot

Crop Inventory

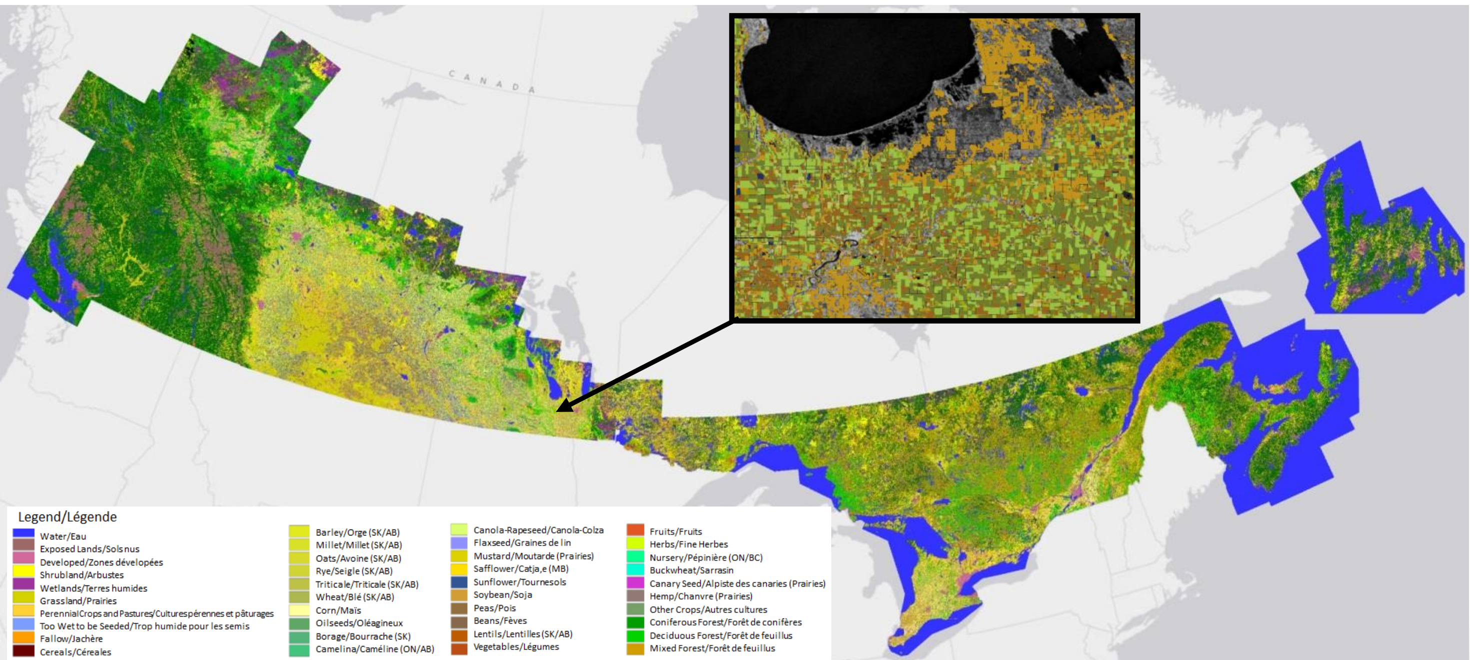
- Operations: Current crop inventory for Canada uses optical sensors, and integration of RADARSAT-2 (VV,VH); method based on supervised classification (Decision Tree)

- Research: Scientists have clearly proven that once users have access to multi-frequency SAR, operationally, a SAR-only solution is possible
  - eliminates operational burden of cloud removal
  - SAR mitigates risks in delivery of products due to interference by cloud cover
  - automation of ortho-rectification of SAR (using satellite ephemeris data) is now possible
  - pre-classification image processing of SAR (mostly filtering) is easily automated

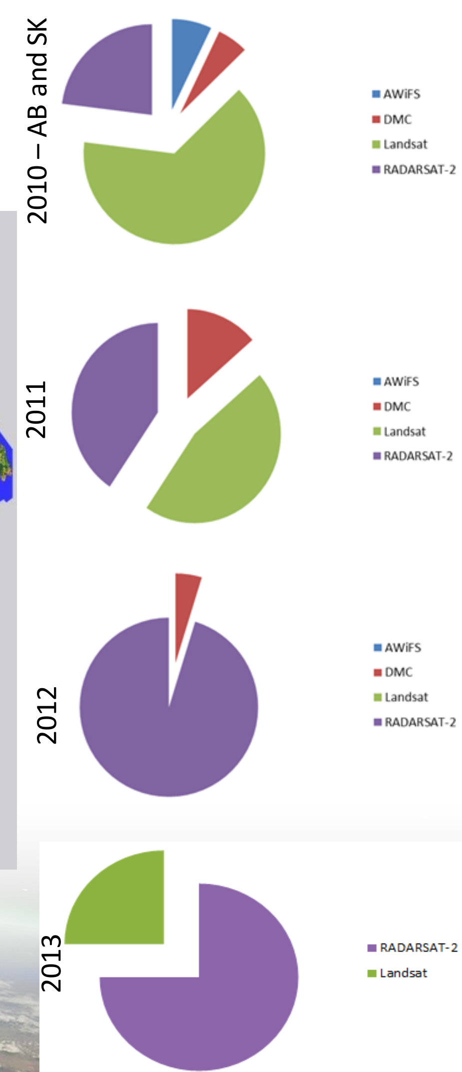
- Research: Has also demonstrated that polarization diversity is critical and the best results are observed using full and compact polarimetry

2013 National Crop Inventory
- Completed by Earth Observation Unit

Several years of research (2004-2006) (by AAFC Research Branch) on 5 sites across Canada ensured that method was robust and repeatable over different cropping systems.



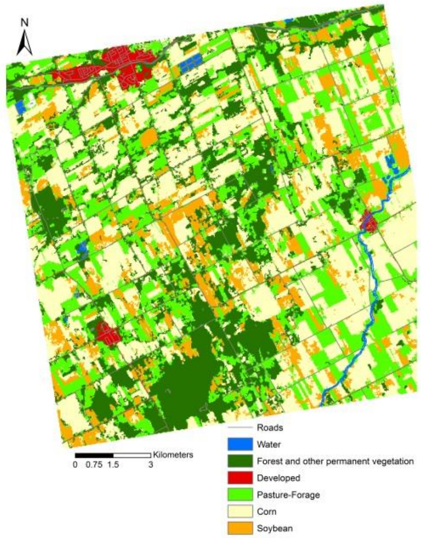
RADARSAT-2 usage



Fisette T, Rollin P, Aly Z, Campbell L, Daneshfar B, Filyer P, Smith A, Davidson A, Shang J, Jarvis I (2013) AAFC annual crop inventory: Status and challenges. The Second International Conference on Agro-Geoinformatics 2013, Fairfax, Virginia, 12 - 16 August 2013

Next Generation Products - Research

Early season crop identification

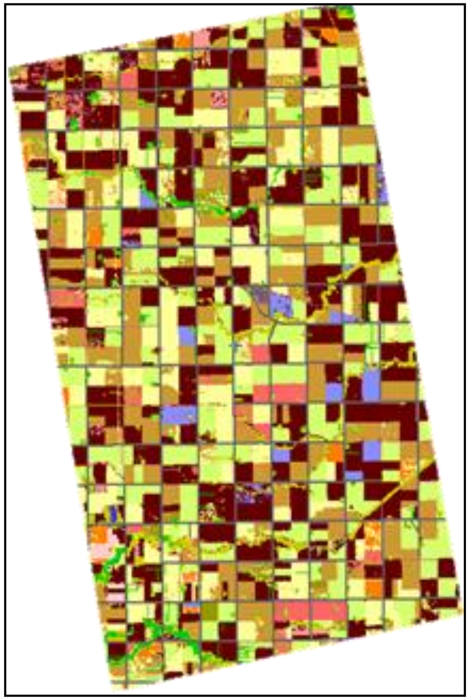


End of season TerraSAR-X crop classification: Ottawa 2012
Overall accuracy: **97.2%**

Early season: Corn can be identified at V6 or 6th leaf collar stage (about 6 weeks after planting)

McNairn, H., Kross, A., Lapen, D., Caves, R., and Shang J. 2014. Early season monitoring of corn and soybeans with TerraSAR-X and RADARSAT-2, International Journal of Applied Earth Observation and Geoinformation 28 (2014) 252–259.

