Monitoring crop harvest and tillage using Sentinel-1 coherence change detection and polarimetric parameters

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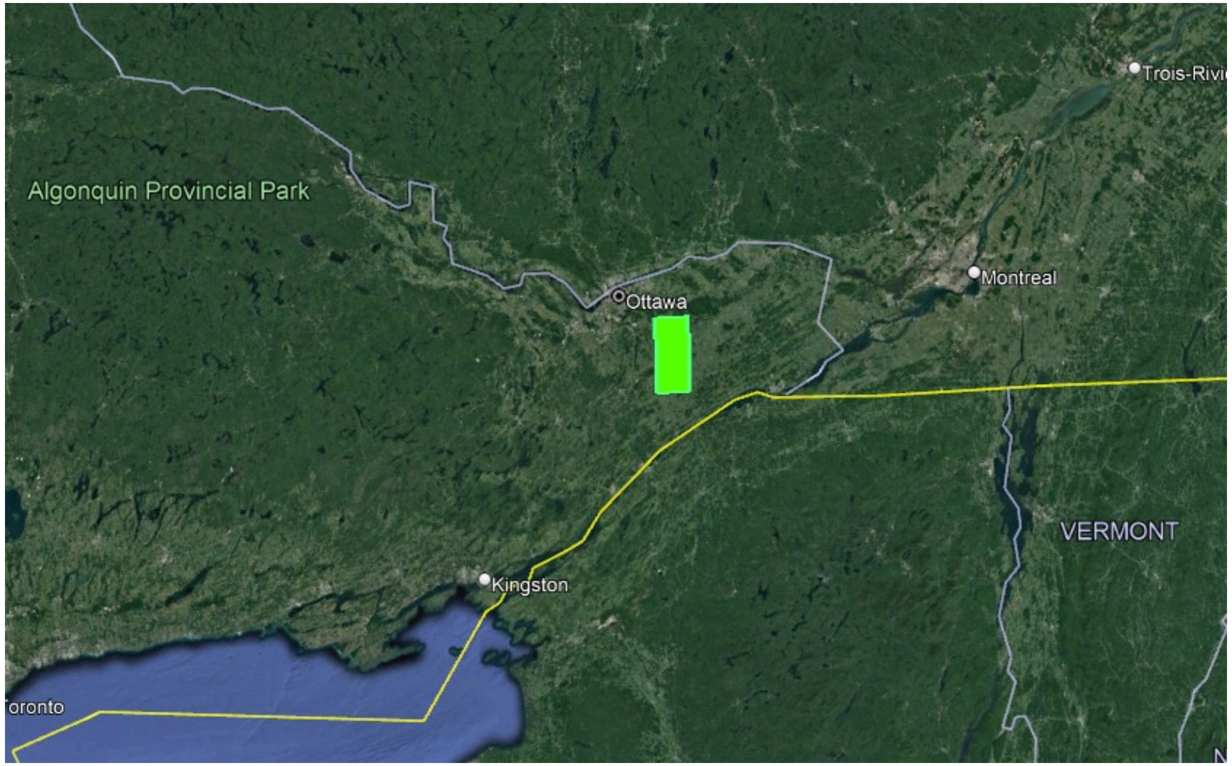
Study site and data collection

A study site located in the area of Russell-Embrun in eastern Canada.

Within the Russell-Embrun area, much of land is used for agriculture. Corn and soybean are major field crops.

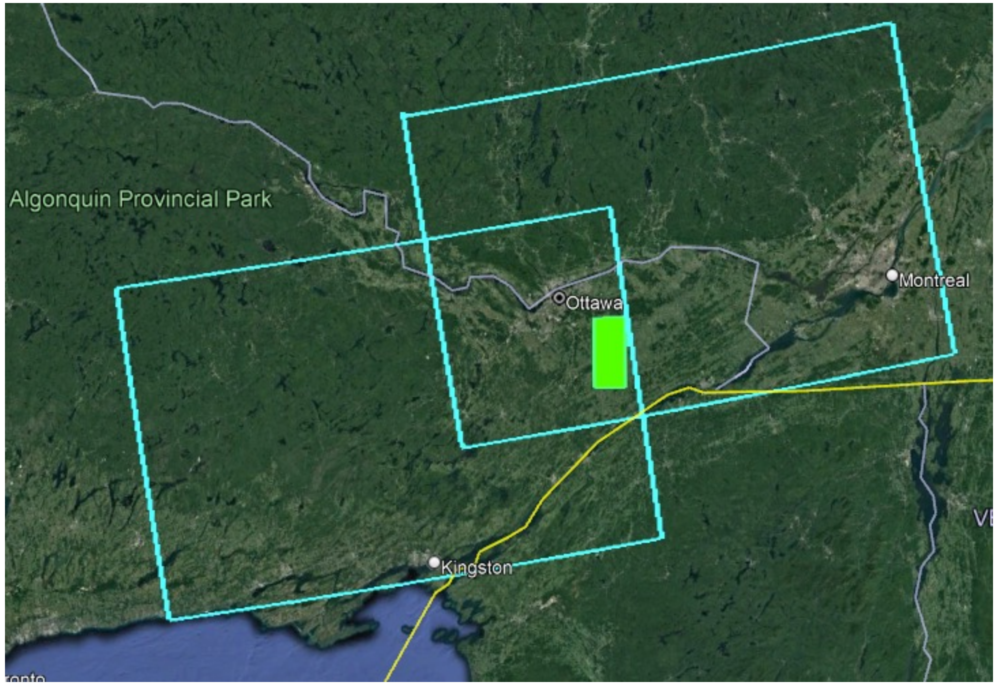
The growing season begins with seeding around late May and harvest in late October.

Typically, early October to late November is an active period of harvest and tillage.



Study site and data collection

- A time series of Sentinel-1 Interferometric Wide (IW) dual pol (VV,VH) mode Single Look Complex (SLC) data were acquired in 2022.
- Two adjacent Sentinel-1A swaths overlap the site, 15 images of each swath were collected from beginning of June to end of November, 2022.

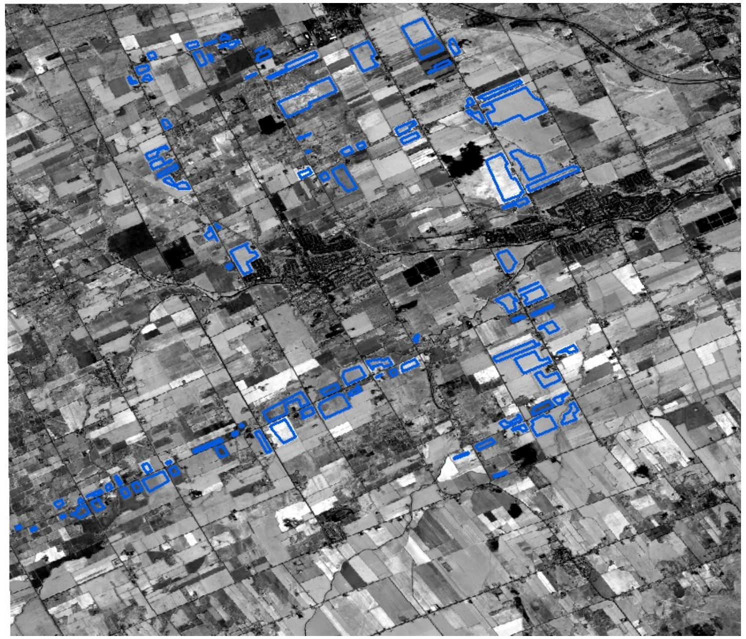


Sentinel-1 IW mode , Ascending, VV+VH

Path106, frame 143	Path 33, frame 146
6/8/2022	6/3/2022
6/20/2022	6/15/2022
7/2/2022	6/27/2022
7/14/2022	7/9/2022
7/26/2022	7/21/2022
8/7/2022	8/2/2022
8/19/2022	8/14/2022
8/31/2022	8/26/2022
9/12/2022	9/7/2022
9/24/2022	9/19/2022
10/6/2022	10/1/2022
10/18/2022	10/13/2022
10/30/2022	10/25/2022
11/11/2022	**11/6/2022(HH+HV)**
11/23/2022	11/18/2022

Study site and data collection

- 23 corn and 32 soybean fields were selected to collect ground data.
- Windshield surveys started on August 26, 2022 and continued approximately weekly until November 11, 2022. This schedule resulted in a total of 12 re-visits. Each of the 12 visits were conducted on the same day or one day after the overpass of the Sentinel-1A satellite.
- On each visit, observations were noted including occurrence of farming activities such as harvest, tillage, manure applications, visual assessment of soil moisture status (dry, moist, wet), and estimates of the percent of the soil covered by green vegetation or post-harvest residue. Finally, a photo was taken at the location of the observations.

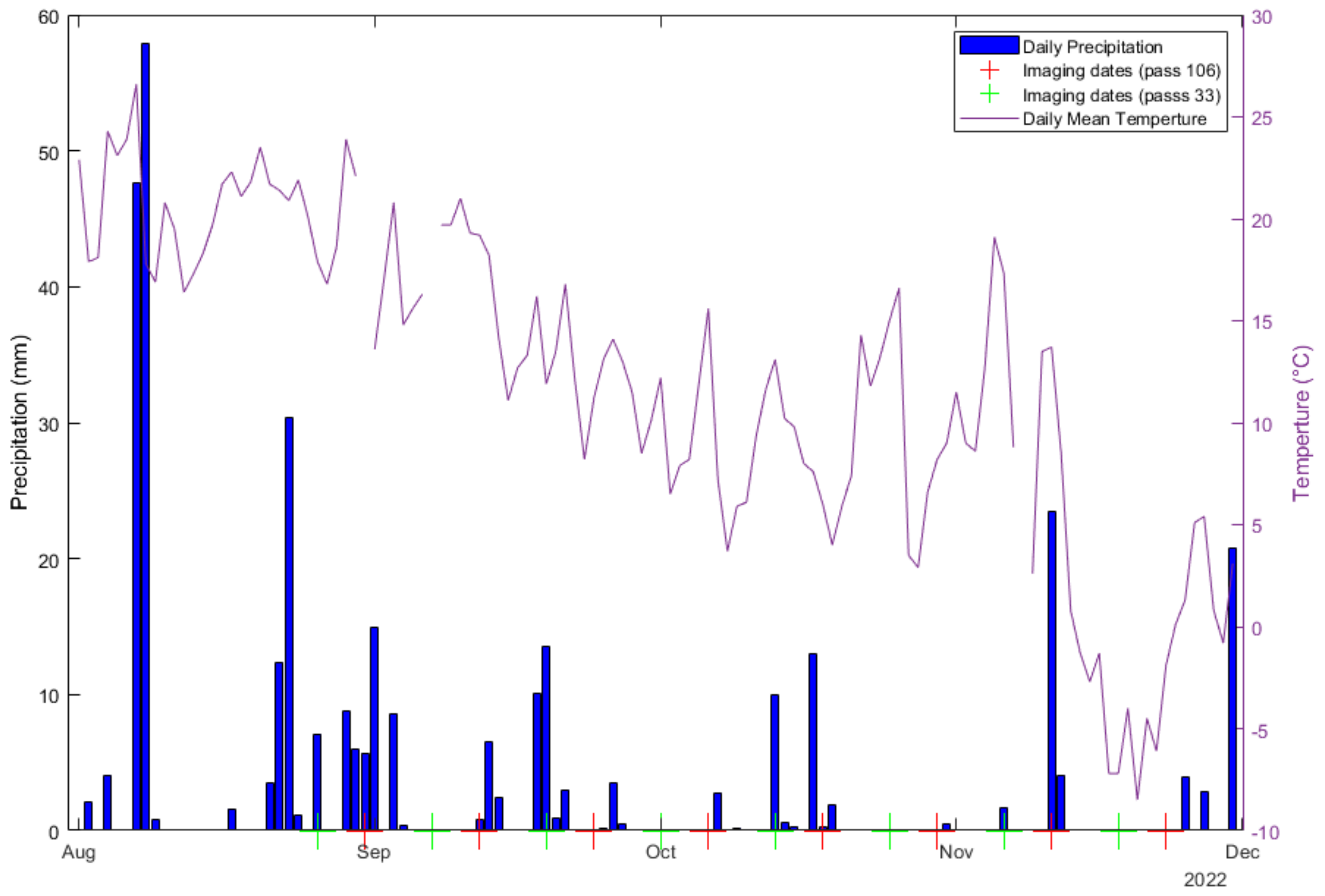


Number of fields observed for harvesting and tillage in the fall of 2022

Imaging dates	Ground Observation dates	Number of fields observed			
		Soybean (n=41)		Corn (n=26)	
		Harvest	tillage	Harvest	tillage
24-Sep	26-Sep	3		2	
6-Oct	6-Oct	15	2	1	
18-Oct	19-Oct	12	6		1
30-Oct	1-Nov	8	10	11	2
11-Nov	7-Nov		3	9	5

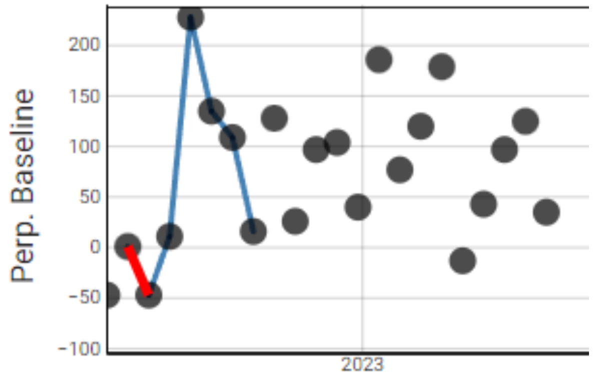
Study site and data collection

- Seasonal Meteorological data were also obtained from a climate station maintained by Environment and Climate Change Canada
- More frequent heavy rain events occurred on acquisition dates for the images of pass 33.
- The rain impacts the radar signal and reduces the image coherence.
- This study analyses the images of pass 106 only.



