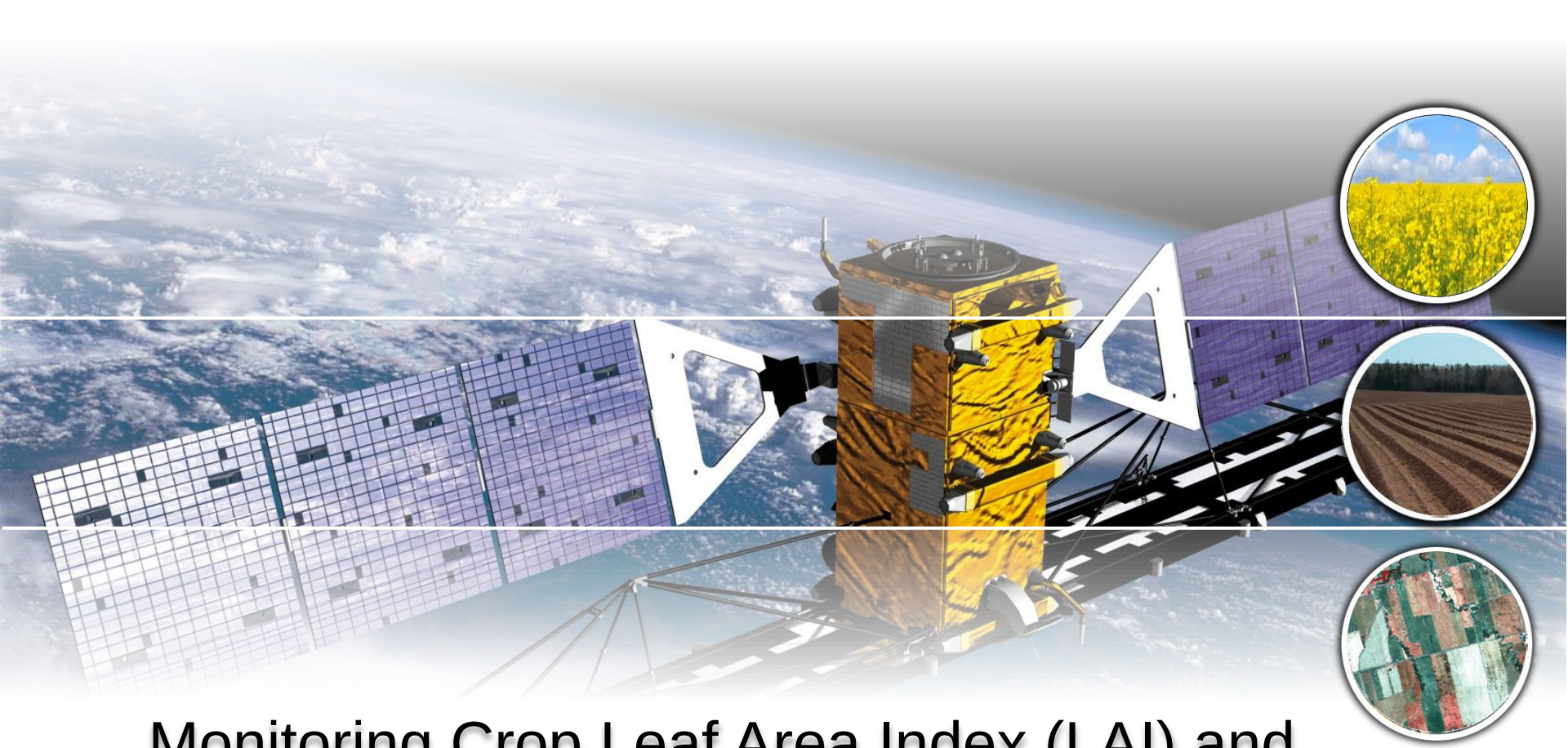


Monitoring Crop Leaf Area Index (LAI) and Biomass Using Synthetic Aperture Radar (SAR)

Mehdi Hosseini, Heather McNairn, Andrew Davidson, Laura Dingle-Robertson

*Agriculture and Agri-Food Canada

JECAM SAR Inter-comparison

Overall purpose:

- to advance the use of **SAR** and/or **SAR+optical** for mapping and monitoring crops in diverse cropping systems

- there is both a **research** (years 1-3) and a **technology transfer/training** (focused in year 3) component of JECAM

- although research focused, strong linkages are to be developed with the implementers of this technology, namely the institutions mandated for operational/on-going mapping and monitoring

- Although many high quality science publications are expected, an important aspect of success will be engaging these institutions

Project Logistics

Canadian Leadership and Support:

- Principal Investigators (Andy Davidson; Heather McNairn)
- Science leads (Laura Dingle-Robertson (classification); Mehdi Hosseini (LAI/biomass))
- 3 years of funds from the Canadian Space Agency (April 2017-March 2020) and in-kind support from Agriculture and Agri-Food Canada

Outcome:

- robust (accurate and repeatable across time and space) method or methods to
  - Identify crop type
  - Estimate important biophysical indicators of crop productivity – Leaf Area Index and above ground biomass

- There may be one universal method for all cropping systems (less likely) or variants of a method adapted for different systems (more likely)

- Training and transfer of knowledge and tools on how to apply radar technology for crop monitoring

Responsibilities

For the Canadian team (Andy, Heather, Laura, Mehdi) the priorities are:

- Coordinate new data collections
- Collate, quality check, validate in situ measures and make a high quality data set available to all participants
- Pre-process satellite data and make available
- Test the **Canadian** methods (Decision Tree for classification and WCM for LAI/biomass) across international sites; develop new models for select new crops
- Statistically compare AAFC & partners' crop inventory classification accuracy results
- Transfer knowledge and methods to partners

- Partners
  - Provide in situ data over test sites
  - Optional: access pool of in situ (collated by AAFC) and satellite data to test own methods for classification and modeling
  - Share results with JECAM partners
  - However – a true comparison means comparing apples with apples and thus best practice will be to communicate well with AAFC team to ensure that this is a valid inter-comparison of methods

Next Steps

- Coordinate uploading of in situ data with Laura and Mehdi. They will be having meetings with individual partners to understand and assess in situ data
- Data pre-processing of satellite data has already begun
- As soon as in situ and satellite processed data are ready – Laura will notify team for those who wish to test their own method
- Depending on how quickly in situ data comes in, AAFC hopes for some initial results from their methods in next 6-12 months
- NASA (Brian Killough) is developing data cubes for some countries. A possibility that applications could be built onto these data cubes.
- In discussion with IGARSS 2018 to have a special event for JECAM

Comments from Partners

- Project needs to develop a policy/understanding with partners in terms of data sharing and publication. Laura circulated a draft policy on both. Please read and comment back as this is a dialogue.

Data Sharing (2017-2020)

- Initial thought is that if you are providing in situ data to the project and accessing in situ data from other partners, your data are considered "shared property" in that it could be accessed by all partners
- There could be special cases considered if you are interested in only, for example, a bilateral exchange