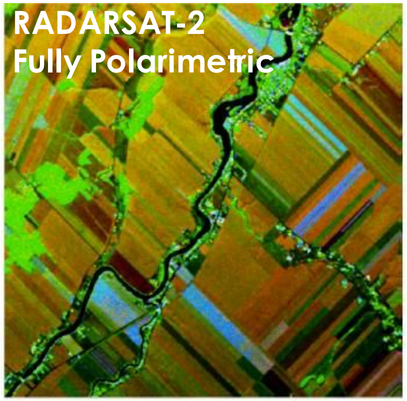
Multi-frequency SAR-only classification



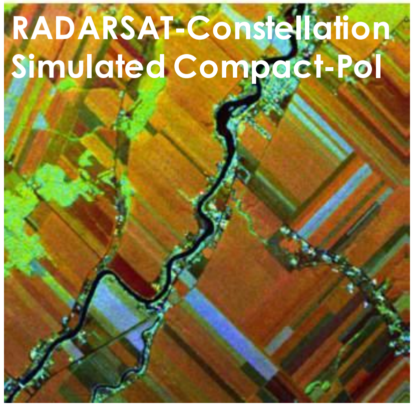
X-, C- and L- Band: Carman 2009
Overall accuracy: **91.4%**

McNairn, H., Shang, J., Jiao, X., and Champagne, C. 2009. The Contribution of ALOS PALSAR Multi-polarization and Polarimetric Data to Crop Classification, IEEE Geoscience and Remote Sensing, 47(12): 3981-3992.

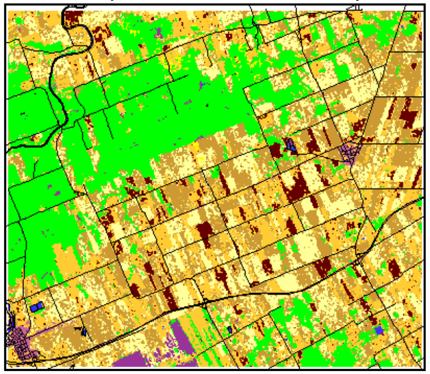
SAR - The Brave New World



Source: Francois Charbonneau



Classification Using Full and Compact Polarimetry



Accuracies in descending order :
Fully polarimetric
Compact polarimetric
Polarization diverse (VH, then VV, then HH)

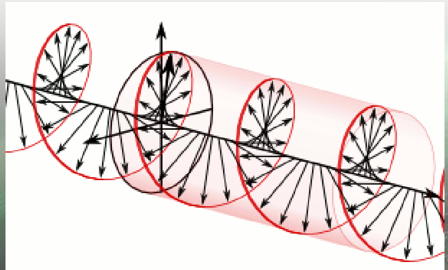
McNairn, H., and Shang, J. 2013. Evaluation of C-Band Polarimetric Synthetic Aperture Radar for Crop Classification. In Principles and Applications of PolInSAR, European Space Agency (ESTEC), Noordwijk, The Netherlands, in press.

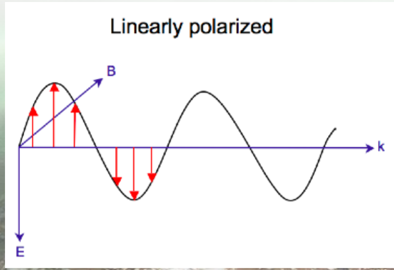
Charbonneau, F.J., Brisco, B., Raney, K., McNairn, H., Liu, C., Vachon, P.W., Shang, J., DeAbreu, R., Champagne, C., Merzouki, A., and Geldsetzer, T. 2010. Compact Polarimetry Overview and Applications Assessment, 36 (Suppl 2): S298-S315.

Polarimetric Change Detection
- Wishart Chernoff Distance -

Manitoba – 2012
Change from June 13-July 7

Source: Mohammed Dabboor (EC) and Brian Brisco (NRCan)

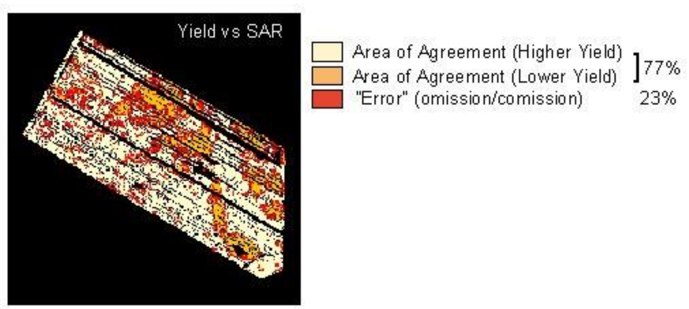




Monitoring Crop Condition

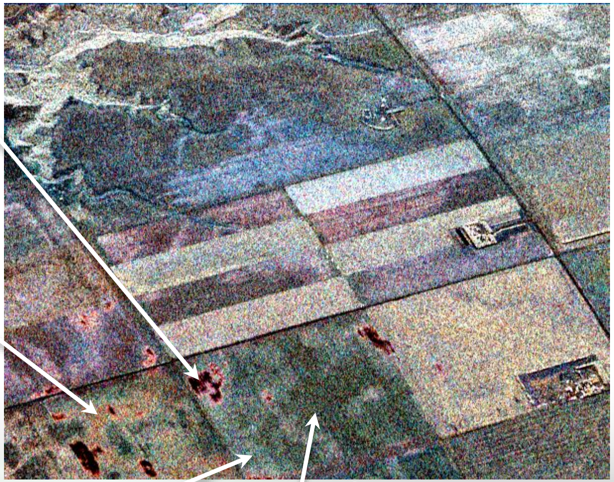
- Crop condition determination
  - temporal tracking of changes in crop condition
  - quantitative estimation of production indicators such as Leaf Area Index and biomass
  - identification of crop phenology and risk factors for crop disease

CV-580 June 30, 1999 (ON)
Agreement between wheat yield monitor data and SAR response