Generation of Geocoded Sentinel-1 CCD Images

- In order to achieve pass-to-pass coherence, the spatial separation between two **passes** must be less than a critical baseline. As the baseline increases, coherence decreases. For Sentinel-1, this critical baseline is about 5 km.(https://hyp3docs.asf.alaska.edu/guides/insar_product_guide/)



- Seven images from pass 106 collected from August 19 to October 30, 2022, were used to estimate InSAR coherence. Six CCD image pairs were created, and the perpendicular baselines of the CCD image pairs are less than 250 m.

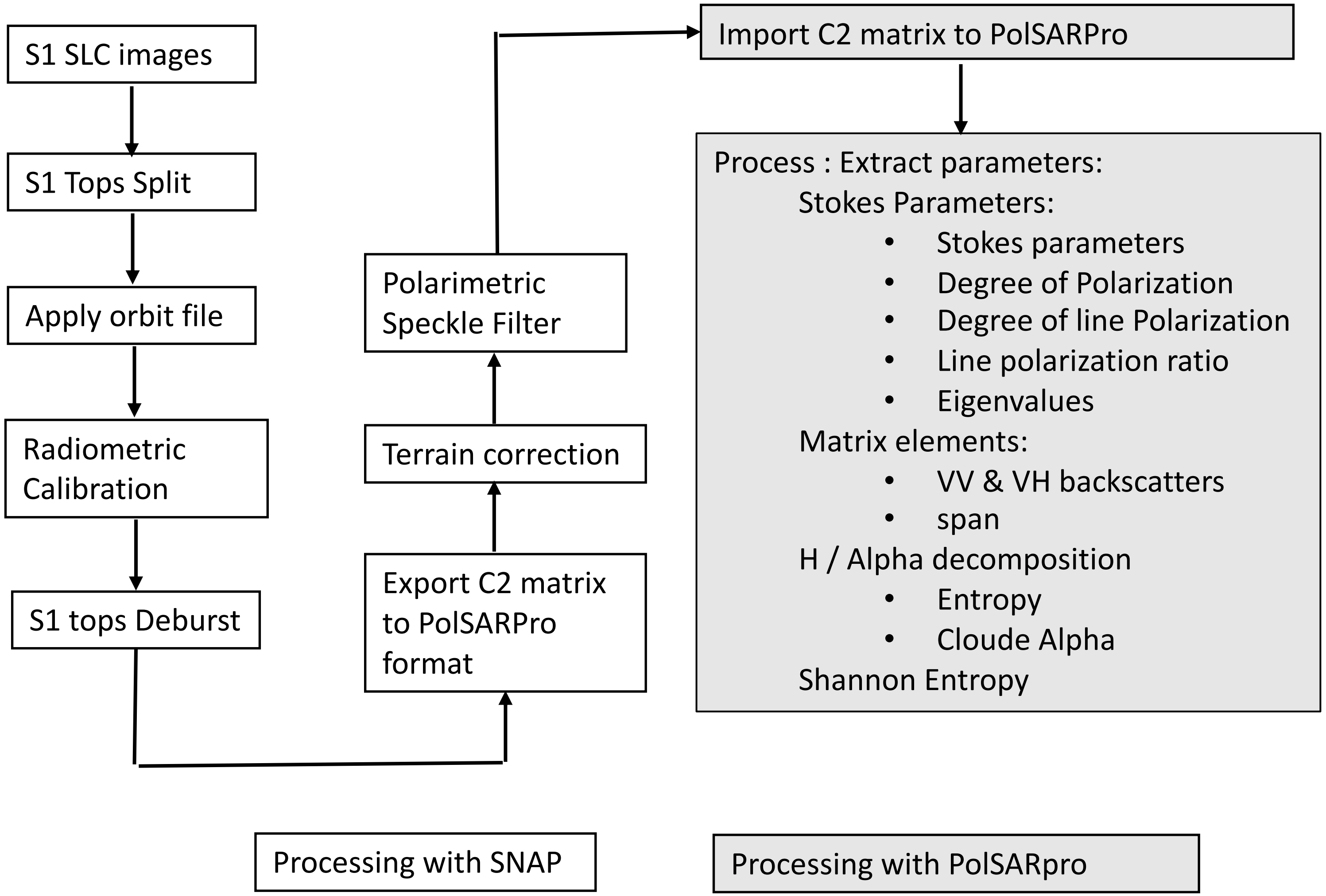
CCD images were processed with ESA SNAP:

- **Co-registration**: the study site was covered by IW 3 sub-swath of pass 106 images. For each 12-days image pairs, the first acquisition was used as master scene. The SNAP Coregistration function generates a stacked file.
- **Coherence Estimation**: coherence was estimated using a kernel of 5 in the range and 20 in the azimuth. Each kernel has approximately 100 samples.
- **Terrain correction**:Once the CCD image was created in slant range, terrain correction was applied to facilitate the interpretation of coherence using the field observations.

Estimation of Sentinel-1 polarimetric parameters

- ESA's SNAP was used to pre-process the Sentinel-1 SLC data. A precise orbit file was applied to update the state vectors, and subsequently, the image was radiometrically calibrated and saved in a complex format. Next, the selected sub-swath was de-bursted, a polarimetric speckle filter was applied (boxcar 5 by 5), and the filtered image was ortho-rectified using the Range Doppler algorithm. Finally, the ortho-rectified image was exported as a 2 x 2 covariance matrix [C_2] with the PolSARPro format.

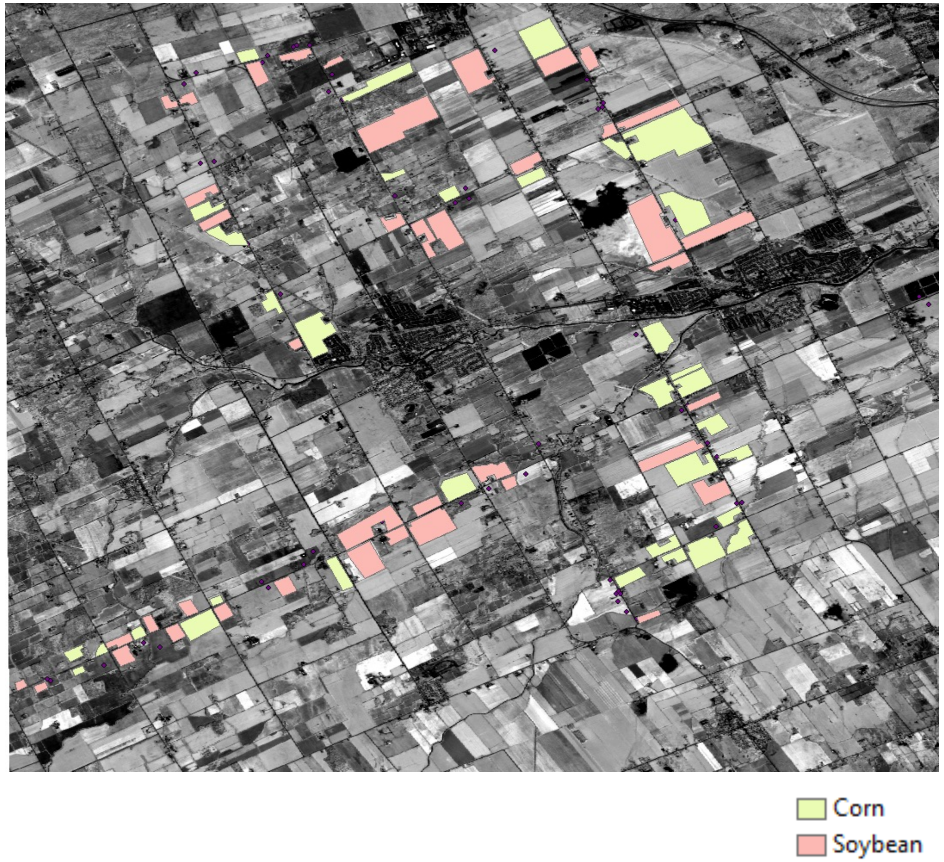
- All SAR parameters were calculated from the [C_2] matrix using PolSARpro.



Analysis of time series of SAR images for ground data -- Soybean

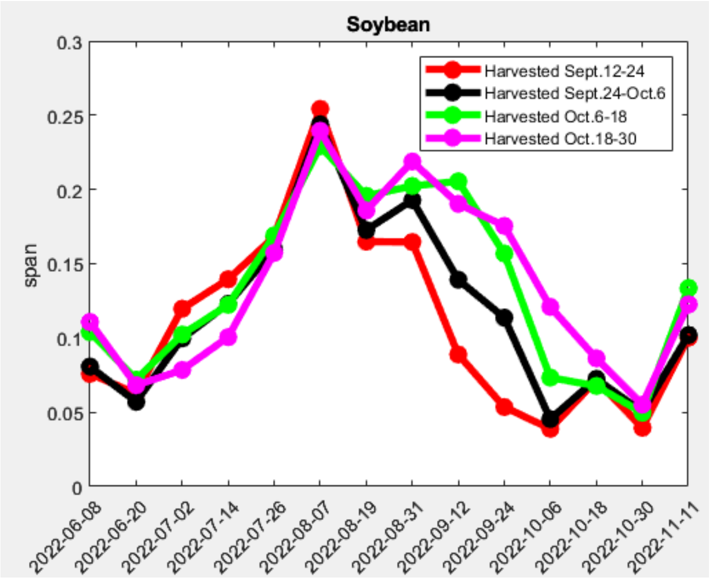
Number of fields observed for harvesting and tillage in the fall of 2022

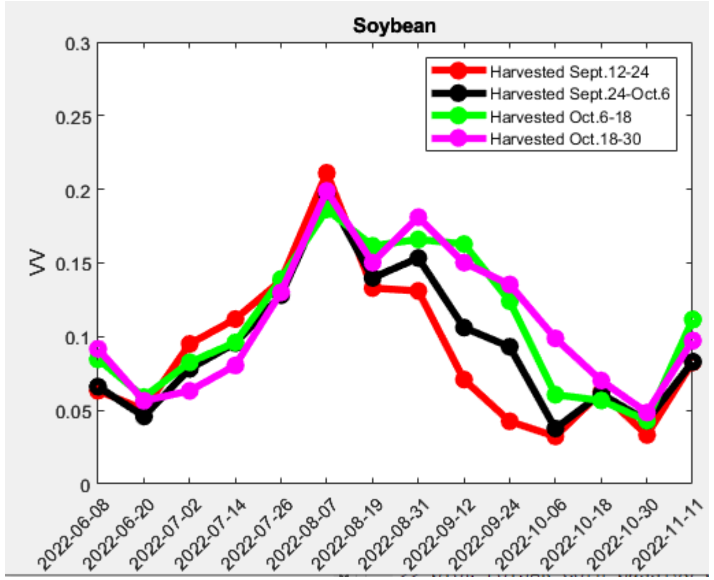
Imaging dates	Ground Observation dates	Number of fields observed	
		Soybean (n=41)	
		Harvest	tillage
24-Sep	26-Sep	3	
6-Oct	6-Oct	15	2
18-Oct	13-Oct	12	6
30-Oct	25-Oct	8	10
11-Nov	7-Nov		3