Post 2020

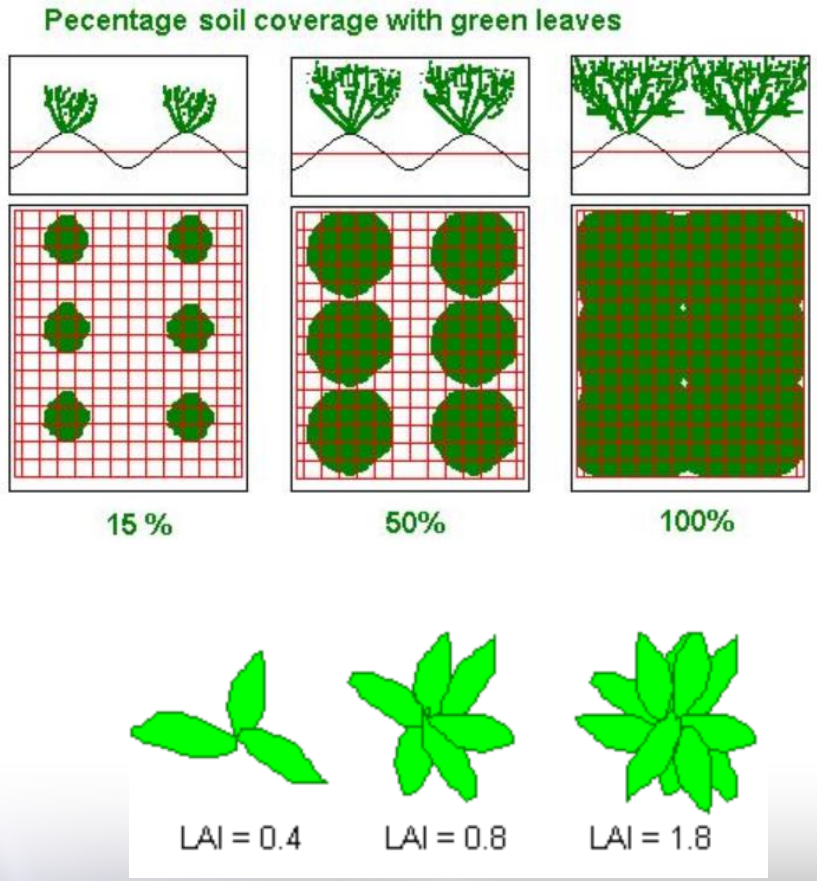
- Should consider making the data globally accessible

Authorship

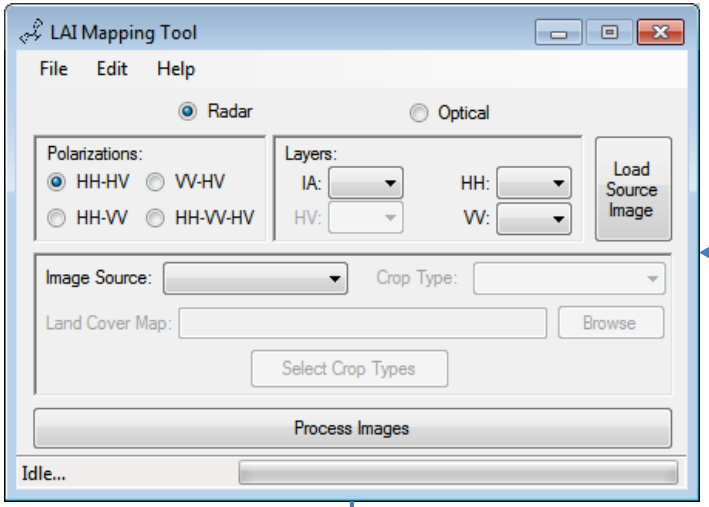
- Principal of fair authorship – if you are using another partners data in your research in a meaningful way then co-authorship should be afforded

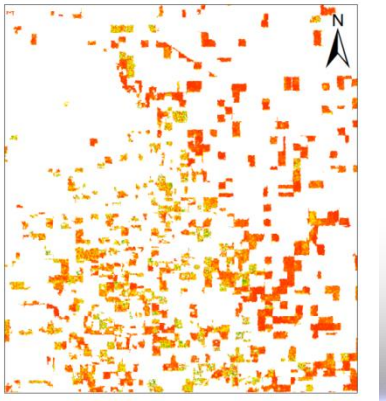
Leaf Area Index Monitoring with SAR

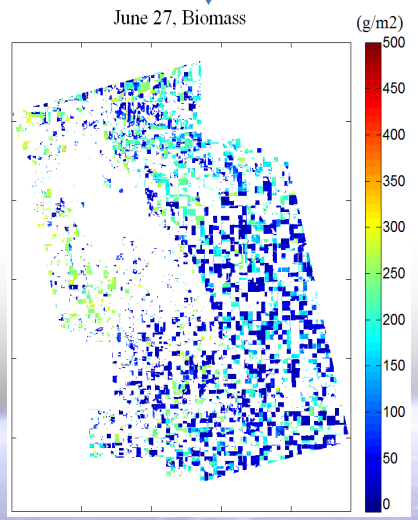
- LAI is an important indicator of crop productivity linked directly to crop yield.
- True LAI is the one-half of the total green leaf area in 1 square meter. Effective LAI is one-half of the total area of light intercepted by leaves in 1 square meter.
- Retrieval using optical data was successful but cloud cover is a limitation especially given the importance of dense observation during the crop growth season.
- SAR scattering is intrinsically related to the structure of the target and thus SAR responses are quite sensitive to both LAI and biomass.



LAI and Biomass Process







Crop Map

SAR Data

HH, VV, HV

X-, C-, L-band

Coefficients

Modeling

Soil Moisture

Ground Data

LAI

Biomass

Ground Data Requirements

LAI

- True LAI
- Effective LAI

Biomass

- Total above ground dry biomass
- Heads biomass

Soil Moisture

- Top 6 cm soil surface
- Calibrated volumetric soil moisture

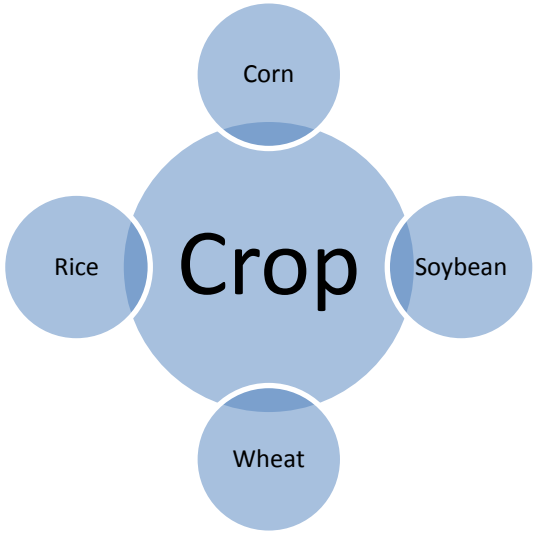
Phenology

- Leaf development
- Stem Elongation
- Heading and Flowering, Development of Fruit