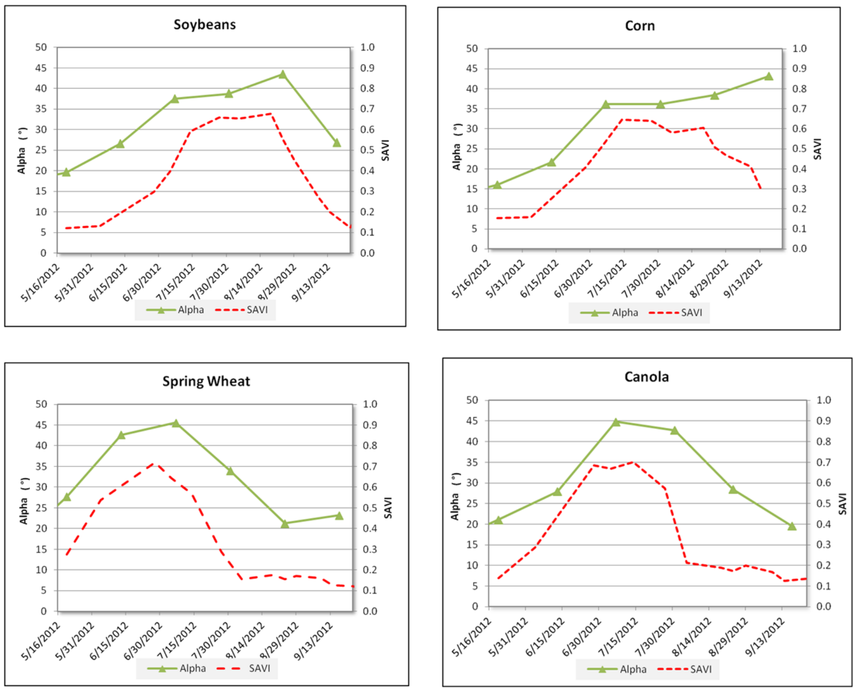
McNairn, H., Hochheim, K., and Rabe, N. 2004. Applying Polarimetric Radar Imagery for Mapping the Productivity of Wheat Crops, Canadian Journal of Remote Sensing, 30 (3): 517-524.

CV-580 June 28, 2000 (SK)
Impact of saturated soils on wheat and barley development
(causes oxygen deficiency in soil and loss of N due to denitrification and leaching)



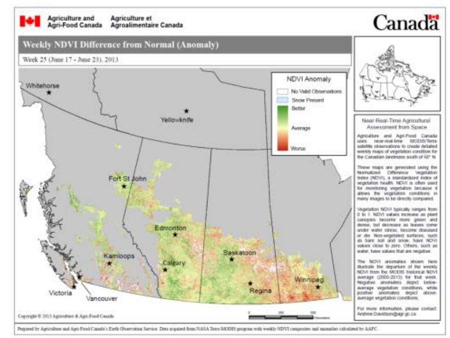
Temporal Crop Condition Monitoring

Temporal tracking of crop development using RADARSAT-2 (alpha angle)



Homayouni, H., McNairn, H., Wiseman, G., Shang, J., and Powers, J. Time Series Analysis of Synthetic Aperture Radar Polarimetric Data for Agricultural Crop Monitoring, in review.

- Most nations monitor crop condition using temporal sequences of optical indices, usually NDVI
- Cloud cover necessitates temporal compositing to remove clouds with the result being weekly or 10-day NDVI products



Typical MODIS-derived weekly NDVI product from AAFC EO Unit

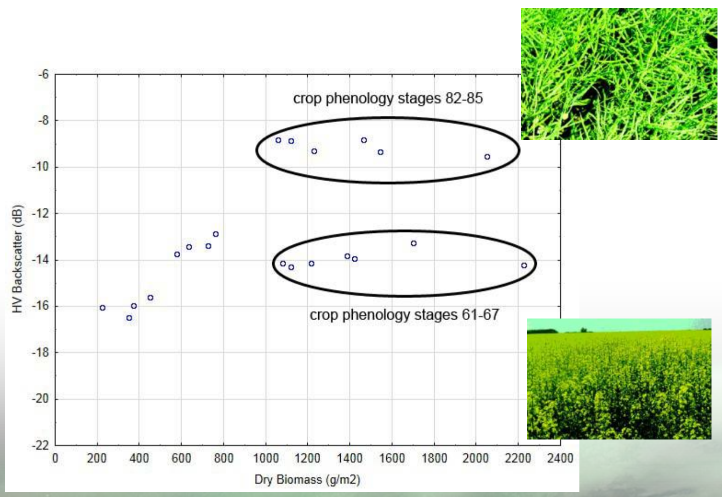
- Research using RADARSAT-2 is demonstrating that some radar parameters (HV intensity and decomposition parameters) track crop growth in a similar pattern as that observed from optical indices such as the Soil Adjusted Vegetation Index (SAVI)
- SAR could augment or eventually replace optical approaches

Estimating Dry Biomass

Correlations between RADARSAT-2 and crop dry biomass

SAR Parameter	Canola (n=64)	Corn (n=107)	Soybean (n=210)
HV	0.645	0.824	0.785
VOL	0.575	0.768	0.807
ENT	0.806	0.838	0.665
APH	0.803	0.833	0.662

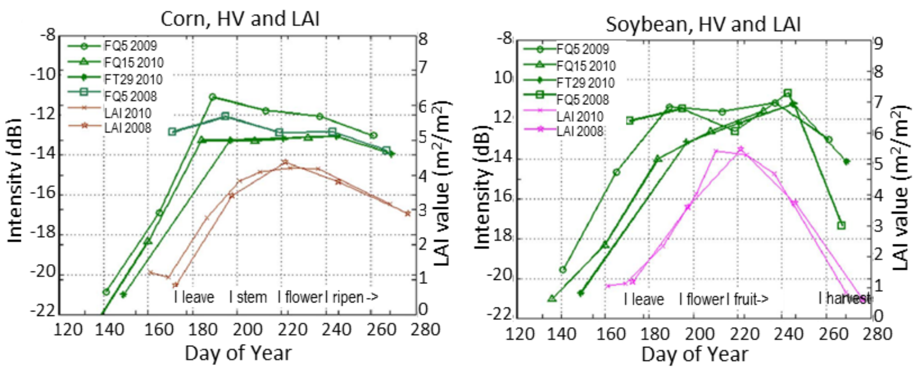
RADARSAT-2 response to canola pod development (top) and flowering (bottom)



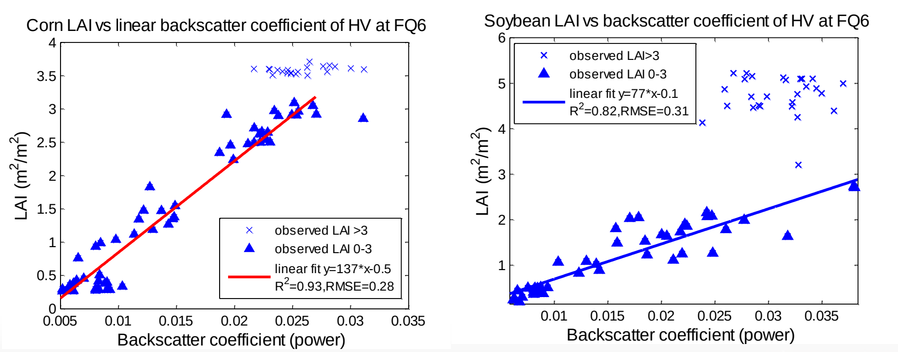
- Above ground dry biomass is a strong indicator of crop production
- Some radar parameters (HV intensity and decomposition parameters) are strongly correlated with biomass
- In addition, there are indications SAR responds to crop conditions indicative of yield potential and disease risk
    - canola flowering and pod development
    - height of corn
    - density of soybeans
    - progression of wheat to milking and dough stages

Wiseman, G., McNairn, H., Homayouni, H., and Shang, J. RADARSAT-2 Polarimetric SAR Response to Crop Biomass for Agricultural Production Monitoring, IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing, in press.