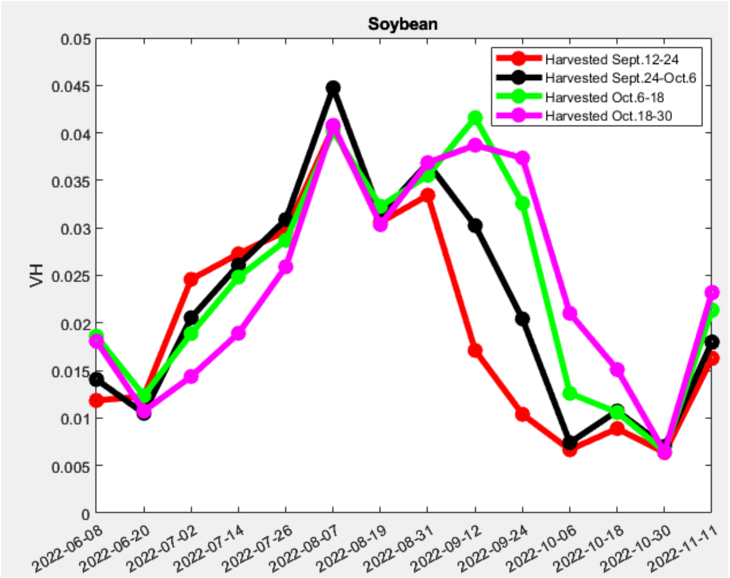


Analysis of time series of SAR images for ground data -- Soybean

Polarimetric SAR Parameters

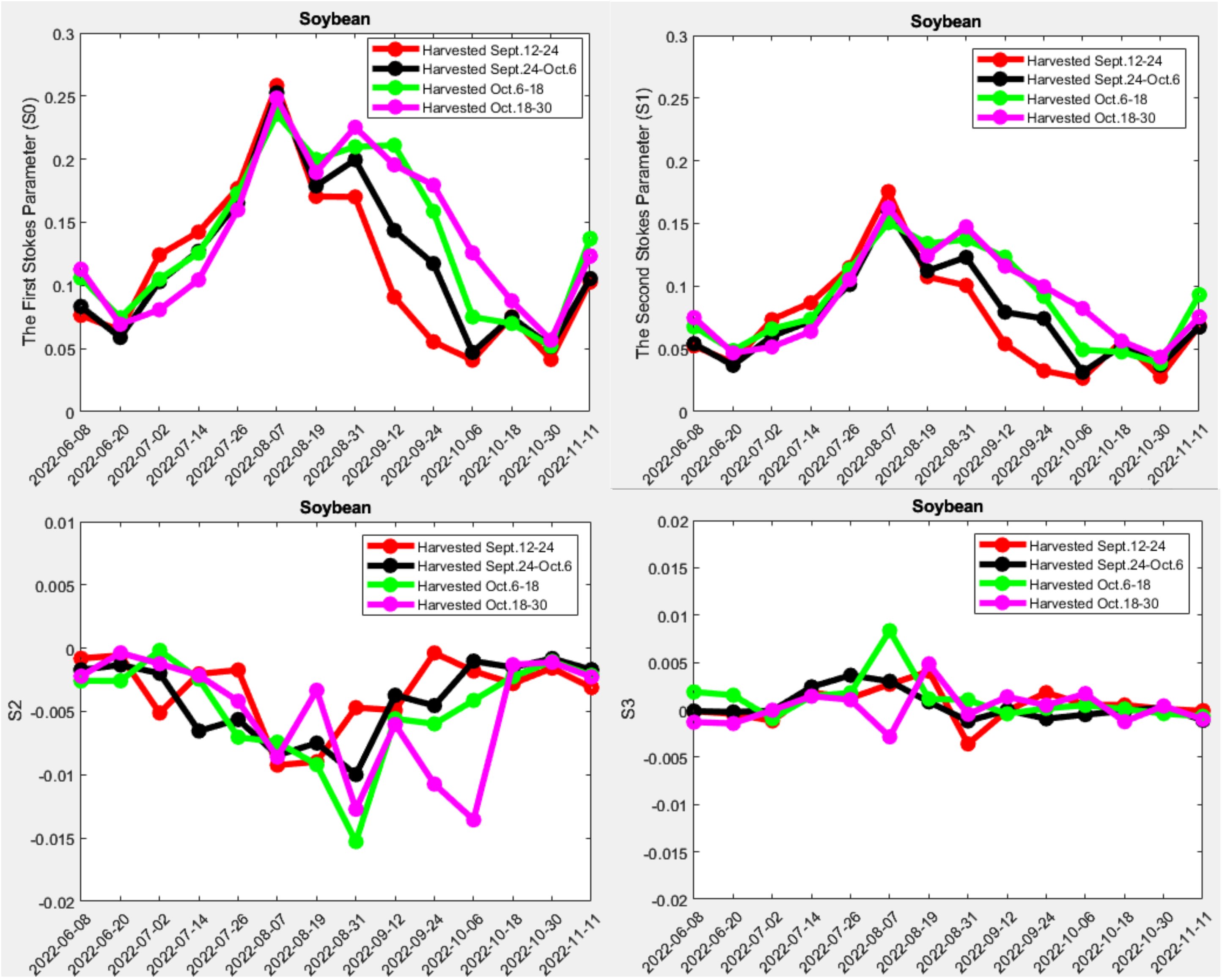






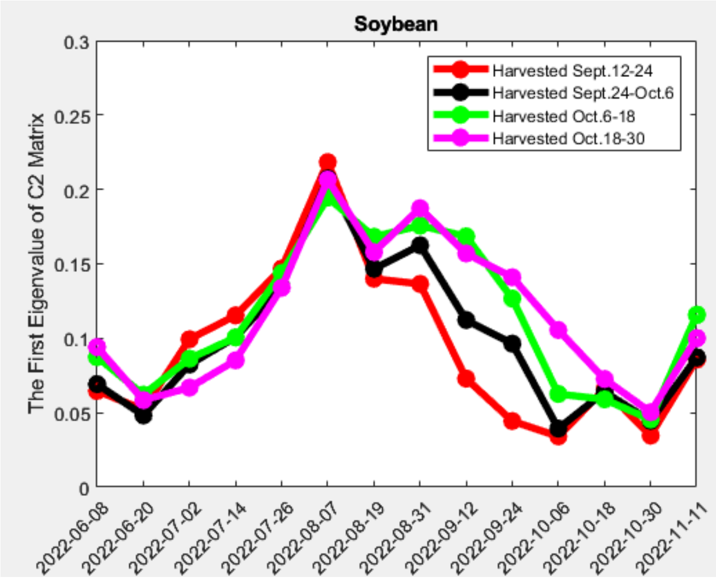
Analysis of time series of SAR images for ground data -- Soybean

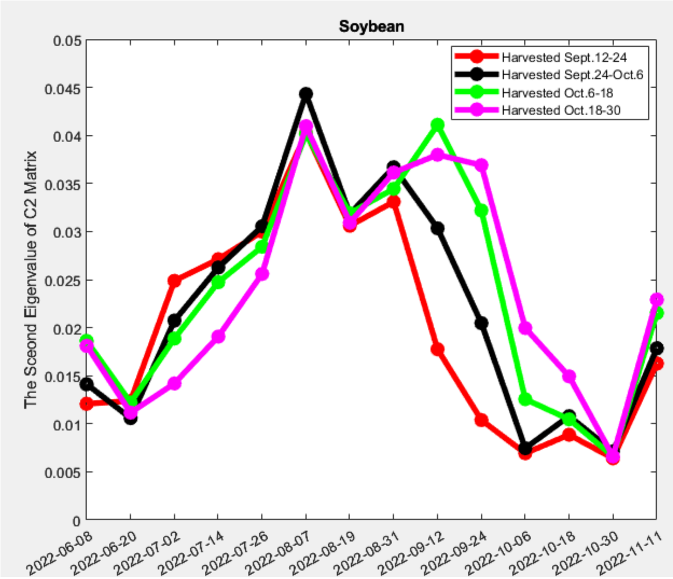
Polarimetric SAR Parameters

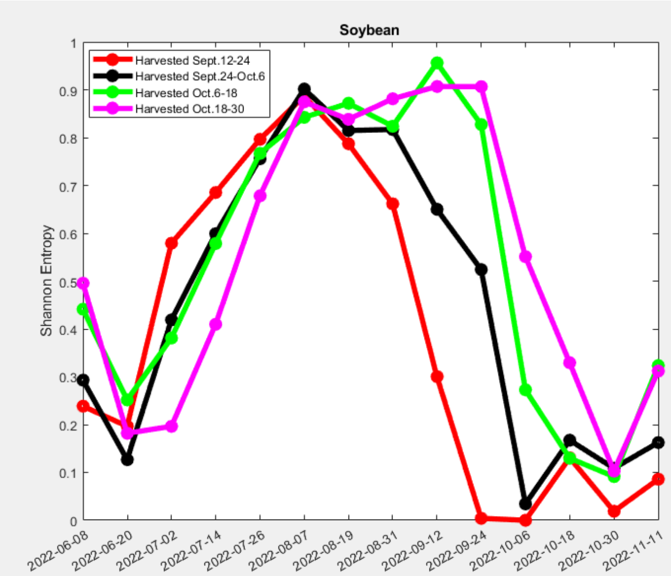


Analysis of time series of SAR images for ground data -- Soybean

Polarimetric SAR Parameters



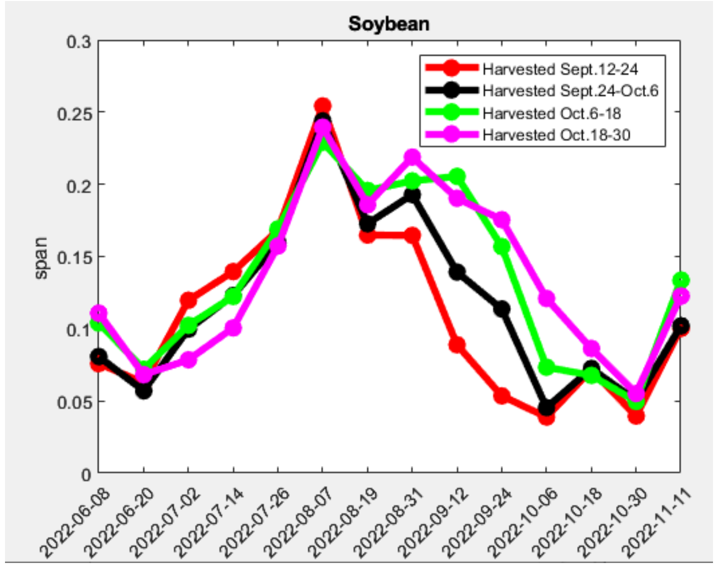




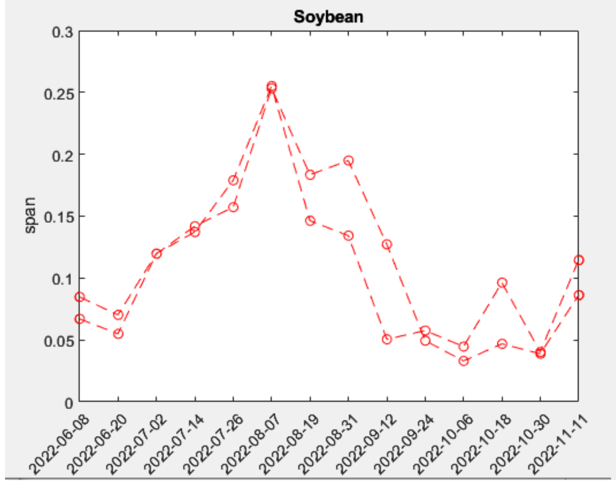
Analysis of time series of SAR images for ground data -- Soybean

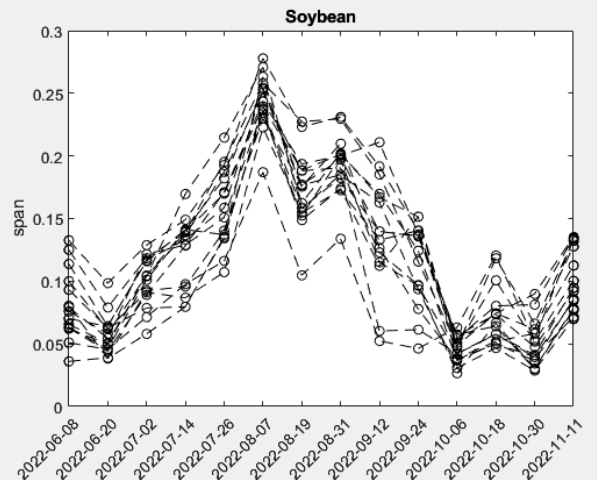
Determine harvest using span

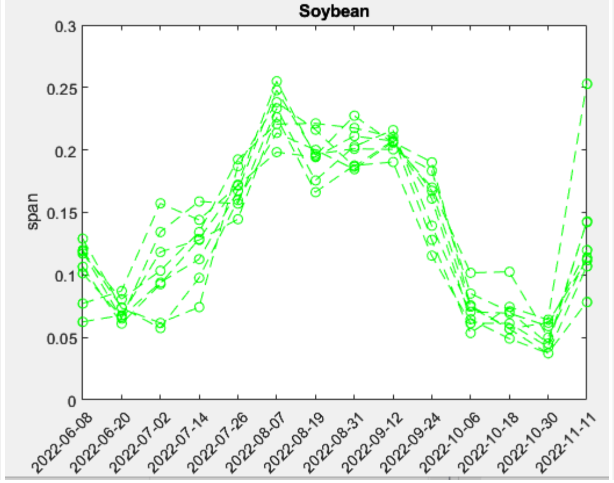
$$Span(t,i) < 0.07 \text{ and } Span(t,i) - Span(t-1,i) < -0.01$$

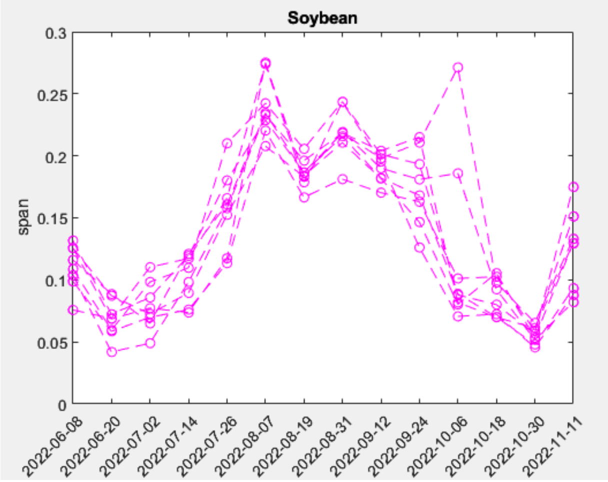


Imaging dates	Ground Observation dates	Span (70%)	
		Harvest	Identified
24-Sep	26-Sep	2	1
6-Oct	6-Oct	15	13
18-Oct	13-Oct	8	3
30-Oct	25-Oct	8	6
11-Nov	7-Nov		