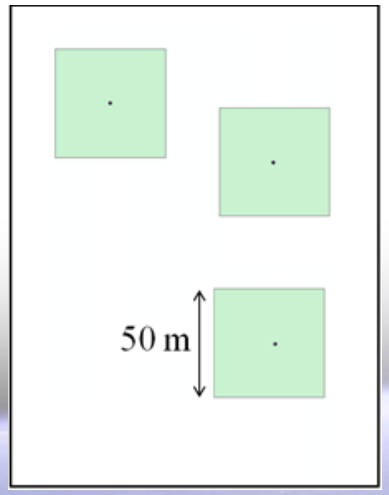
Ground Data Requirements

Data continuity

All interested crop types

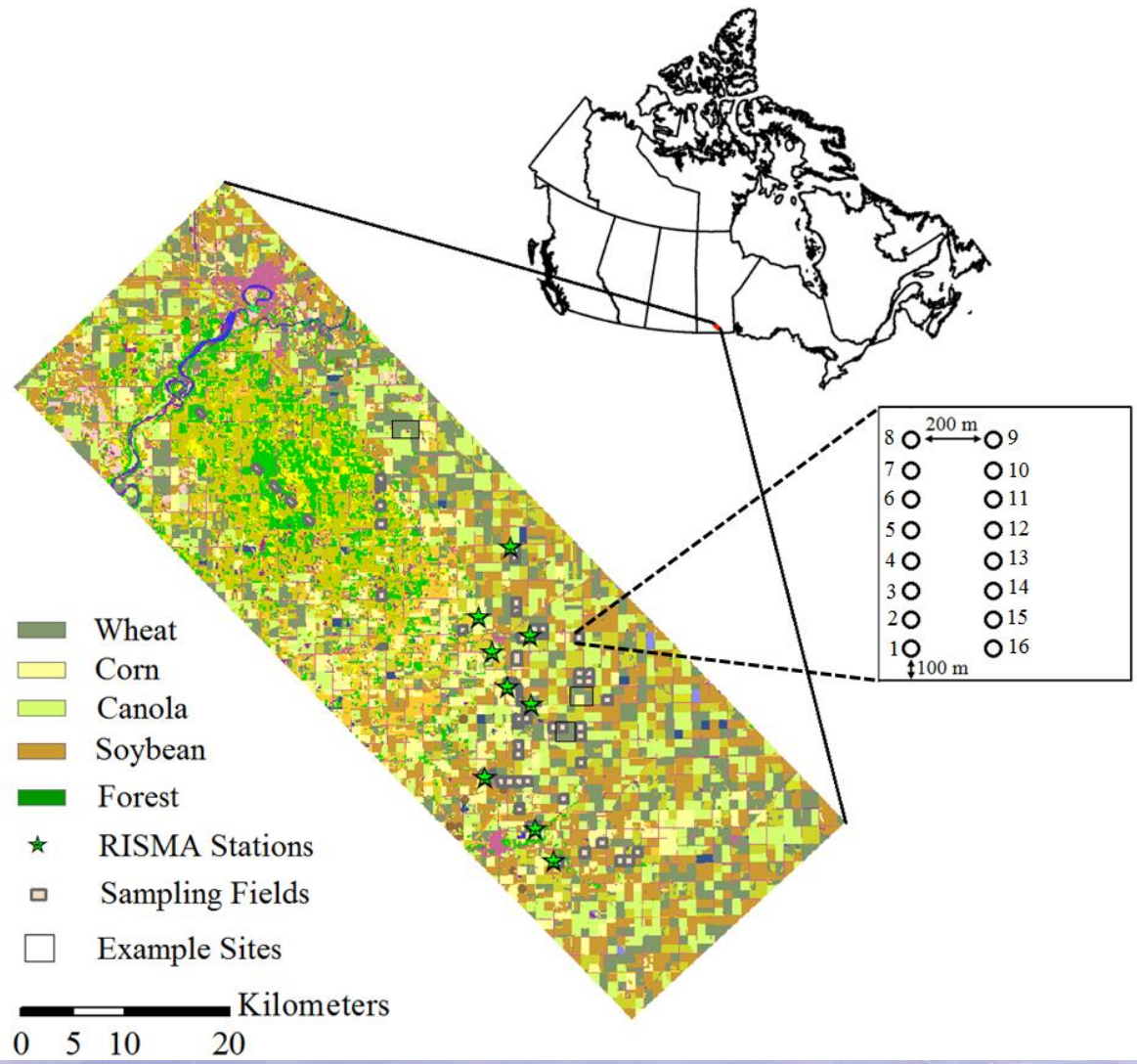


Minimum size of field



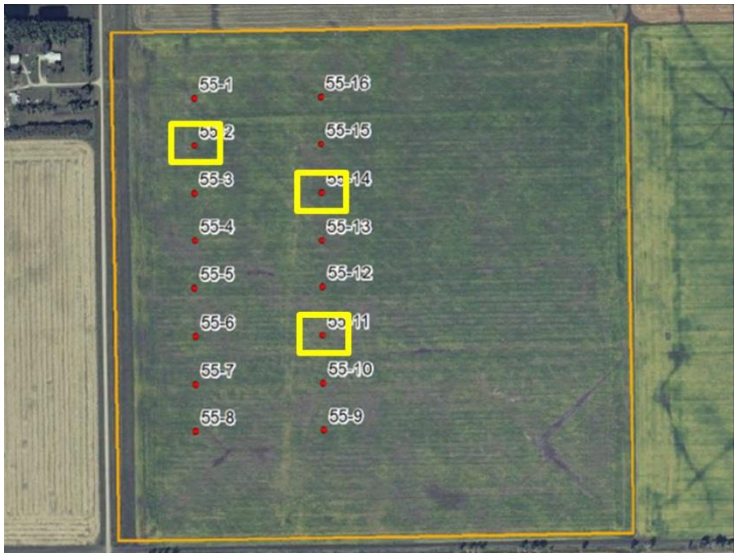
Sufficient number of fields/sites

SMAPVEX12 and SMAPVEX16-MB

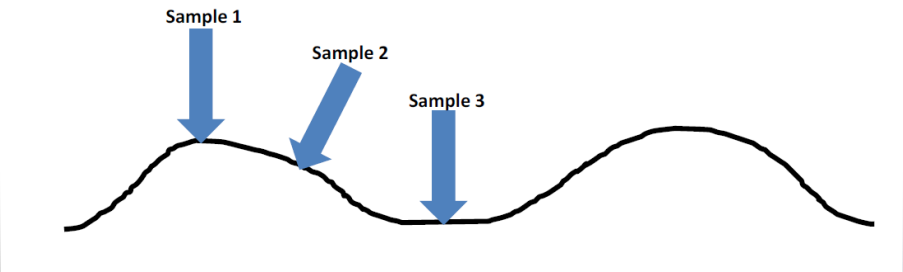


- Conducted in Manitoba from June 6 to July 17, 2012 and June 8 to July 20, 2016
- Objective: Acquire and process data to calibrate, test, and improve models and algorithms for SMAP soil moisture products.
- Approach: Acquire a large validation database of surface measurements for the factors that influence the sensor readings coincident with the time of the aircraft data acquisition: 1) Soil Moisture 2) Surface Temperature 3) Biomass 4) Surface Roughness

Soil Moisture Sampling



- Soil moisture measurements need to be coincident in time to flight overpasses.
- Top soil moisture (0-6 cm) was measured using Stevens Hydro probe .
- At each sample point, crews were instructed to collect three replicate soil moisture measurements.



Soil Core Sampling

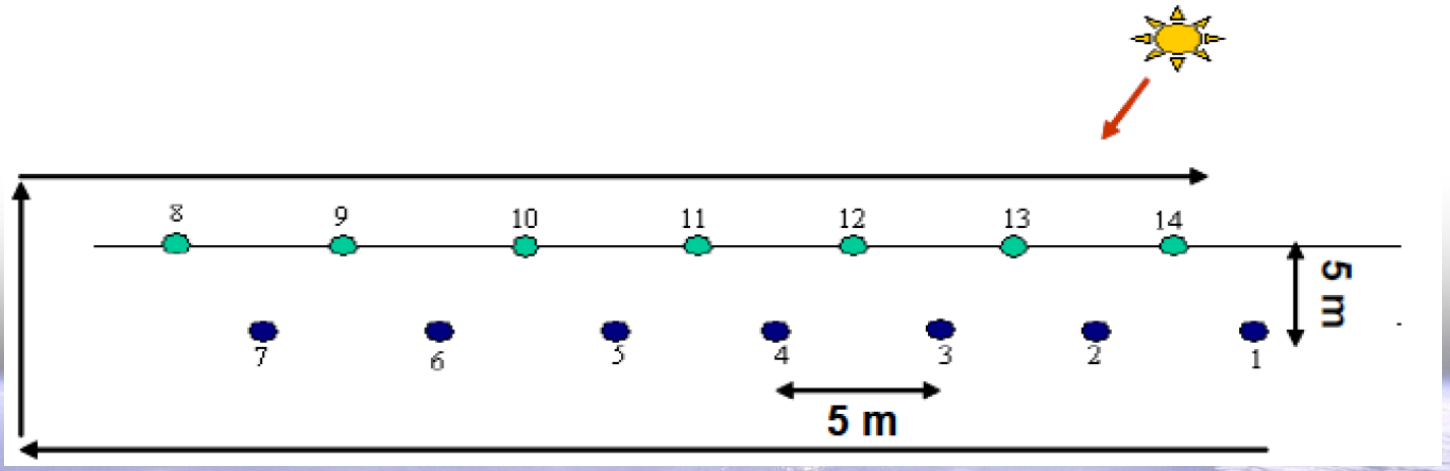
- Site specific calibration of measurements is necessary.
- During flight days, one bulk density core per field was collected.
- Volumetric soil moisture is needed.
- The entire sample (soil, core, tin and bag) was weighed. The tin was then removed from the plastic bag and placed in a soil drying oven. The samples were oven dried for 24 hours at 105oC. Following drying, the entire sample (soil, core, tin) was then re-weighed.