Crop Condition: Leaf Area Index



RADARSAT-2 response to LAI of corn and soybeans over growing season



Correlation between RADARSAT-2 backscatter and LAI of corn and soybeans

- LAI is a strong indicator of crop productivity and is linked through crop process models to yield and biomass
- LAI from optical data have been assimilated into yield models and have improved model estimates
- Gaps in access to optical data, especially early in the season when growth accelerates, is problematic
- SAR parameters sensitive to volume scattering (HV intensity, entropy and F-D volume component) have all proven to be highly correlated with LAI
- Track LAI until reproductive phase begins, then use SAR to determine phenology changes
- HV is very sensitive to LAI, but are advantages in using FP or CP configurations

Liu, C., Shang, J., Vachon, P., and McNairn, H. 2013. Multi-year crop monitoring using polarimetric RADARSAT-2 in IEEE Transactions on Geoscience and Remote Sensing, 51(4): 2227-2240.

Jiao, X., McNairn, H., Shang, J., Pattey, E., Liu, J., and Champagne, C. 2011. The Sensitivity of RADARSAT-2 Polarimetric SAR Data to Corn and Soybean Leaf Area Index in Canadian Journal of Remote Sensing, 37:69-81.

Estimating Leaf Area Index from RADARSAT-2

SAR modelling with Water Cloud Model

$$\sigma^0 = AL^E \cos\theta(1-\exp(-2BL/\cos\theta)) + \sigma^0_{soi}\exp(-2BL/\cos\theta)$$

Total backscattered by the whole canopy (σ^o) at incidence angle (θ)

$$\sigma^0_{veg} = AL^E \cos\theta(1-\tau^2)$$

Vegetation component

$$\sigma^0_{soil} = C + DM_s$$

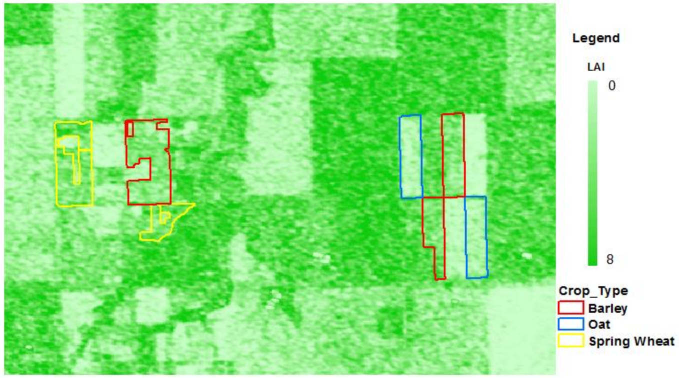
Soil component

$$\tau^2 = \exp(-2BL/\cos\theta)$$

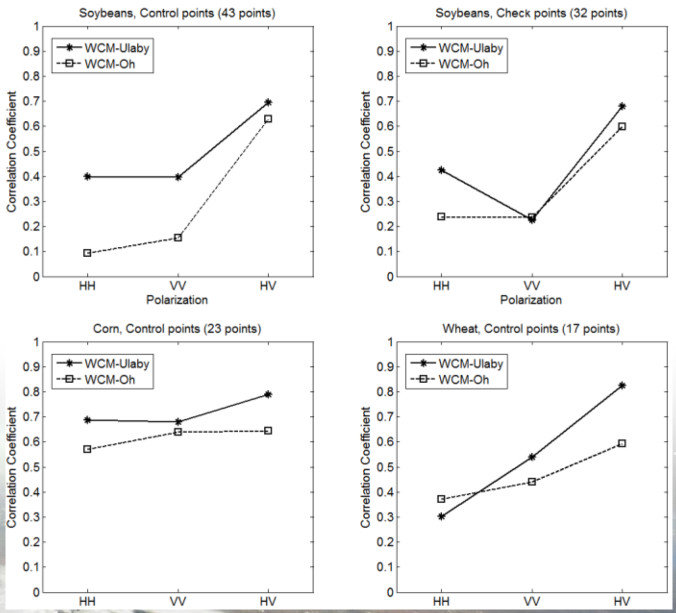
τ^2 is the two-way attenuation through the canopy layer
L is the LAI, expressed in (m^2m^{-2})
A,B,C,D and E are model coefficients defined by experimental data (A,B, E depend on canopy type)

- the parameterization of C and D, as determined by Jiao et al. (2011), was used (only one soil moisture station).
- remaining parameters (A, B, and E) simultaneously determined using a nonlinear least squares method in the Matlab Curve Fitting Toolbox

RS2 derived LAI map on June 24th



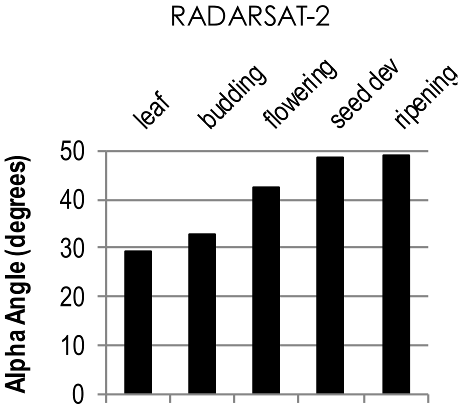
Inversion of WCM using RADARSAT-2 entropy and ancillary soil moisture



Coupling WCM with soil moisture models

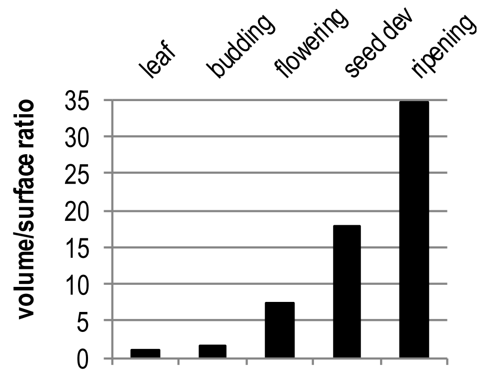
Deriving Indicators of Crop Disease Risk

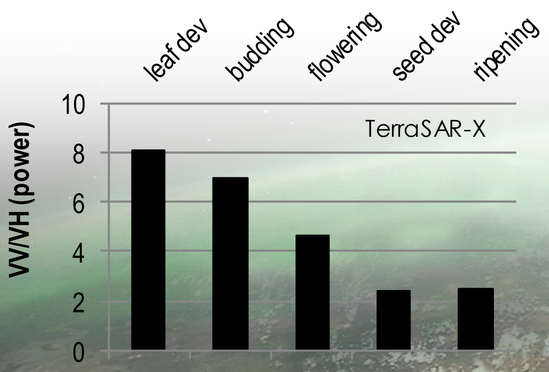
- Canola is susceptible to a host of diseases and infestations
- Sclerotinia stem rot affects canola when the crop is in bloom, reducing yields up to 50%
- Canola is also susceptible to insect infestations at the pod stage
- Identifying fields at risk requires knowledge of meteorological and soil moisture conditions, and information on crop phenology



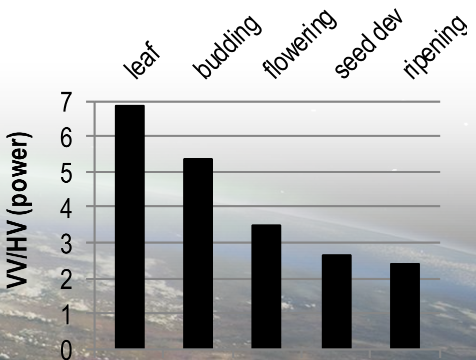
10% bloom 50% bloom sclerotinia stem rot effects at harvest

(photos from canolawatch.org and canolacouncil.org)





McNairn, H., Wiseman, G., Powers, J., Merzouki, A., and Shang, J. 2014. Assessment of Disease Risk in Canola using Multi-Frequency SAR: Preliminary Results. Proceedings of EUSAR 2014 – 10th European Conference on Synthetic Aperture Radar, 3-5 June 2014, Berlin, Germany.