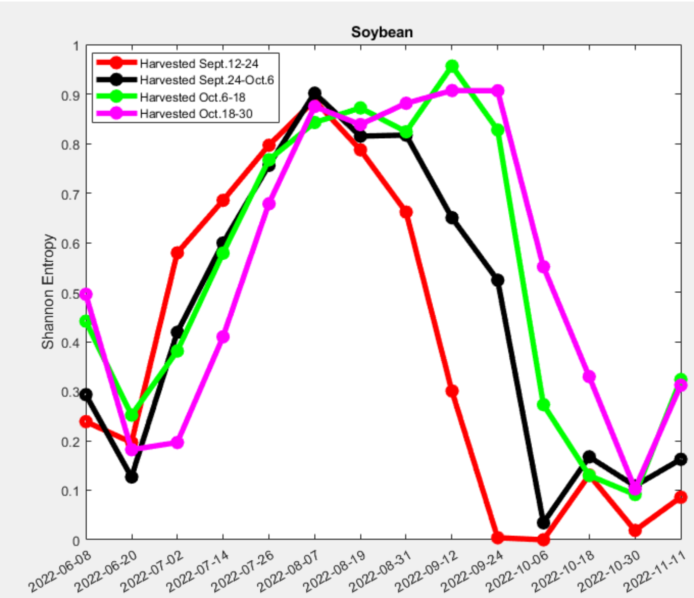
Analysis of time series of SAR images for ground data -- Soybean

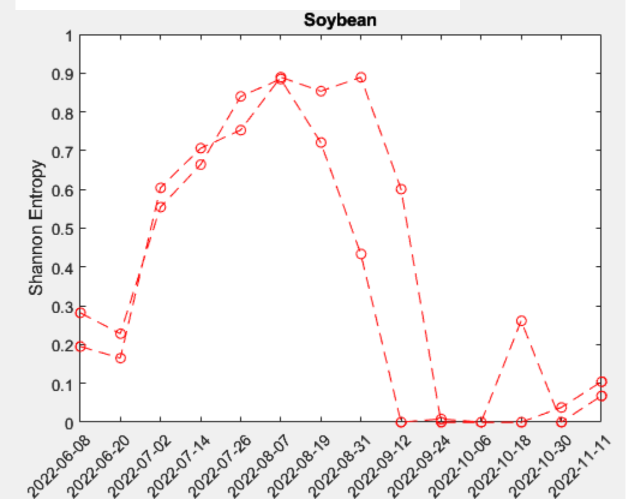
Determine harvest using Shannon entropy

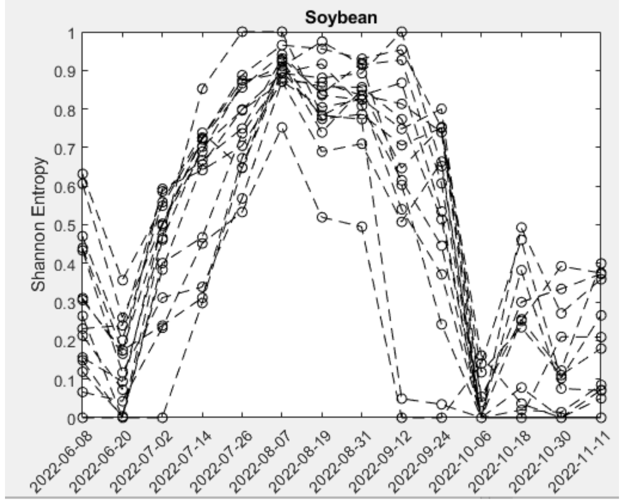
$SE(t, i) < \ 0.15$ and

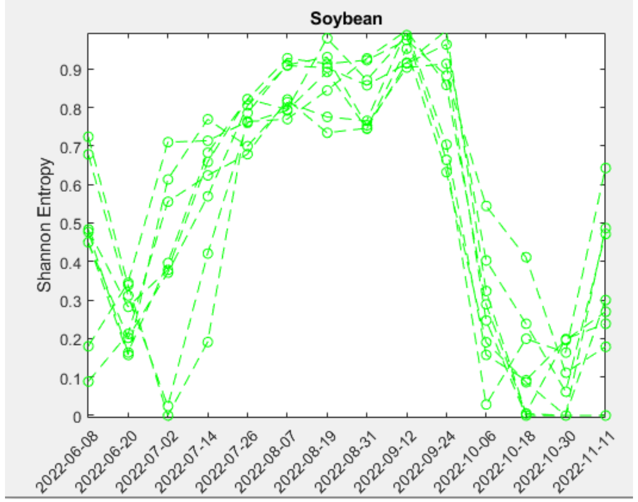
$\text{Shannon Entropy}(t, i) - Shannon\ Entropy(t-1, i) < -0.01$

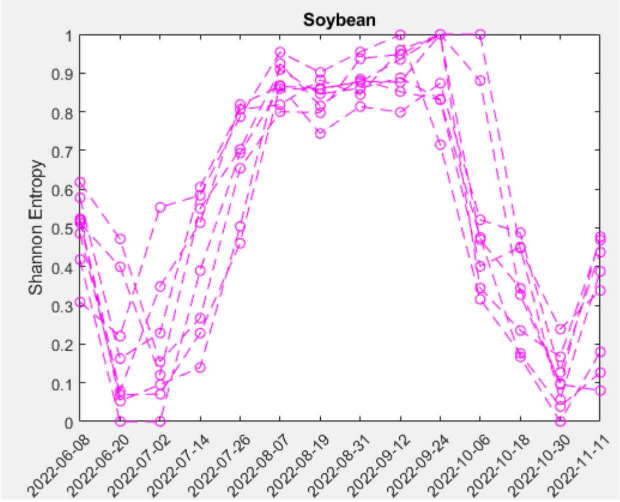
Imaging dates	Ground Observation dates	SE (70%)	
		Harvest	Identified
24-Sep	26-Sep	2	1
6-Oct	6-Oct	15	12
18-Oct	13-Oct	8	5
30-Oct	25-Oct	8	6
11-Nov	7-Nov		







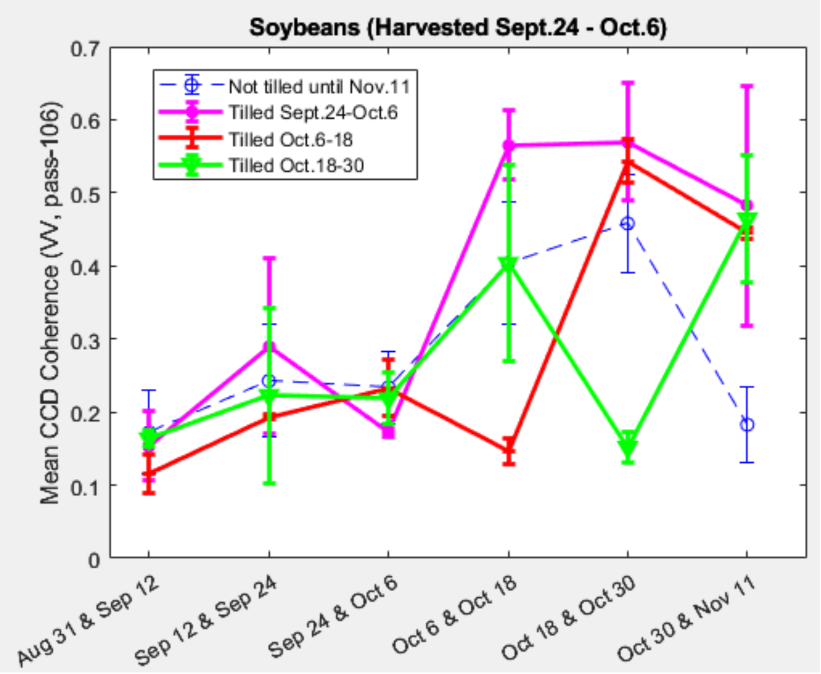


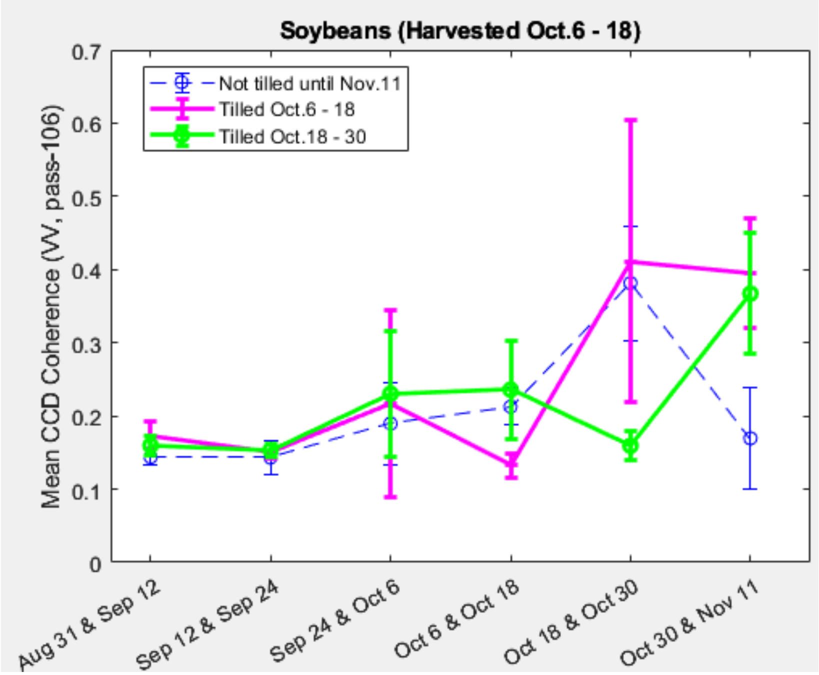


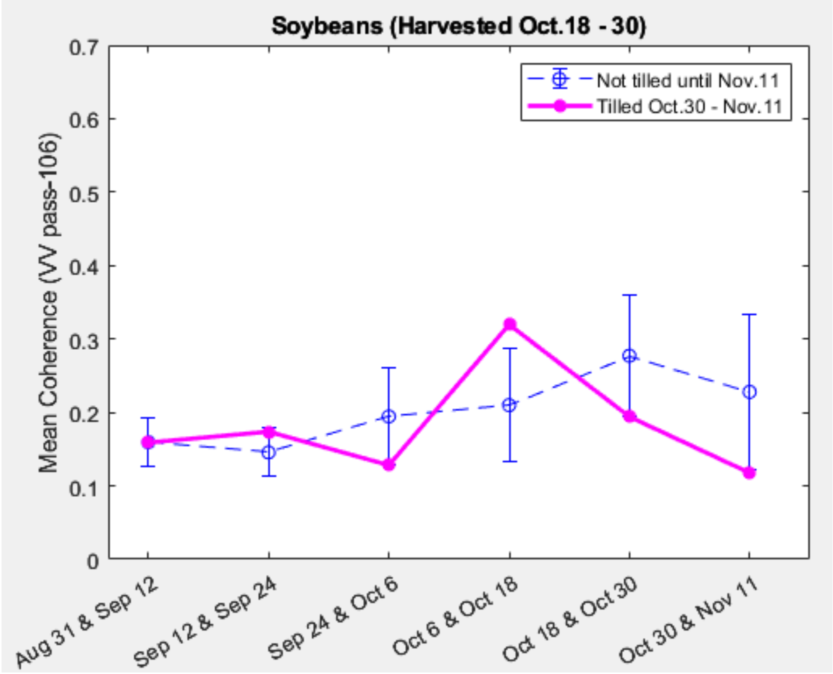
Analysis of time series of SAR images for ground data -- Soybean

CCD Coherence

Imaging dates	Ground Observation dates	Number of fields observed	
		Soybean (n=41)	
		Harvest	tillage
	26-Sep	3	
Sept. 24 - Oct.6	6-Oct	15	2
Oct. 6 – Oct.18	13-Oct	12	6
Oct.18 – Oct.30	25-Oct	8	10
Oct.30 – Nov.11	7-Nov		3







Interferometric pairs

Analysis of time series of SAR images for ground data -- Soybean

Determine tillage using CCD coherence

- If harvest dates were detected using polarimetric parameters, 100% tillage activities can be identified with 1 CCD image pair

$$\gamma(t,i) < 0.2$$

- Two conjunctive CCD image pairs will need to identify the tillage activities without harvest information, and identification accuracy is 75%