Biomass Sampling

- Vegetation biomass was determined via destructive sampling. One biomass sample was collected at each of the three measurement sites (2, 11 and 14).
- For wheat, canola and pasture fields a 0.5 m x 0.5 metre square was placed over the canopy. All above ground biomass was collected by cutting all vegetation at the soil level.
- For beans and corn, five plants along two rows (10 plants in total) were collected.
- Wheat was partitioned and the biomass of the heads of wheat was also measured.

LAI Sampling

- LAI was captured using hemispherical digital photos. In each field, seven photos were taken along two transects (14 photos in total) at each of the three sites (2, 11, 14).
- The fisheye camera lens was positioned at nadir, at a minimum of 50 cm above the highest point of the canopy (when photos were taken downward) or 50 cm below the lowest leaf of the canopy (when photos were taken upward).
- Photos were taken with the crew facing the sun to avoid shadows in the photos. These photos are post-processed to estimates of LAI.
- It is useful to have both True and Effective LAI.



How to Estimate LAI and Biomass from SAR?

- There are several modeling approaches, but we settled on a semi-empirical model
- With this model, LAI (or biomass) and soil moisture can be simultaneously estimated without the need of any data other than the radar data
- Model has been parameterized for 3 crops: corn, soybeans and wheat

SAR modelling with Water Cloud Model (Semi-Empirical)

$$\sigma^0 = AL^{E_1}\cos\theta(1-\exp(-2BL^{E_2}/\cos\theta)) + \sigma^0_{soil}\exp(-2BL^{E_2}/\cos\theta)$$

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

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

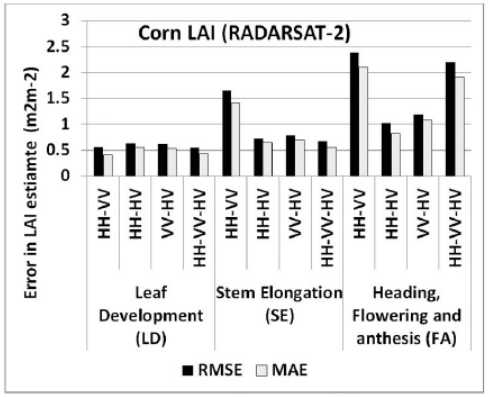
Vegetation component

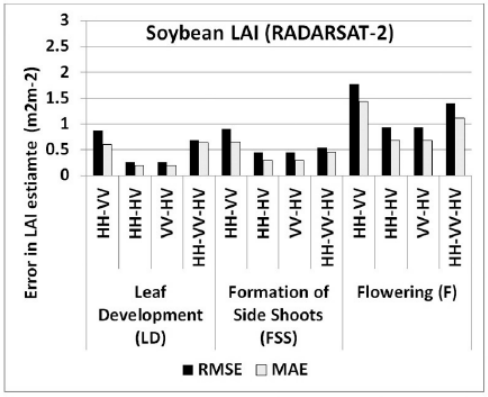
$$\sigma^0_{soil} = C + DM_s$$

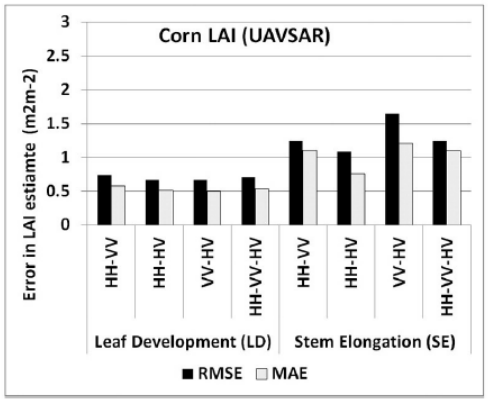
Soil component

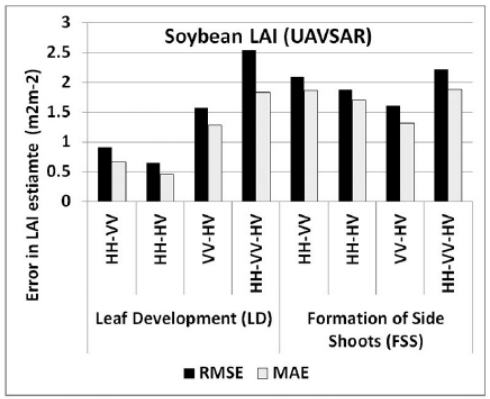
t^2 is the two-way attenuation through the canopy layer
L is the LAI or biomass (expressed in m^2/m^2 or g/m^2)
A,B,C,D, E_1 and E_2 are model coefficients defined by experimental data (A,B, E_1 and E_2 depend on canopy type)

LAI Estimation of Corn and Soybeans







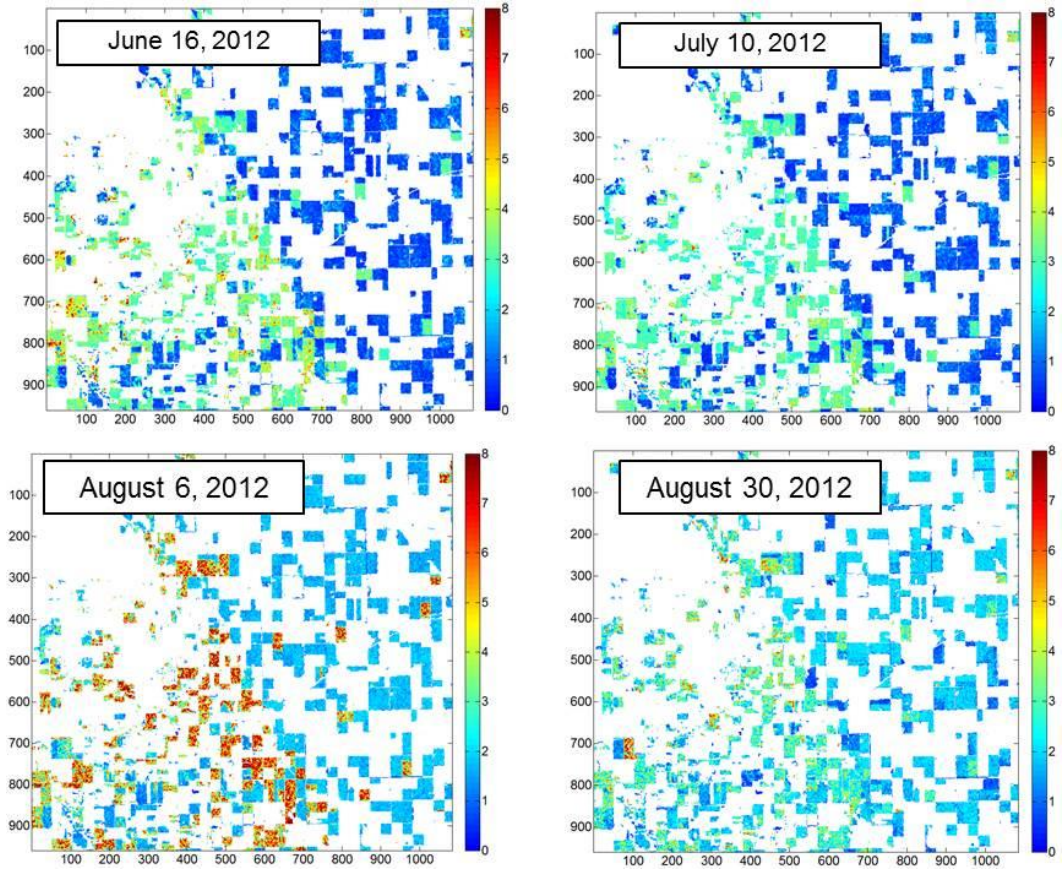


Accuracies with C- and L-band similar (or better than) than accuracies using optical data

Hosseini, M., McNairn, H., Merzouki, A., and Pacheco, A., "Estimation of Leaf Area Index (LAI) in corn and soybeans using multi-polarization C- and L-band radar data", Remote Sensing of Environment, vo. 170, pp. 77-89, 1 December 2015.