Soil Moisture

2001-02 drought: cost the Canadian economy $5.8 billion

2010 excessive moisture in Canadian Prairies: reduced productive capacity of over 15 million acres, affecting 30,000 producers, resulting in production losses of more than $2.4 billion

2014: Close to 100 communities in Manitoba and Saskatchewan flooded; 400,000 hectares of farmland left unseeded (estimated). Manitoba declares state of emergency.

Response
Fed-Prov Programs for Agricultural Production Losses

2011-12: **> $420M*** spent by Agri-Recovery on climate related disasters mostly related to excess moisture. In addition, $**895M** spent on Crop Insurance programs.

2010-11: **> $400M** spent by Agri-Recovery on climate related disasters. In addition, $**767M** spent on Crop Insurance programs.

Soil Moisture Estimation with SAR

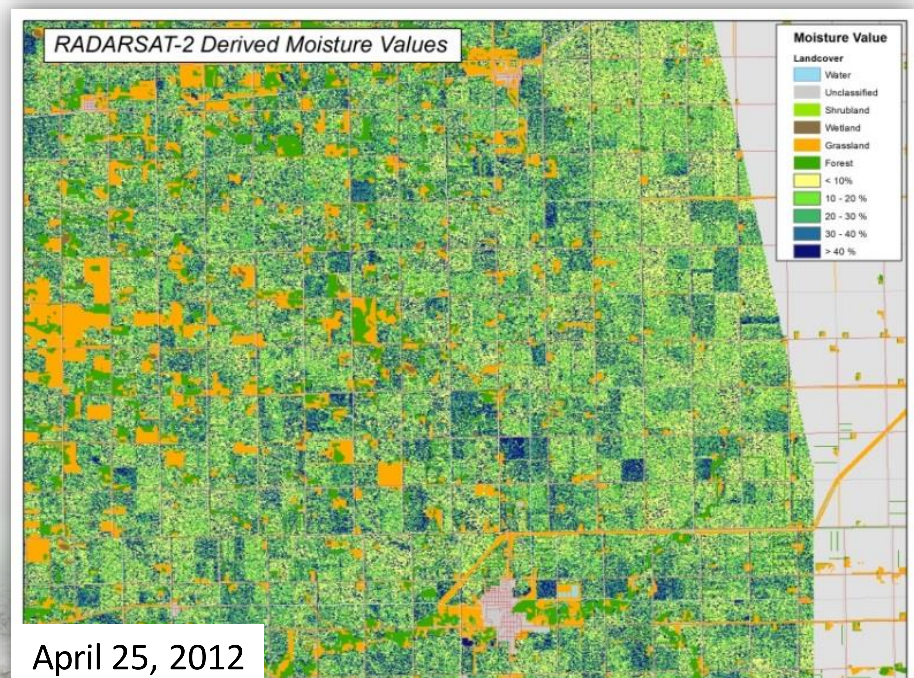
- AAFC Research focused on pre-planting and post-harvest (without significant vegetation)
- Current method has been tested over multiple years and is now being piloted in Manitoba

Measure absolute soil moisture at regional and field scales using SAR

Products identify impact at farm level

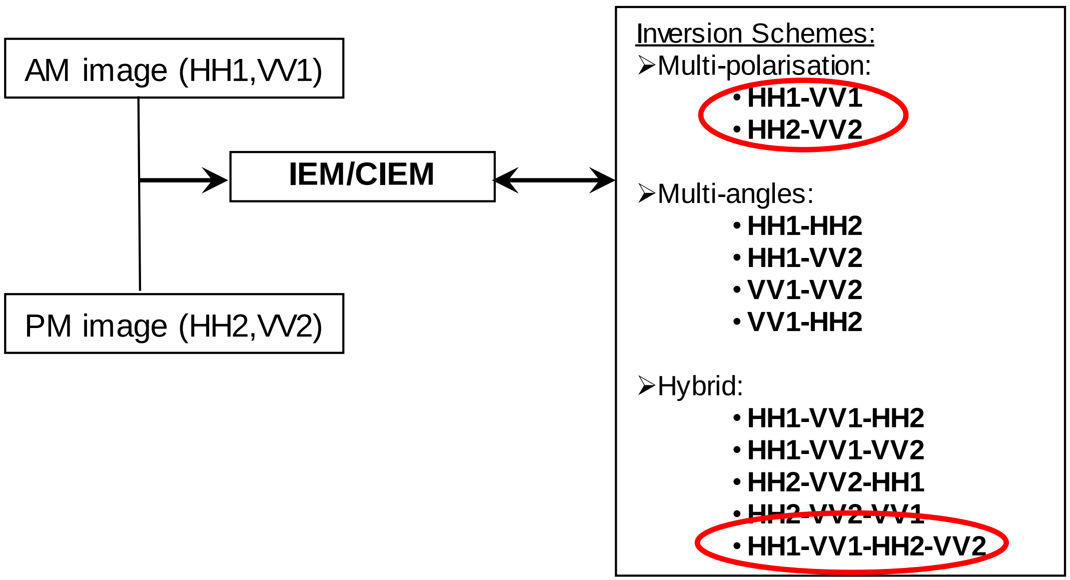
- What about moisture under vegetation?
    - Longer wavelengths offer best option
    - De-coupling of surface from volume scattering
    - "Simpler" scattering models like WCM
    - More complex forward scattering models with crop specific LUTs (NASA, CONAE)