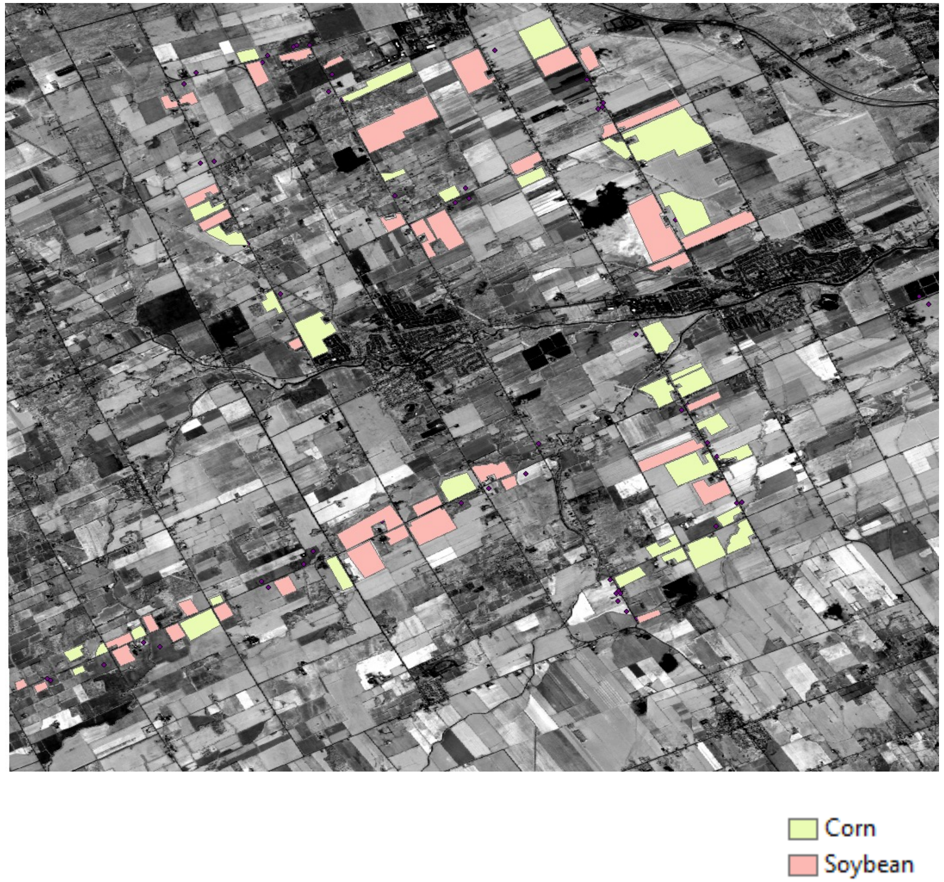
$$\gamma(t,i) < 0.2 \text{ and } (\gamma(t,i) - \gamma(t-1,i) < -0.1 \text{ or } \gamma(t+1,i) - \gamma(t,i) > 0.2)$$

Imaging dates	Ground Observation dates	Number of fields observed	
		Harvest	tillage
24-Sep	26-Sep	3	
6-Oct	6-Oct	15	2
18-Oct	13-Oct	12	6
30-Oct	25-Oct	8	10
11-Nov	7-Nov		3

Analysis of time series of SAR images for ground data -- Corn

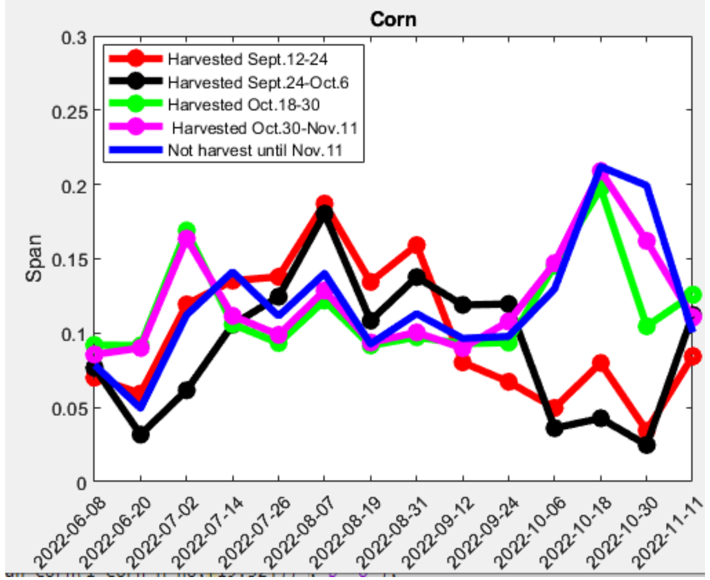
Number of fields observed for harvesting and tillage in the fall of 2022

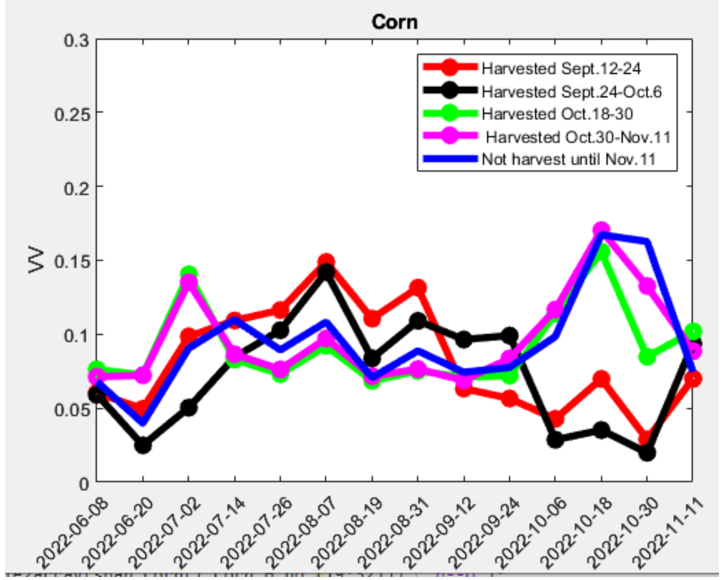
Imaging dates	Ground Observation dates	Number of fields observed	
		Harvest	tillage
24-Sep	26-Sep	2	
6-Oct	6-Oct	1	
18-Oct	13-Oct		1
30-Oct	25-Oct	11	2
11-Nov	7-Nov	9	5

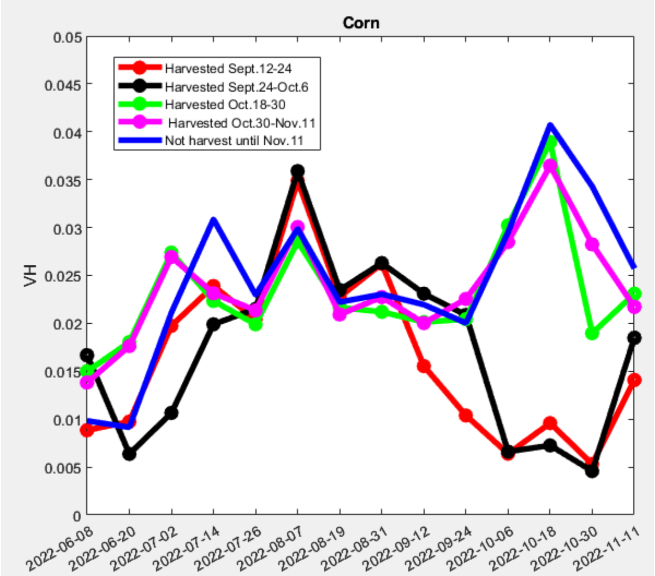


Analysis of time series of SAR images for ground data -- Corn

Polarimetric SAR Parameters

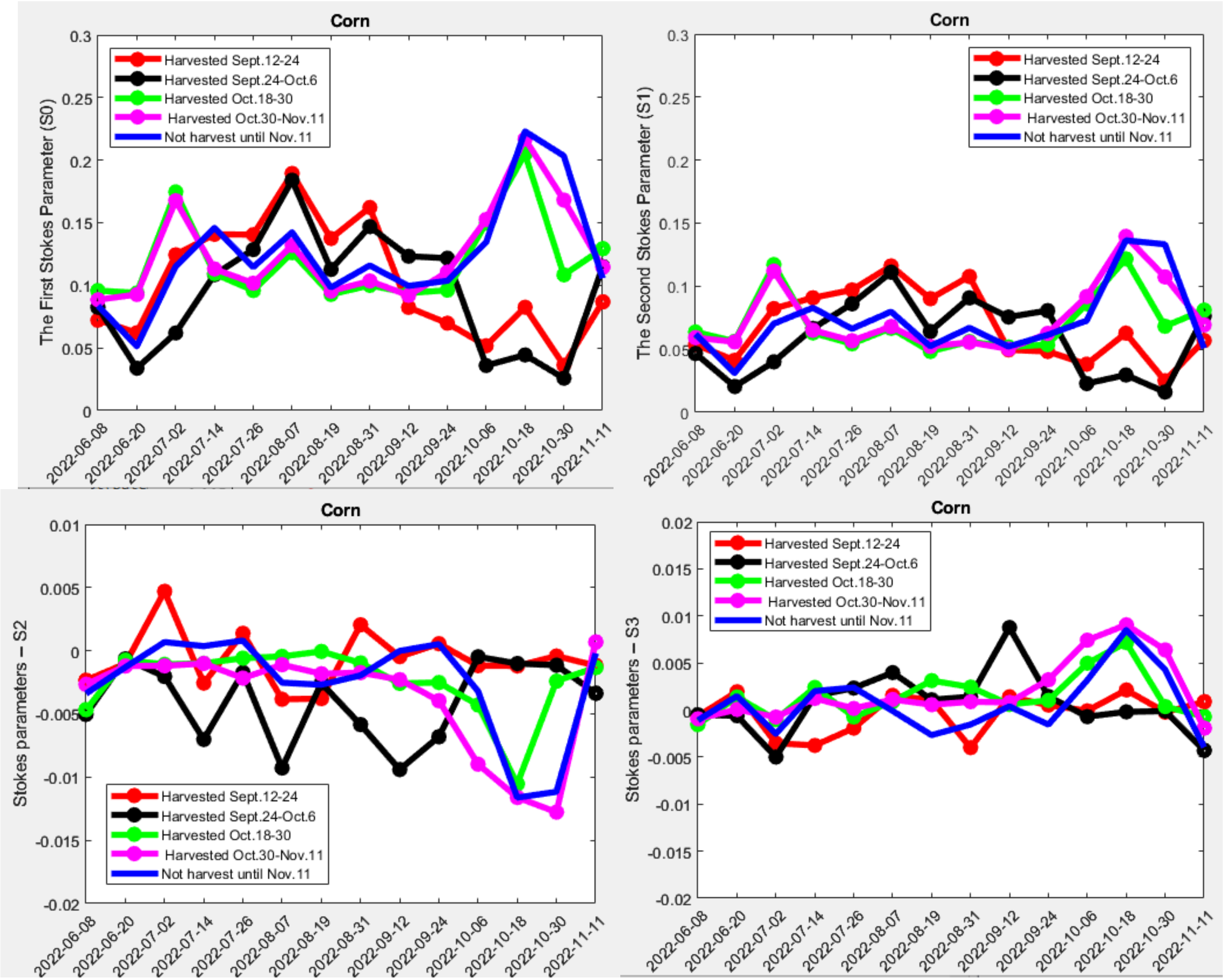






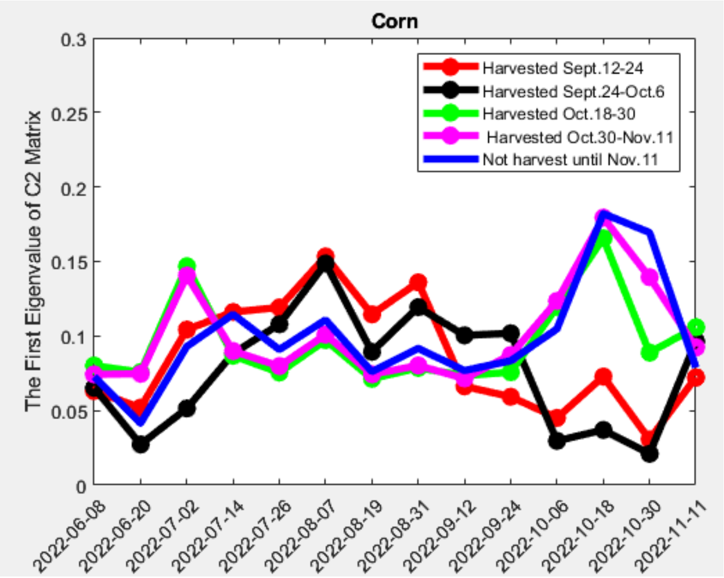
Analysis of time series of SAR images for ground data -- Corn