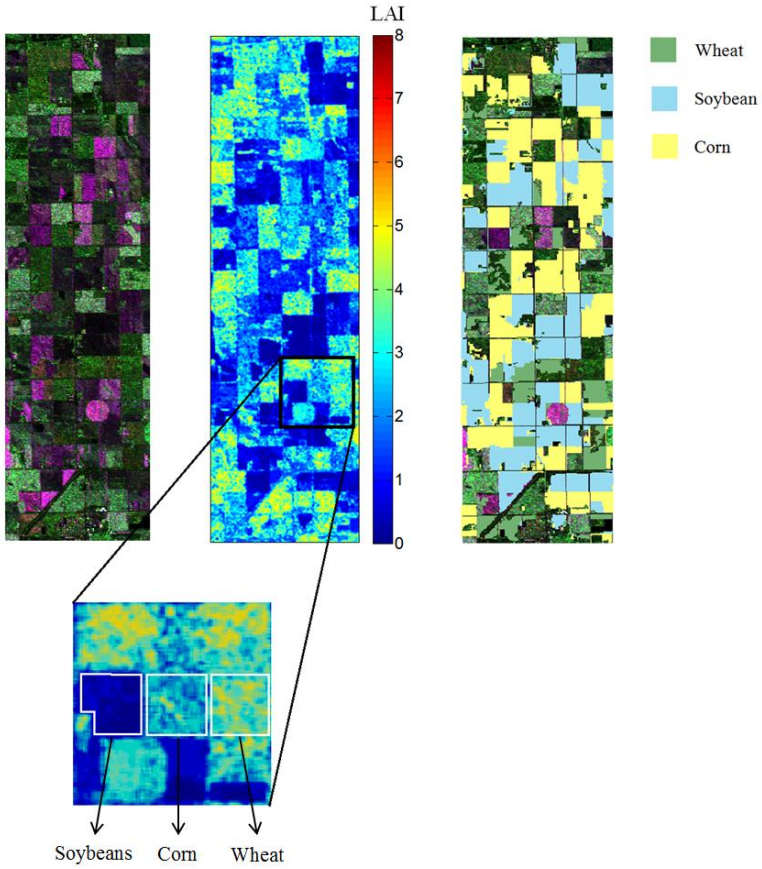
	RMSE (m^2m^{-2})	MAE (m^2m^{-2})	R
Corn HH-HV	0.84	0.65	0.83
Corn VV-HV	0.75	0.62	0.81
Soybeans HH-HV	0.64	0.44	0.80
SoybeansVV-HV	0.63	0.44	0.80

LAI Maps from RADARSAT-2



Manitoba, 2012

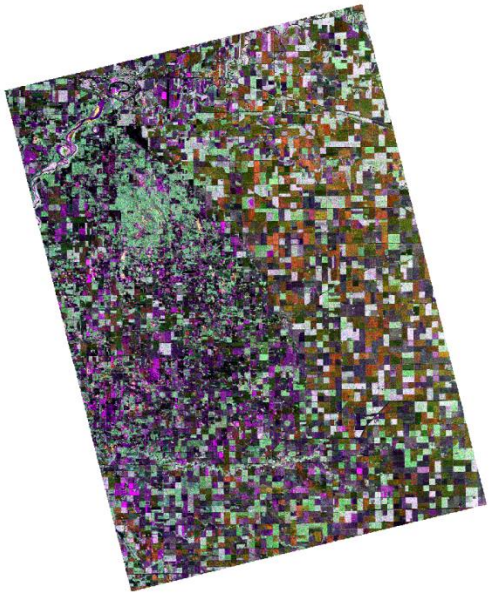
LAI estimates for corn and soybeans



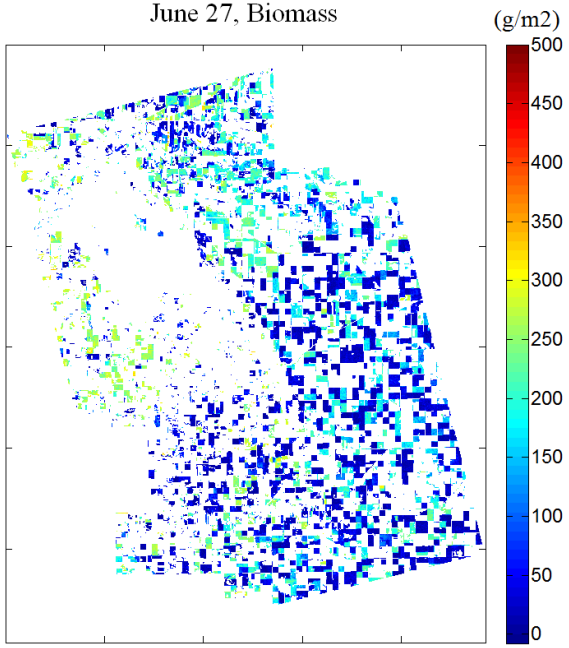
Hosseini, M., McNairn, H., Merzouki, A., and Pacheco, A., "Estimation of Leaf Area Index (LAI) in corn and soybeans using multi-polarization C- and L-band radar data", Remote Sensing of Environment, vo. 170, pp. 77-89, 1 December 2015.

Biomass and Soil Moisture Maps for Wheat

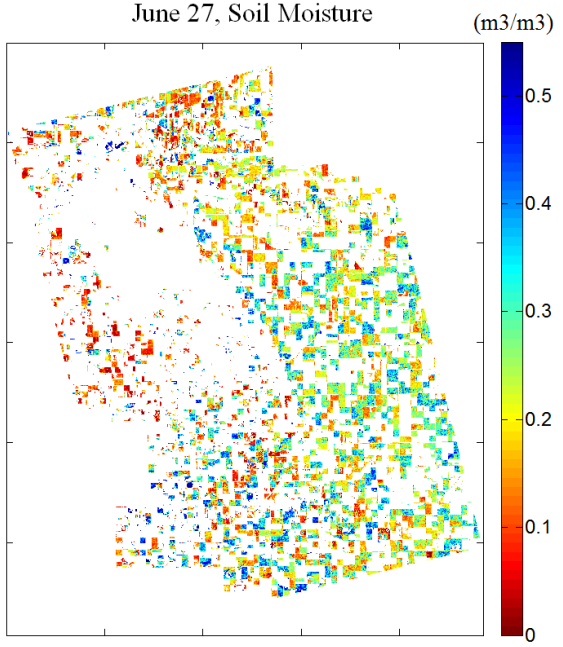
June 27, RADARSAT-2



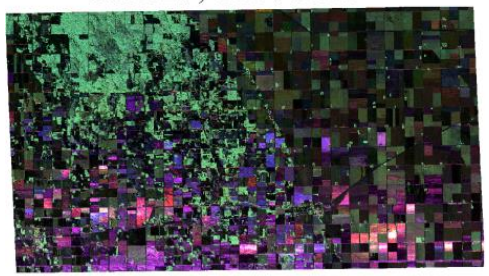
June 27, Biomass



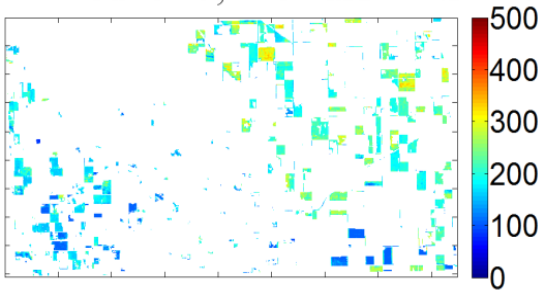
June 27, Soil Moisture



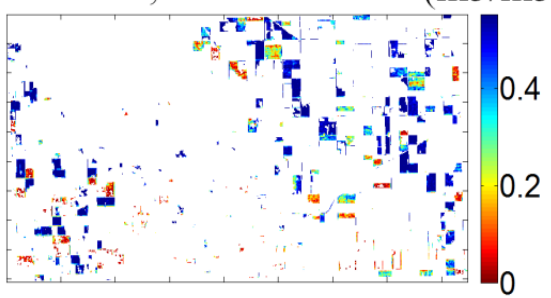
June 27, UAVSAR



June 27, Biomass (g/m2)