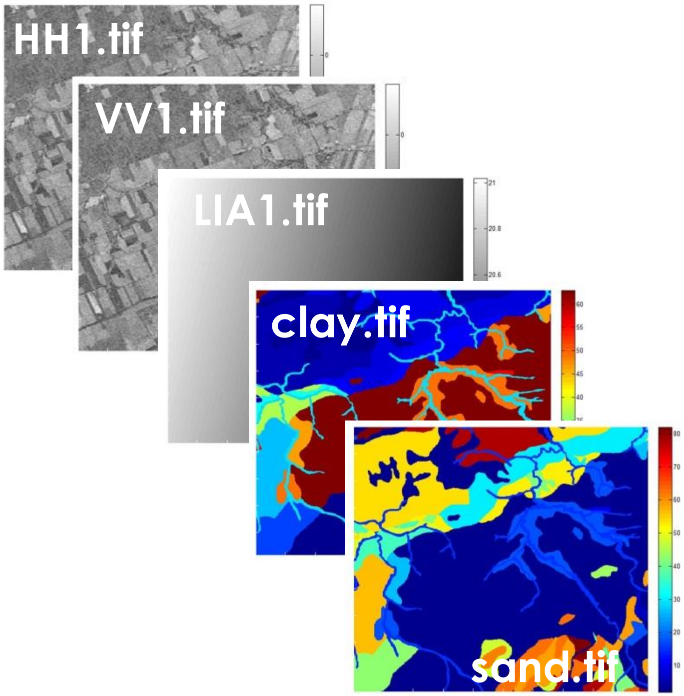
RADARSAT-2



Source: Amine Merzouki/Jarrett Powers

Soil Moisture Estimation Using RADARSAT-2 and IEM Model





Inversion Method	Cost Function
Multi-polarizations	$\Delta = \sqrt{\left(\sigma^{o}_{HH1,\,Meas} - \sigma^{o}_{HH1,\,CIEM}\right)^2 + \left(\sigma^{o}_{VV1,\,Meas} - \sigma^{o}_{VV1,\,CIEM}\right)^2}$
Hybrid	$\Delta = \sqrt{\left(\sigma^{o}_{HH1,\,Meas} - \sigma^{o}_{HH1,\,IEM}\right)^2 + \left(\sigma^{o}_{HH2,\,Meas} - \sigma^{o}_{HH2,\,IEM}\right)^2 + \left(\sigma^{o}_{VV1,\,Meas} - \sigma^{o}_{VV1,\,IEM}\right)^2 + \left(\sigma^{o}_{VV2,\,Meas} - \sigma^{o}_{VV2,\,IEM}\right)^2}$

Merzouki, A., McNairn, H., and Pacheco, A. 2011. Mapping Soil Moisture Using RADARSAT-2 Data and Local Autocorrelation Statistics, Journal of Selected Topics in Earth Observations and Remote Sensing, 4(1): 1-10.

Merzouki, A., McNairn, H., and Pacheco, A. 2010. Evaluation of Radar Backscatter Models over Agricultural Fields: Validation usingPolarimetric C-band RADARSAT-2 SAR Image Data, Canadian Journal of Remote Sensing, 36 (Suppl.2): S274-S286

Soil Moisture Calibration/Validation
Real-time In-Situ Soil Monitoring for Agriculture
- RISMA -

Soil moisture research and operations has migrated to use of in situ networks to assist in calibration and validation.

Includes cal/val for both SAR soil moisture products and passive microwave operational products (SMOS and SMAP)

RISMA will be one of NASA's core cal/val networks for SMAP active-passive

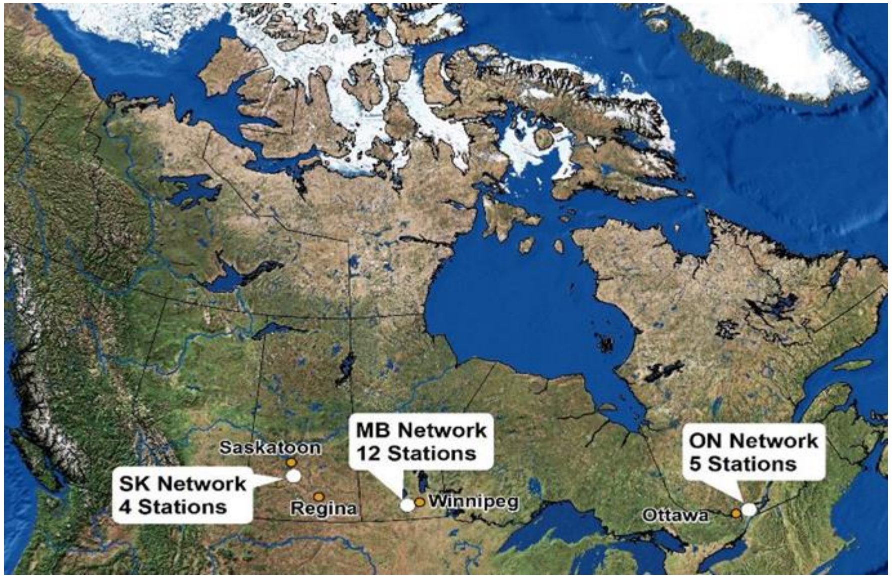
Traditionally validation involves sending teams of 2 to measure soil moisture ± 2 hours of acquisition.

To cover enough fields, crews of 8-20+ are needed.

Temporal discontinuity if acquisitions are at dawn/dusk

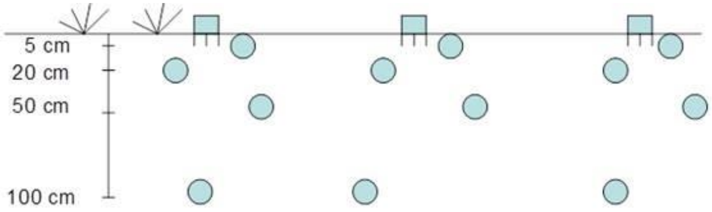
RISMA

- RISMA consists of 3 networks: two in western Canada and one east of Ottawa



- Soil moisture measured in triplicate at: 0-5, 5, 20, 50, 100 cm

- Meteorological measurements: soil temperature, precipitation, air temperature, relative humidity, wind speed, wind direction



- Stations are at edge of field, but probes cabled 10-30m into field

- Site is hand-seeded as per crop planted in field

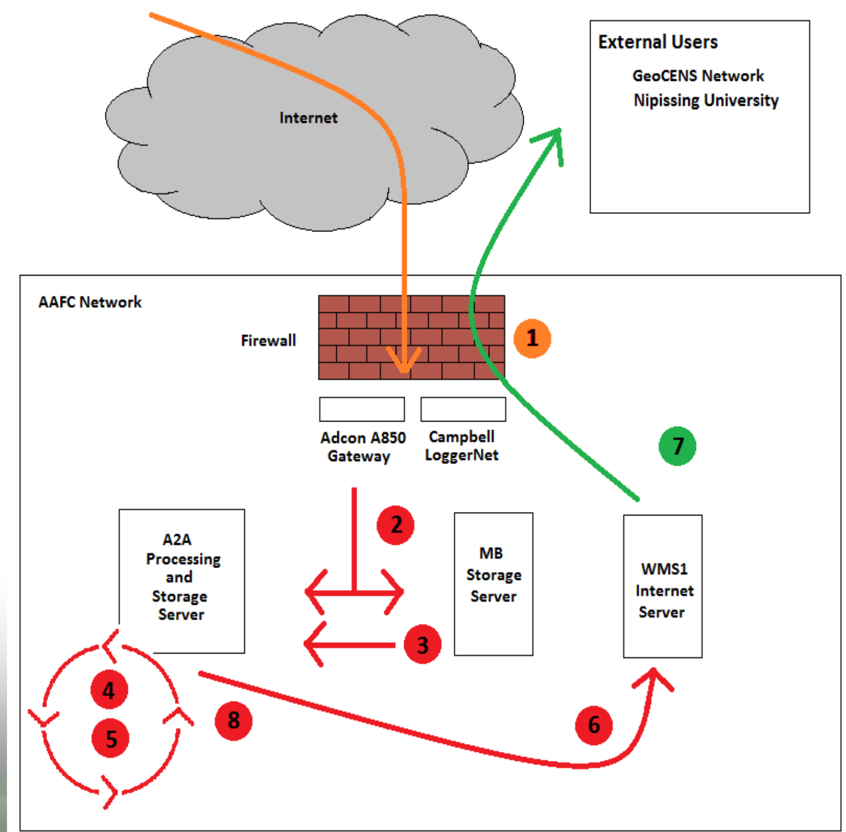
- Regular maintenance/spraying

- Hand harvested coincident with field harvest

Data Access

Data are recorded every 15 minutes, quality checked and calibrated, then distributed every hour