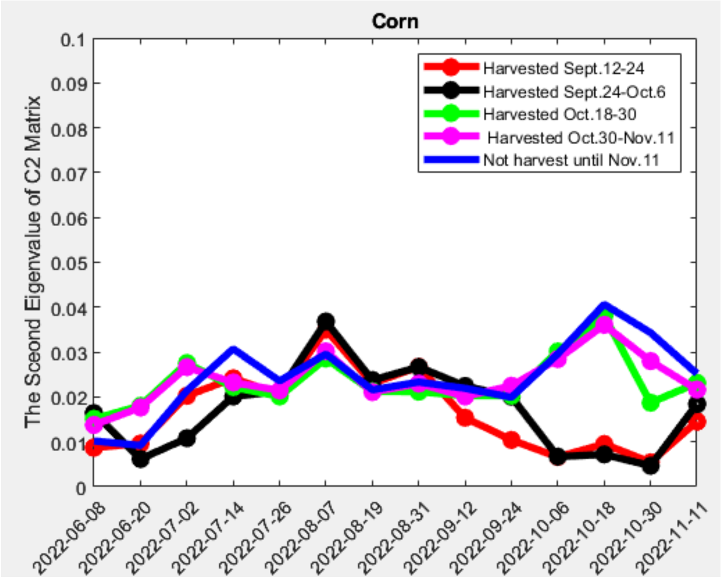
Polarimetric SAR Parameters

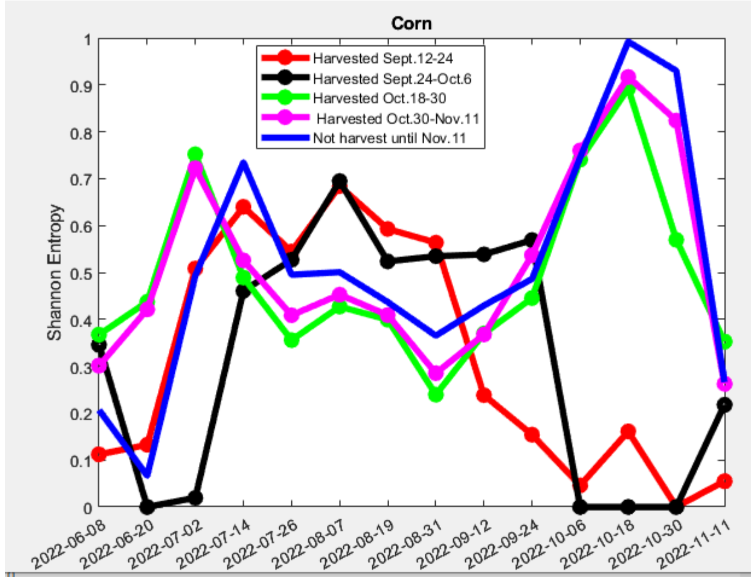


Analysis of time series of SAR images for ground data -- Corn

Polarimetric SAR Parameters





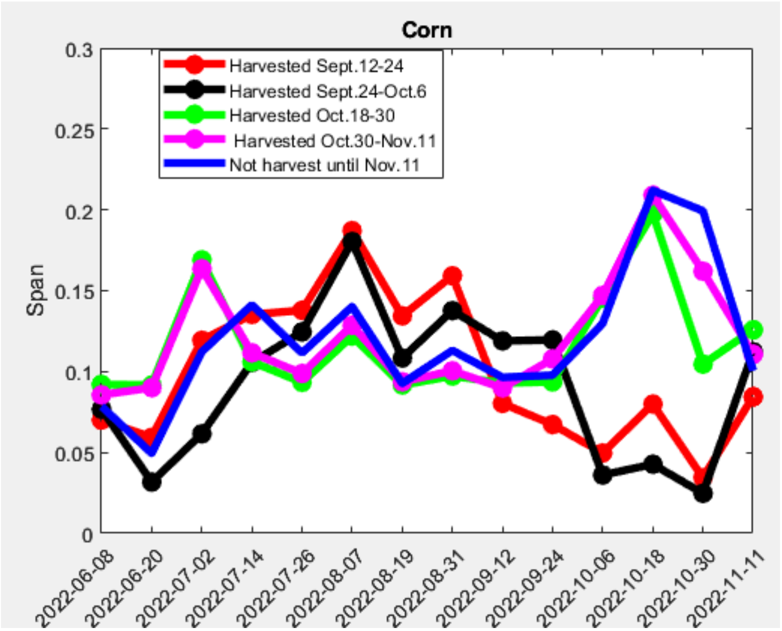


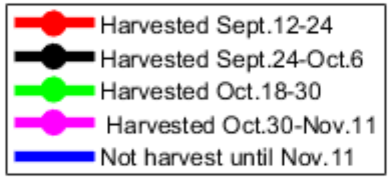
Analysis of time series of SAR images for ground data -- Corn

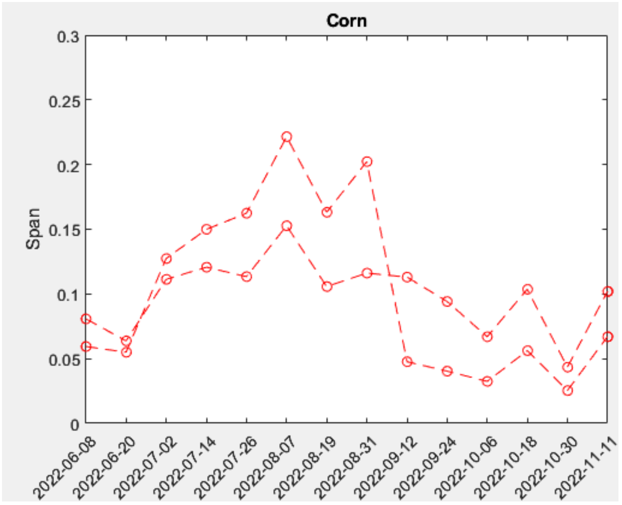
Determine harvest using span

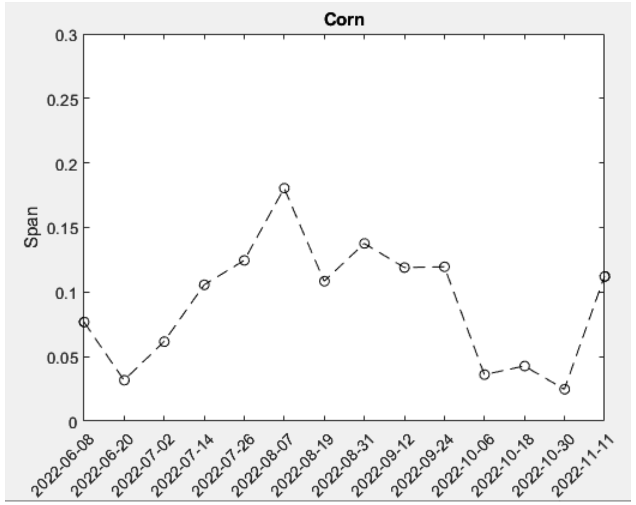
$Span(t,i) - Span(1,i) < 0.05$ and $Span(t,i) - Span(t-1,i) < -0.03$

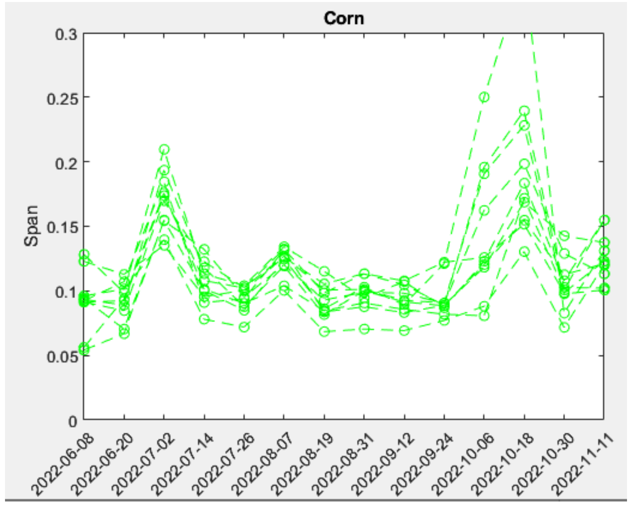
Imaging dates	Ground Observation dates	Span (85%)	
		Harvest	Identified
24-Sep	26-Sep	2	0
6-Oct	6-Oct	1	1
18-Oct	19-Oct		
30-Oct	1-Nov	10	9
11-Nov	7-Nov	9	8
		21	18

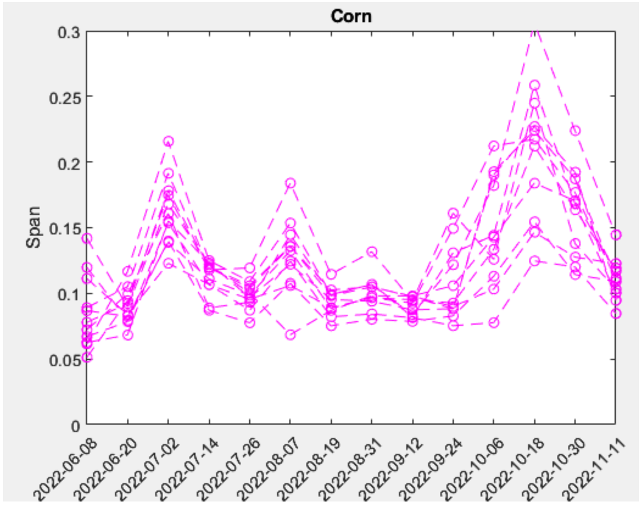












Analysis of time series of SAR images for ground data -- Corn

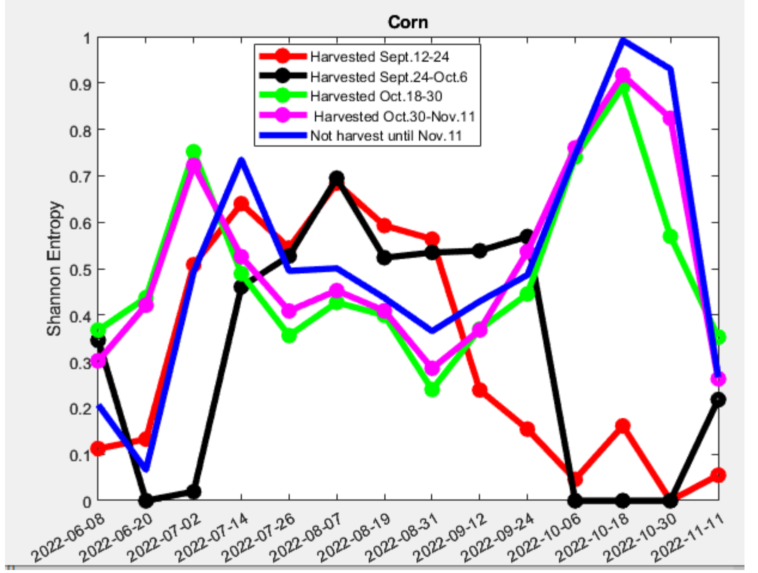
Determine harvest using Shannon entropy

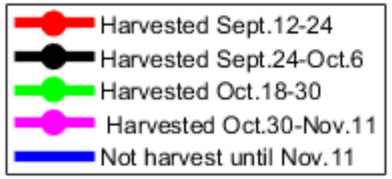
$$Shannon\ Entropy(t,i) - Shannon\ Entropy(1,i) < 0.2$$

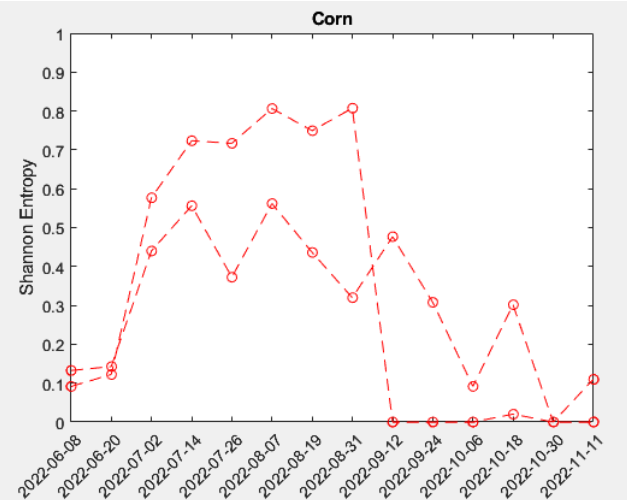
and

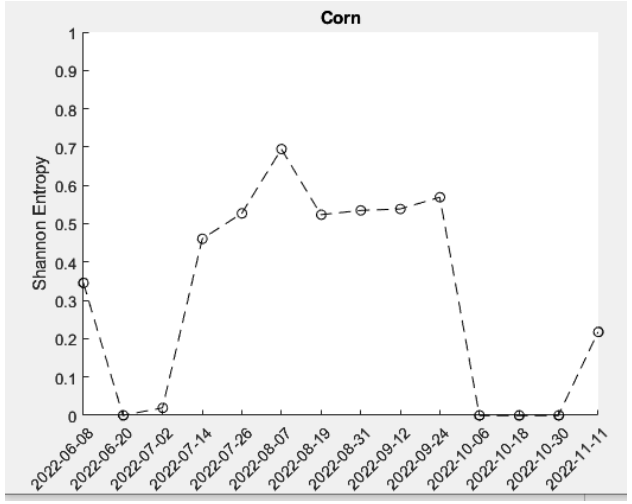
$$Shannon\ Entropy\ (t,i) - Shannon\ Entropy(t-1,i) < -0.2$$

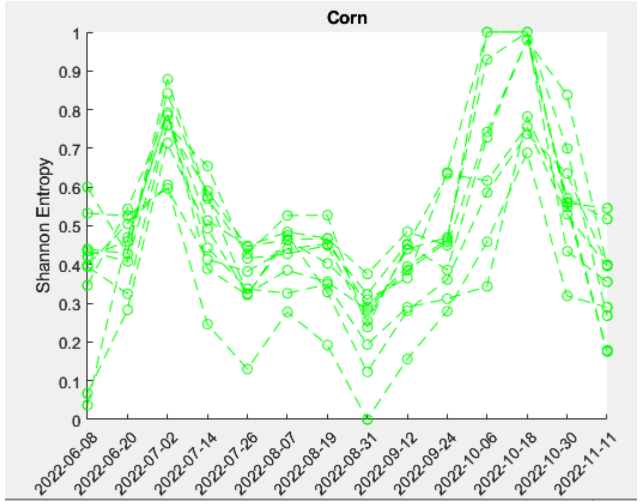
Imaging dates	Ground Observation dates	SE (76%)	
		Harvest	Identified
24-Sep	26-Sep	2	0
6-Oct	6-Oct	1	1
18-Oct	19-Oct		
30-Oct	1-Nov	10	8
11-Nov	7-Nov	9	7
		21	16