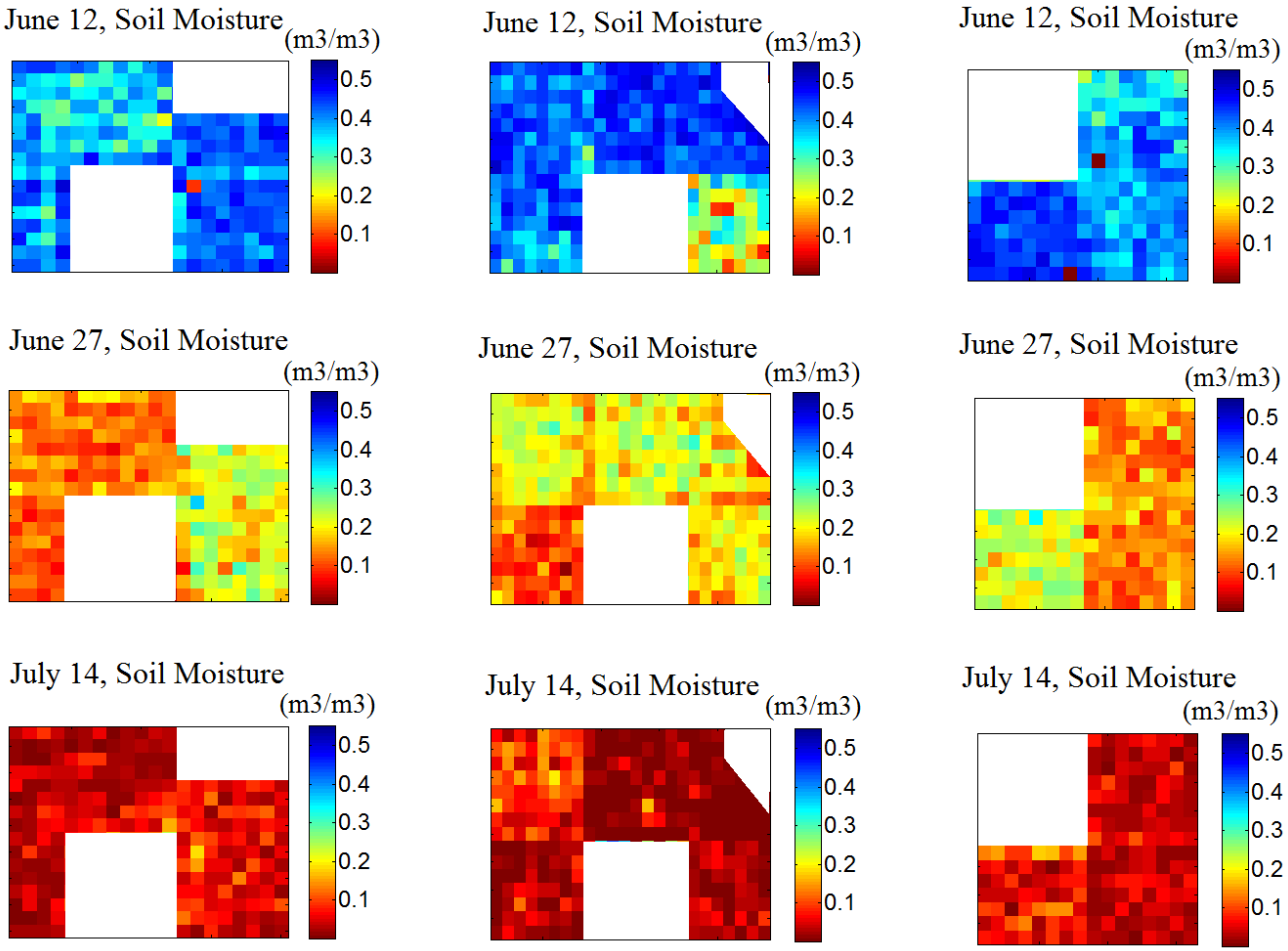


June 27, Soil Moisture (m3/m3)



Hosseini M., McNairn H., 2017, Using multi-polarization C- and L-band synthetic aperture radar to estimate wheat fields biomass and soil moisture. International Journal of Earth Observation and Geoinformation, 58, 50-64.

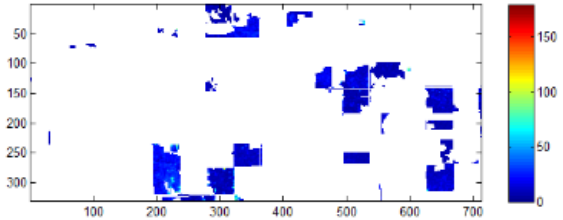
Estimating soil moisture under wheat – RADARSAT-2



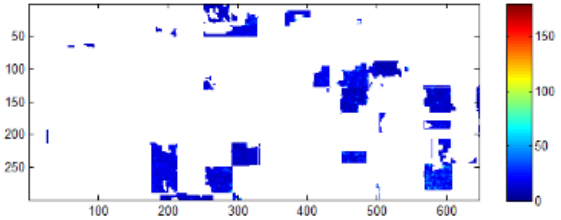
Hosseini, M., and McNairn, H., "Using multi-polarization C- and L-band radar to estimate biomass and soil moisture for wheat fields", International Journal of Applied Earth Observation and Geoinformation, under review.