Will be accessed by NASA for cal/val of SMAP active and passive microwave operational products



From: Patrick Rollin, AAFC

Home Login Browse Networks Data

GeoCENS

Agriculture and Agri-Food Canada

Real-time In-Situ Soil Monitoring for Agriculture (RISMA)

About

Soil moisture is a critical variable in agri-environmental monitoring as it often determines rates of crop growth and productivity, rates of soil biogeochemical processes that impact soil fertility and determines boundary layer conditions that drive meteorological processes. In 2010 and 2011, Agriculture and Agri-Food Canada (AAFC), with collaboration from Environment Canada, established three in situ monitoring networks near Kenaston SK, Carman MB and Casselman ON as part of the Sustainable Agriculture Environmental Systems (SAGES) project titled Earth Observation Information on Crops and Soils for Agri-Environmental Monitoring in Canada. The near real time in situ soil moisture/temperature and precipitation data from these three networks are used to calibrate and validate remote sensing and modelled soil moisture products. By 2014, most of the in situ stations in the Saskatchewan and Manitoba networks will be equipped with additional meteorological sensors to complement the existing data with air temperature, relative humidity, wind speed and wind direction. For more information, click here.

Acknowledgements: AAFC acknowledges the land owners for permission to use their land for stations and surveys; Environment Canada for site maintenance, site collaboration and technical support; University of Guelph and University of Manitoba for technical support; University of Saskatchewan for site collaboration; and University of Calgary for web site support.

Browse

Click on the Browse Button or the Browse Tab above for an interactive map of the network station locations and to view graphs of current and past data, click on the station of interest. Data can also be viewed and downloaded by clicking on the Data tab above. Sign up and log-in to download data series. For more detailed information about the data and the network stations, click here.

Goto Browser »

Explore Networks

In-situ monitoring networks with near-real time soil moisture, soil temperature and meteorological data have been established in Saskatchewan, Manitoba and Ontario to capture conditions for the main agricultural crop types, soil textures and ecozones in Canada. The data can be used by local producers for day to day operational decisions or for scientific verification and calibration of remote sensing products, modelling, flood forecasting and drought monitoring.

View Networks »

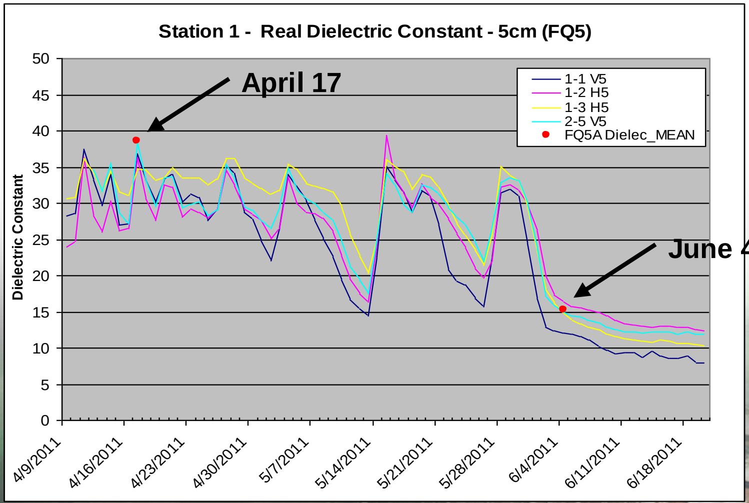
Validation of IEM Soil Moisture Estimates Using RISMA

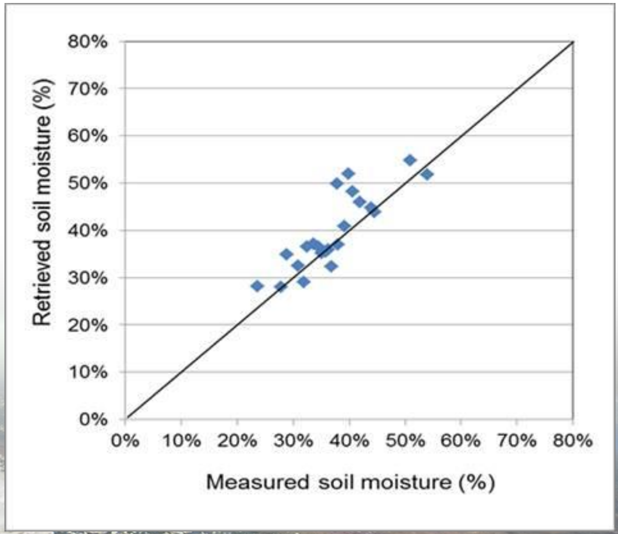
McNairn, H., Merzouki, A., Pacheco, A., and Fitzmaurice, J., 2012. Monitoring Soil Moisture to Support Risk Reduction for the Agriculture Sector Using RADARSAT-2 in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol 5(3):824-834.

Errors Statistics – Hybrid Model
2011-2012

RMSE (%)	MAE (%)	R
4.82	3.45	0.85

Time series of soil moisture from an eastern Canada in situ station and estimated soil moisture by RADARSAT-2 (red dots)



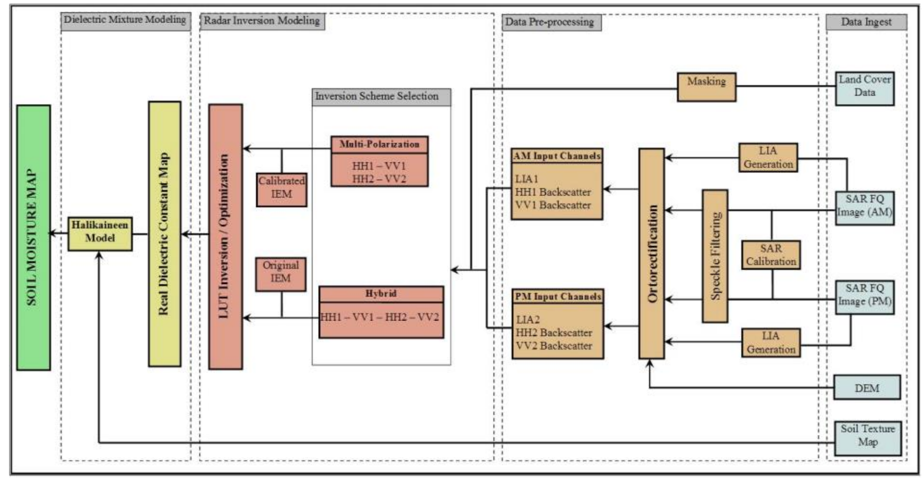


From Research to Implementation - The Soil Moisture Toolkit

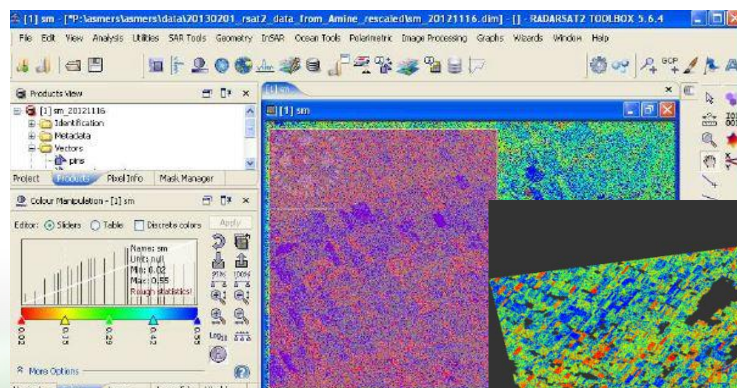
<u>Research</u>: AAFC, Science and Technology Branch (Ottawa and Winnipeg)
10+ years of research