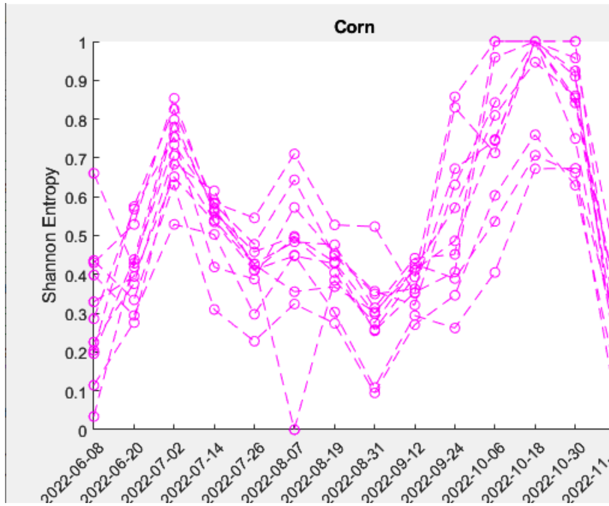








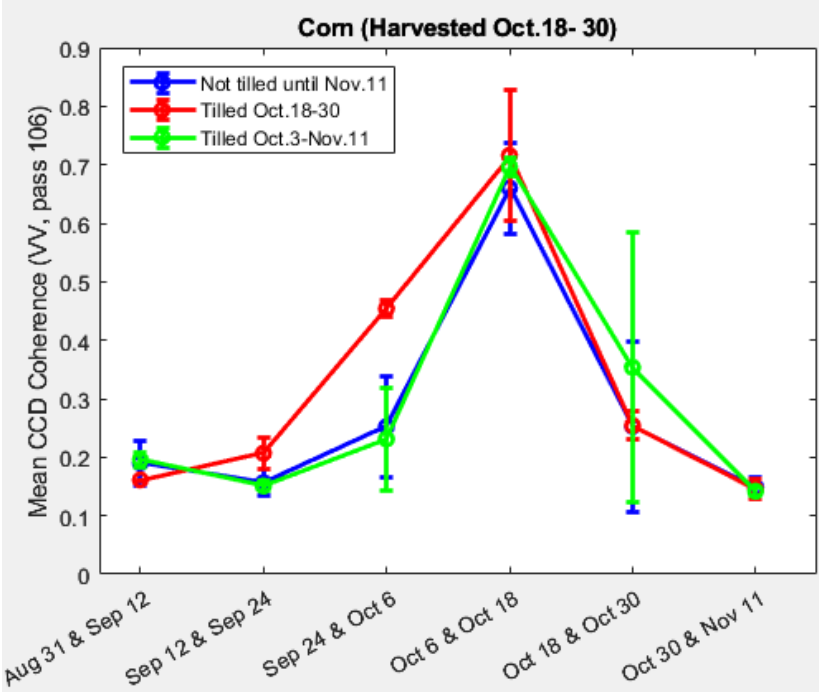


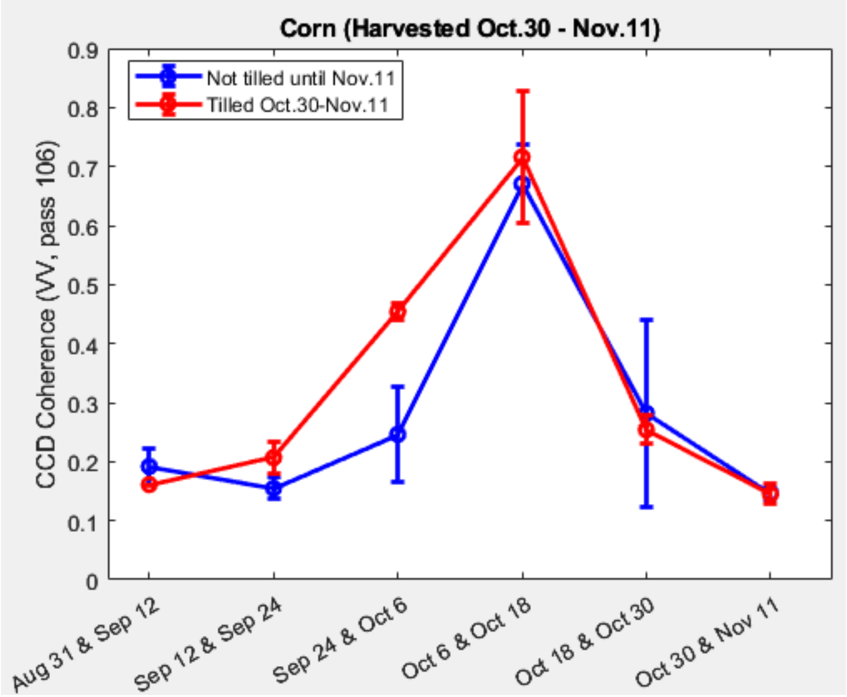


Analysis of time series of SAR images for ground data -- Corn

CCD Coherence

Imaging dates	Ground Observation dates	Number of fields observed	
		Harvest	tillage
	26-Sep	2	
Sept. 24 - Oct.6	6-Oct	1	
Oct. 6 – Oct.18	13-Oct		1
Oct.18 – Oct.30	25-Oct	11	2
Oct.30 – Nov.11	7-Nov	9	5



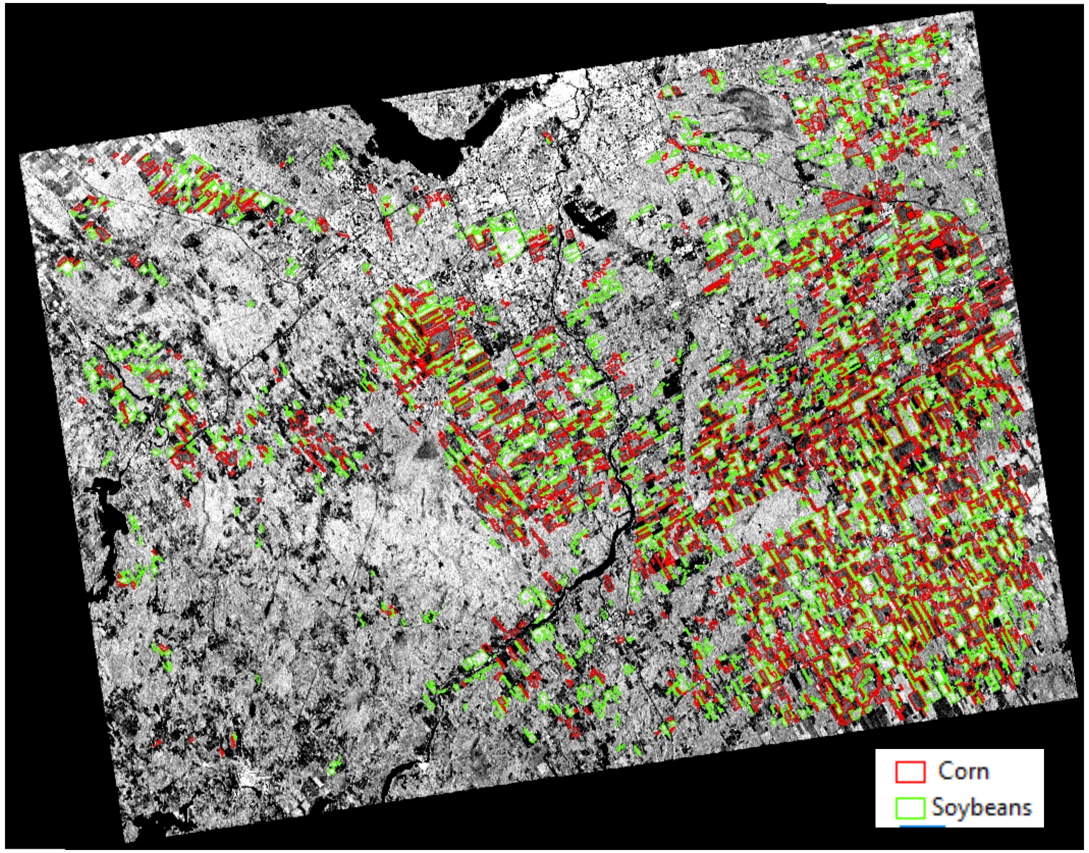


No adequate observations and image pairs to determine corn tillage

Mapping of crop harvest and tillage

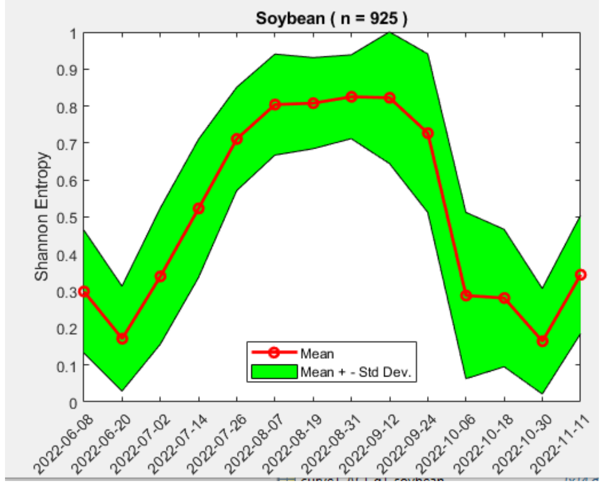
Identify soybean and corn fields in the Russell area from the 2022 the Agriculture and Agri-Food Canada (AAFC) Annual Crop Inventory (ACI) data

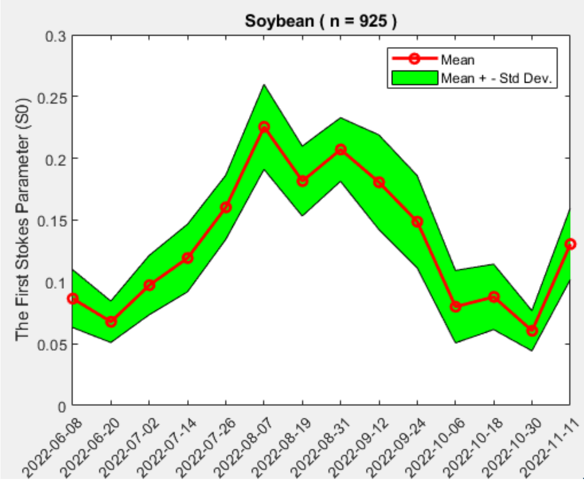
There are 925 soybean and 941 corn fields were identified from the 2022 ACI map.