Estimating Biomass of *The Heads* of Wheat

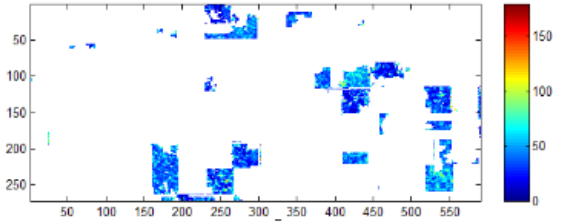
May 20



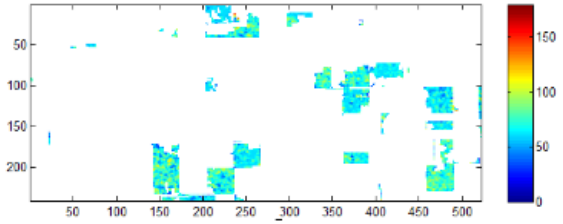
June 12



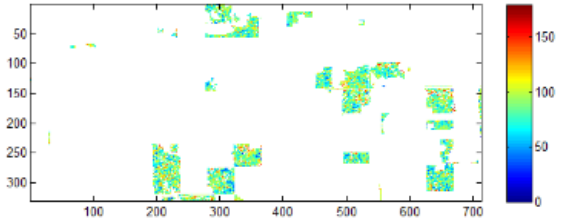
June 20



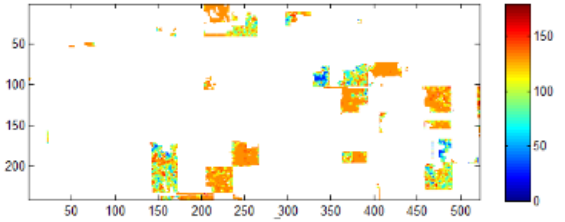
June 29



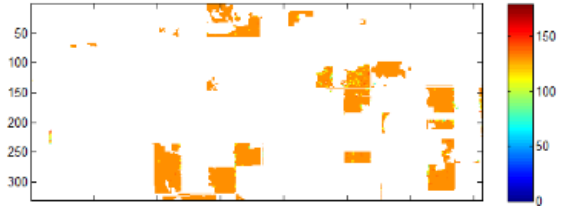
July 07



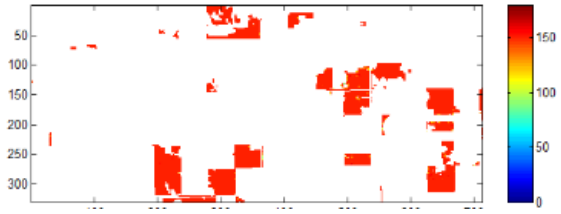
July 23



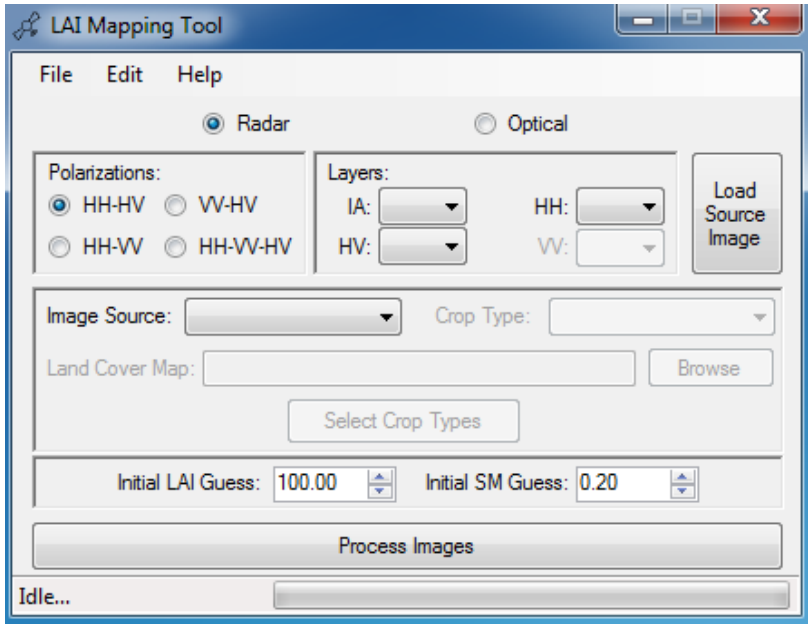
July 31

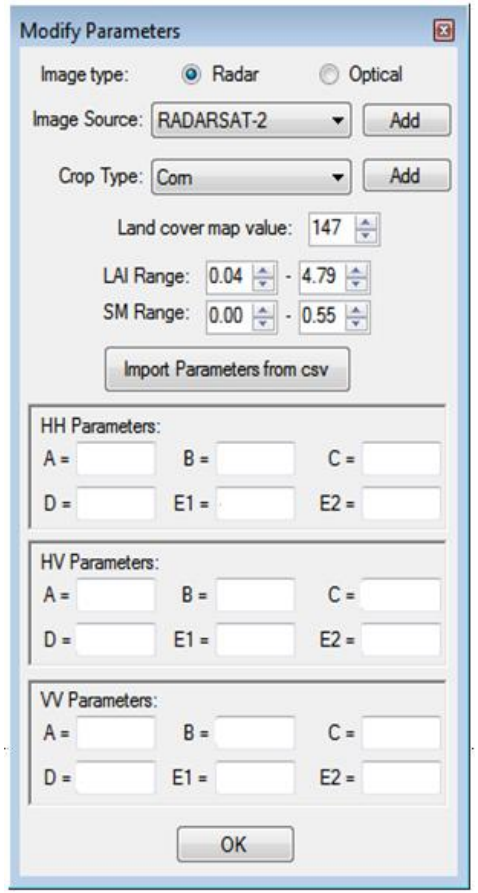


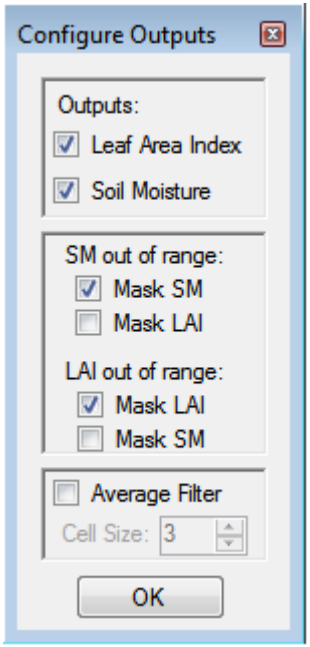
August 24



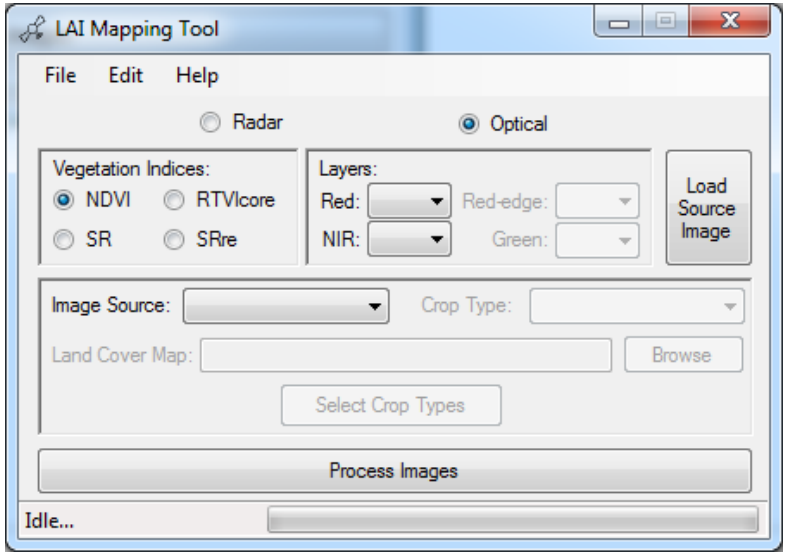
LAI and Biomass Mapping Tool



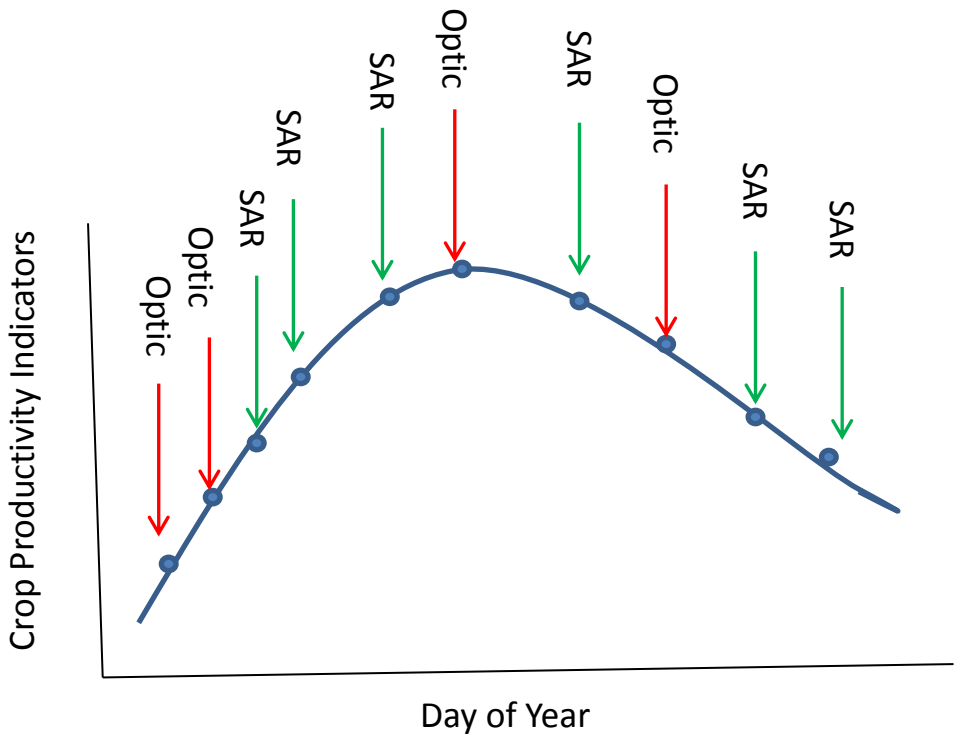




SAR and optical cross-calibrated products

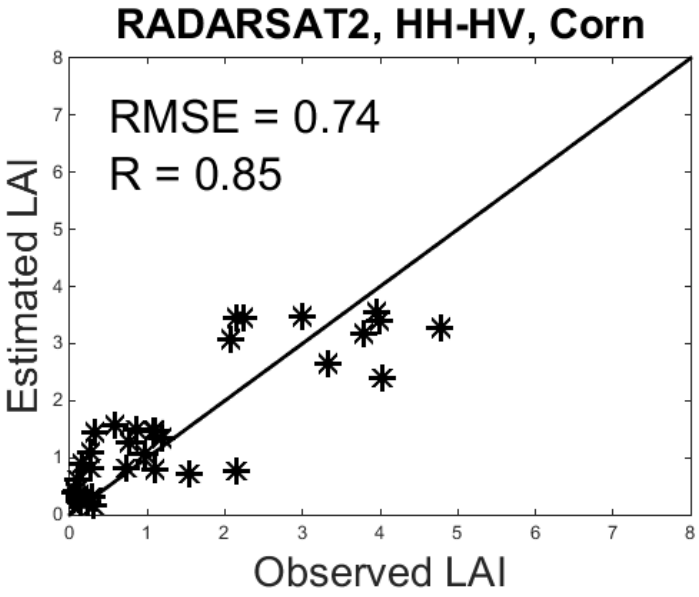


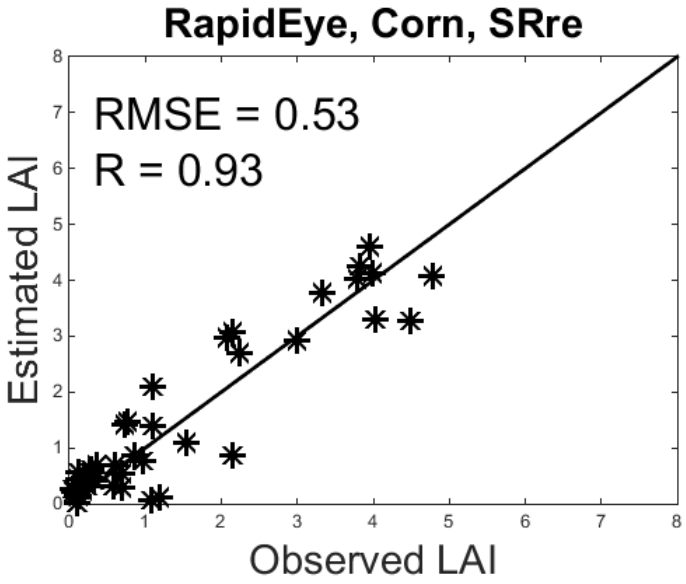