<u>Funding</u>: Canadian Space Agency and AAFC

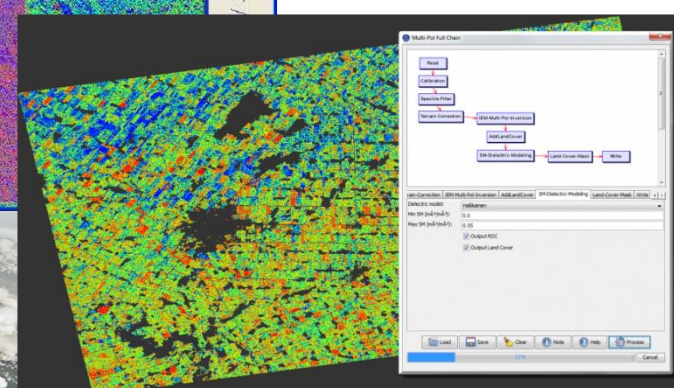
<u>Industry Support</u> (software engineering): Array Systems Computing Inc.



RADARSAT Tool Box



Soil Moisture Toolkit

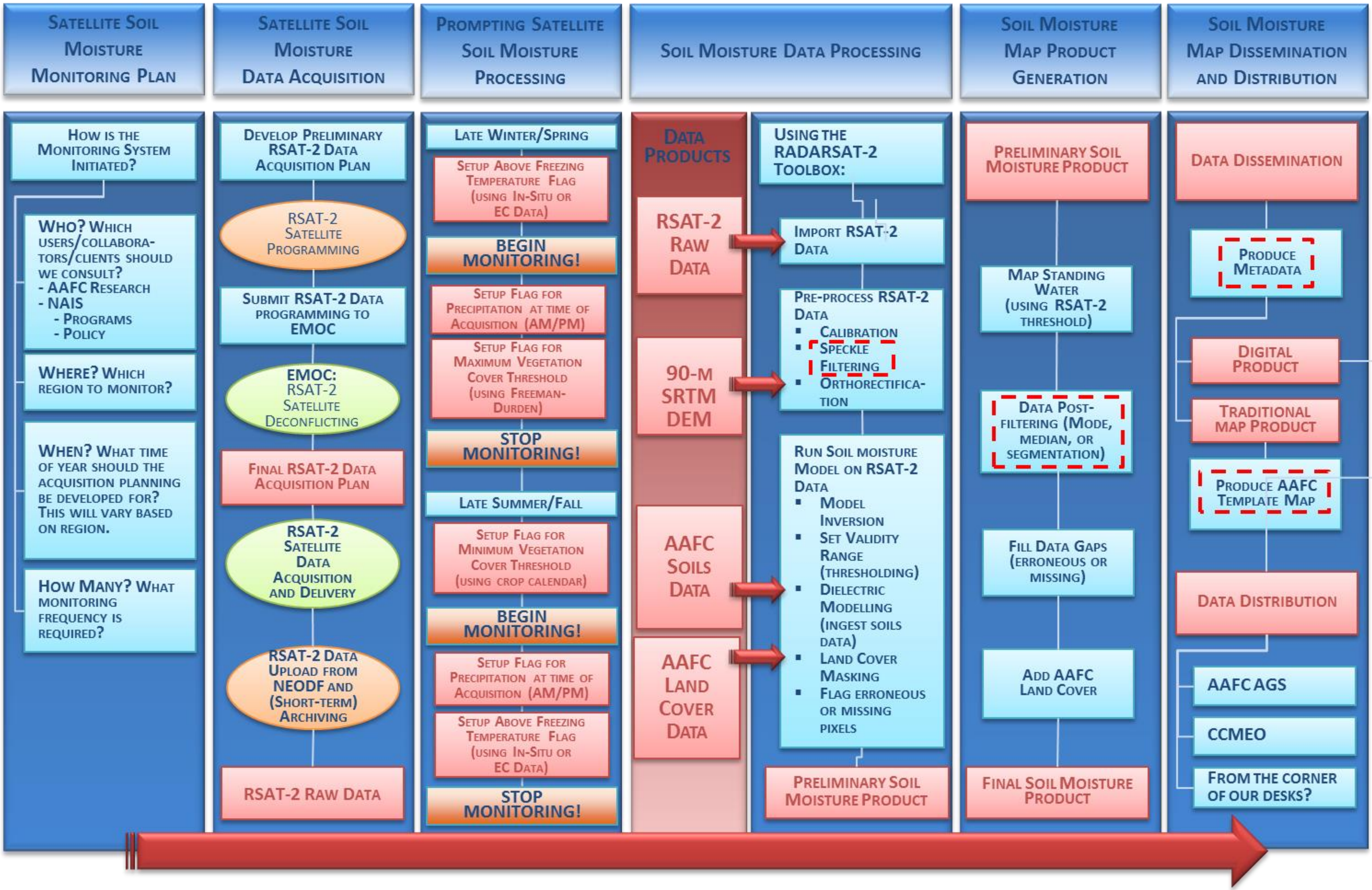


Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

CSA ASC

ARRAY SYSTEMS COMPUTING INC.

AAFC Soil Moisture Monitoring System (AAFC-SMMS)



Forward Modeling for Soil Moisture Retrieval

- FARO scanner re-creates crop 3-D
- Allows detailed crop geometry measurements
- Needed for forward modeling of scattering models to retrieve soil moisture (NASA's approach for SMAP)

Source: Greg Gaskin/Jarrett Powers

Summary

- AAFC has moved some applications towards operations (crop inventory) with others soon to follow (soil moisture)

- Research is reporting sensitivity of SAR to crop condition (via temporal monitoring or estimating crop production indicators such as LAI and biomass); methods to invert SAR response to estimate LAI and biomass under investigation

- Note: AAFC has been requested by the NASA SMAP cal/val team to lead a second field experiment post launch (SMAPVEX16)

Where do we go from here

1. **Action** to get the "easy" wins out the door while the science continues on more complicated requirements, and on improving existing methods.

- What could be an "easy" win?
  - Integration of C-Band and optical (perhaps Sentinel-1(VV+VH) and Sentinel-2) using same/similar approach as AAFC for large crop area mapping
  - Method is robust and can use data from new sensors (RCM) once available
  - Integration of multi-frequency (RADARSAT-2/Sentinel-1 and/or ALOS-2 and/or TerraSAR-X/Cosmo-skymed) for regions where smaller SAR swaths do not limit mapping

- Soil moisture could be next, but still need to gain more confidence in results (Canada, Argentina, U.S….others); however we are very close to being able to implement. As long as errors are well understood. Methods can be highly automated.

2. **Capacity building and mentoring**
  - Jumping from optical to SAR is not easy and should not be underestimated; a lot can go wrong if data planning and processing are not done properly
  - We need to transfer our knowledge and methods and this will take a **committed and concerted** effort
  - Equally important, we need to understand the requirements of user community
  - **What is the best mechanism to mentor**