The tool has optical module for LAI and Biomass mapping

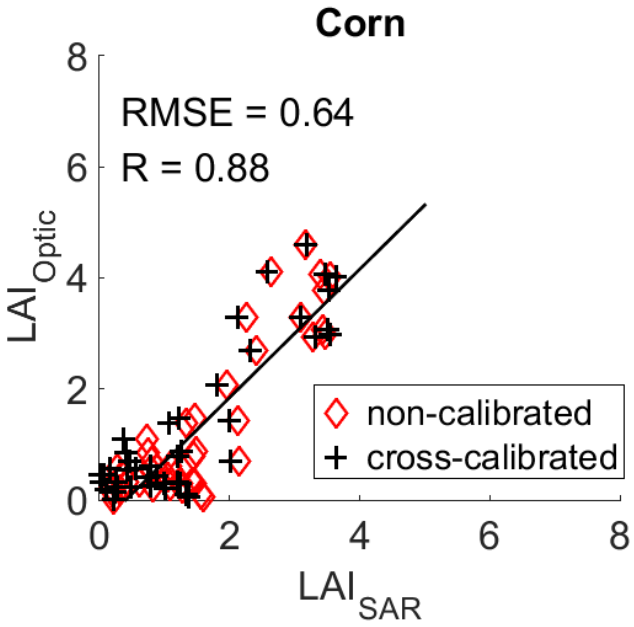


Combination of SAR and Optical sensors will fill the gap

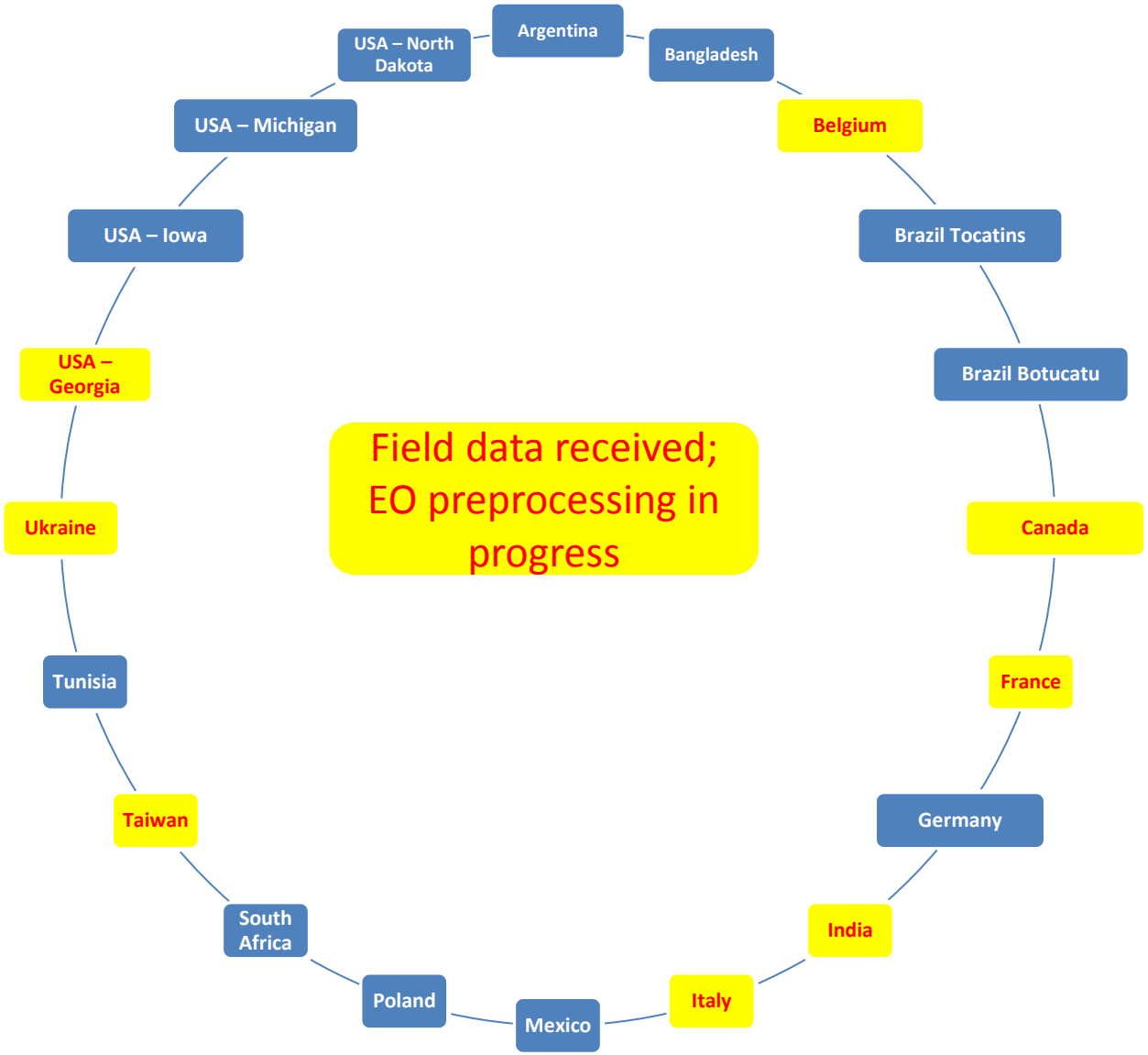
SAR and optical cross-calibrated products







Partners



- Participants interested to the second component are:
  - Argentina, Belgium, Bangladesh, Germany, India, Italy, Mexico, Poland, South Africa, Taiwan and Ukraine

Update on the Project

- Downloading satellite data is on-going.
  - RADARSAT-2, Sentinel-1 & 2 and Landsat-8.
- FTP has been provided to the participants for uploading their data.
- Reviewing other non-JECAM potential data is on-going.
  - MicroWEX, AgriSAR, CanEX-SM10, SMEX02-SMEX05
- Literature review on other available methods is on-going.