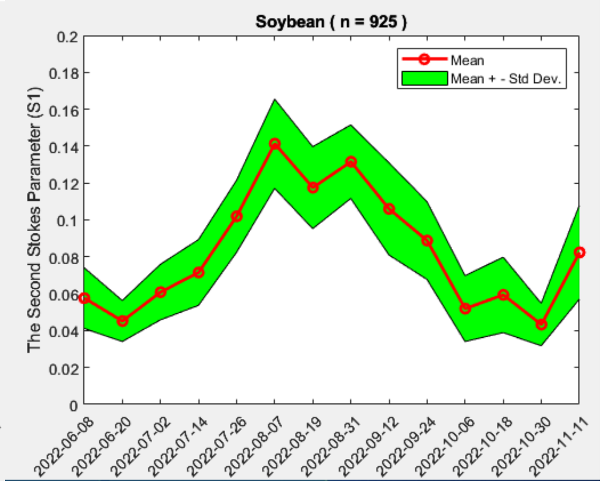


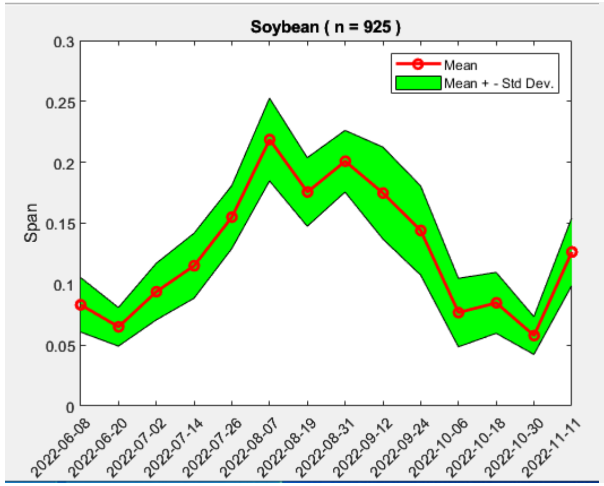
Time-series Polarimetric SAR Parameters

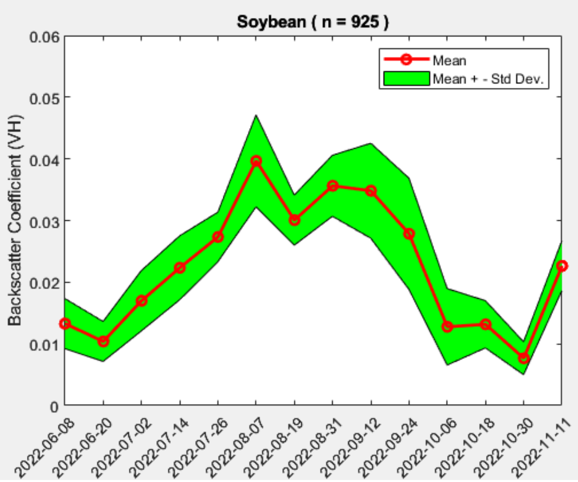
Soybean

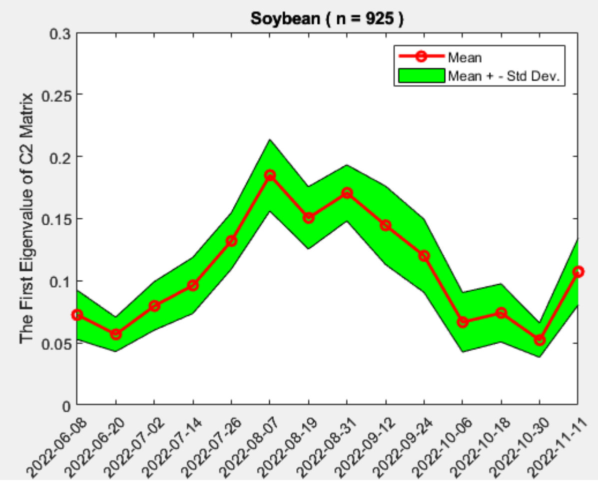


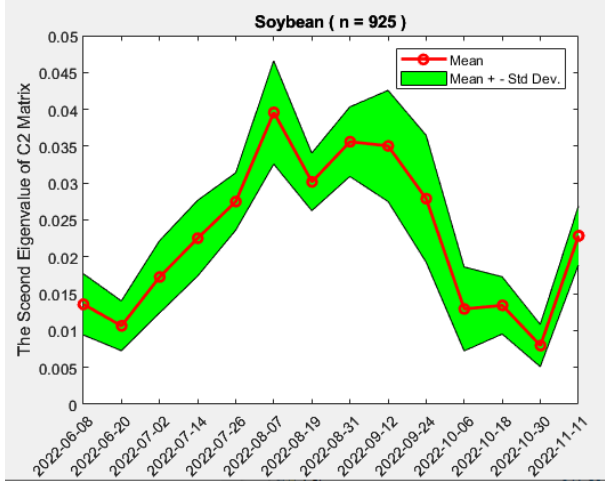






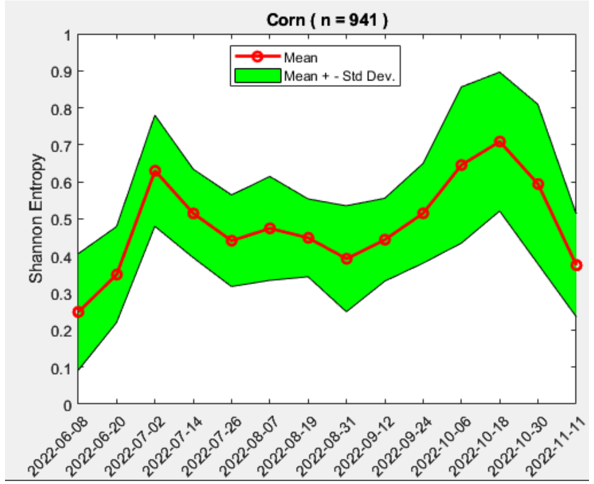


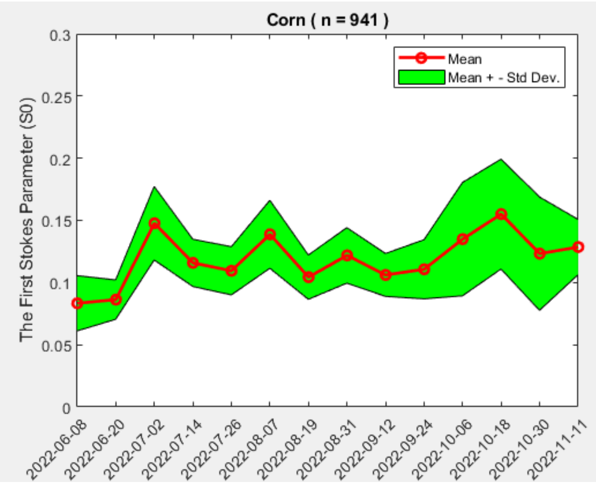


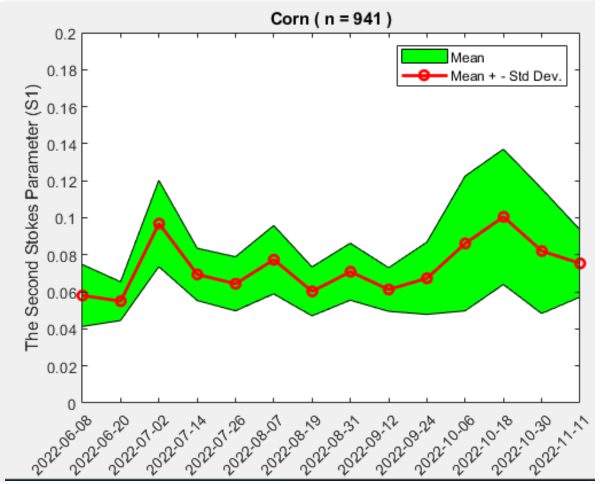


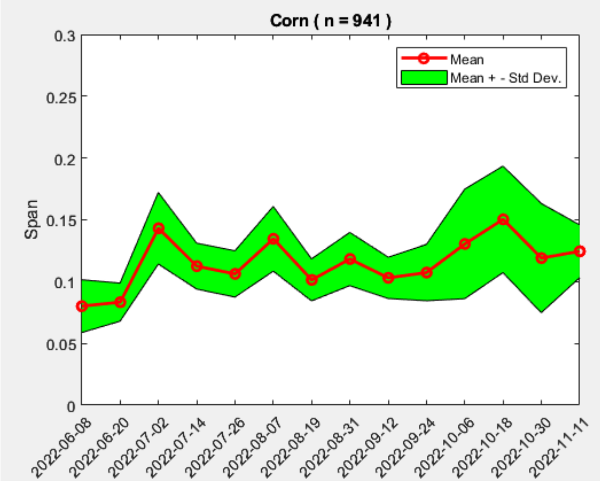
Time-series Polarimetric SAR Parameters

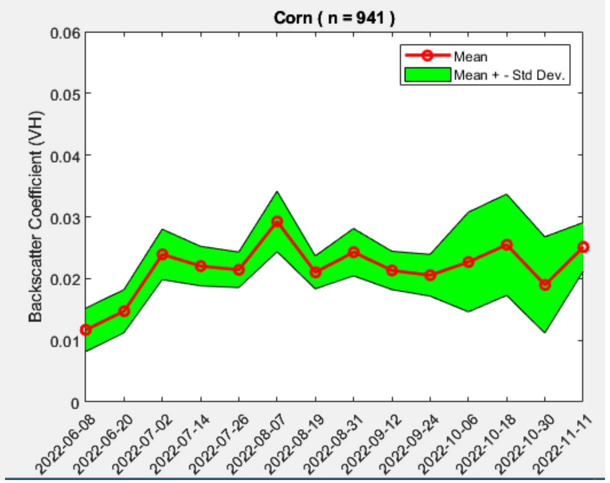
Corn

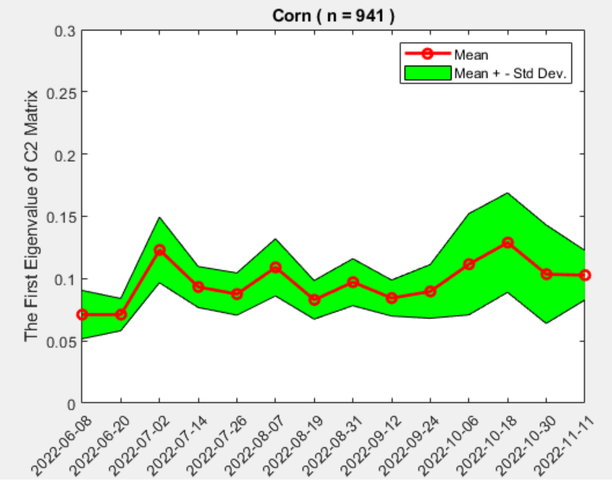


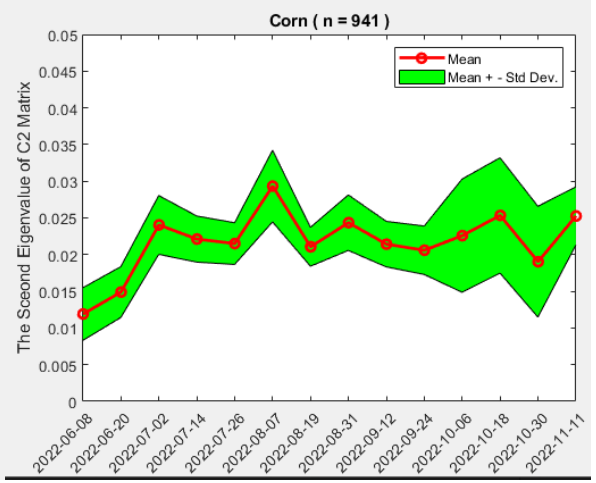




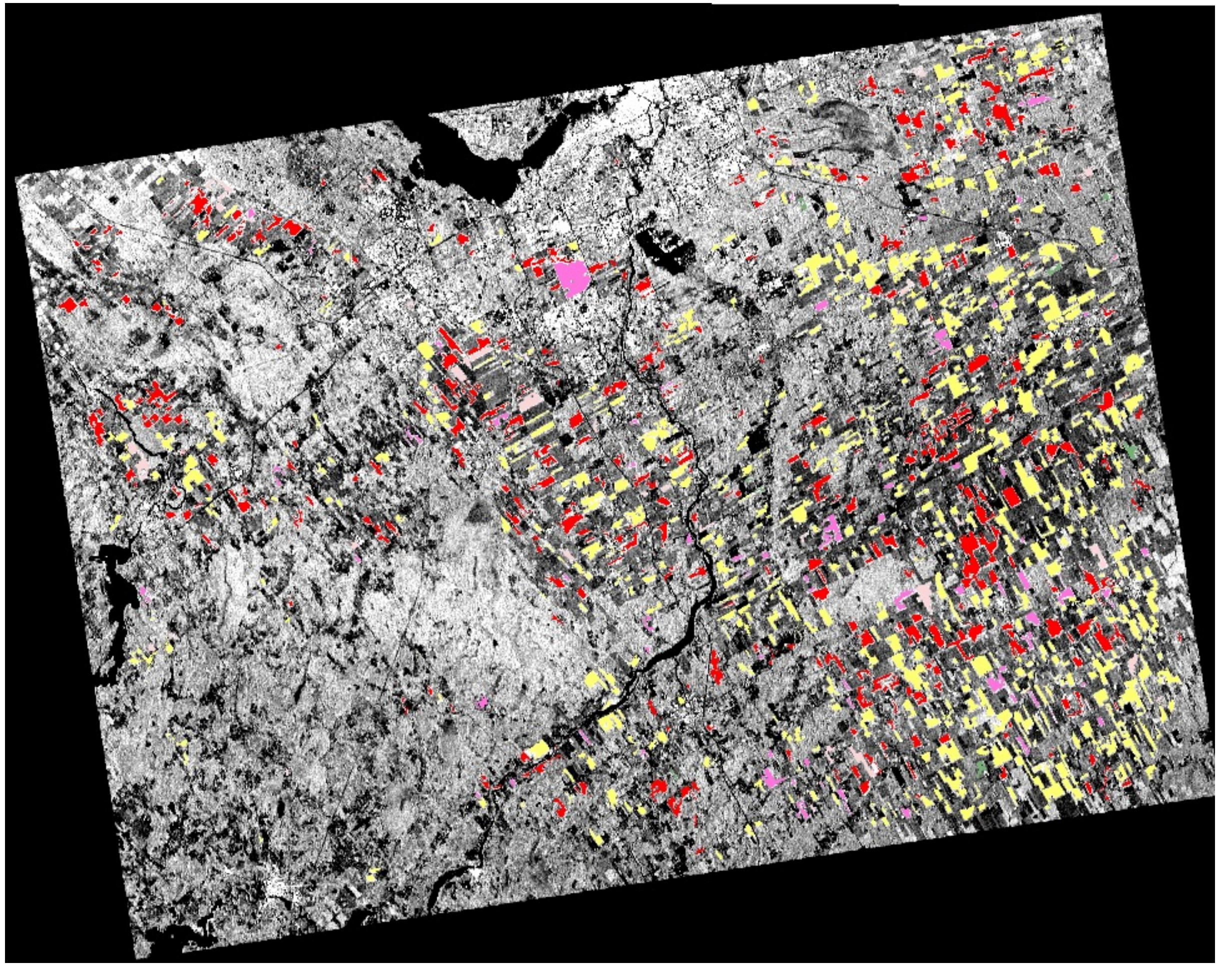






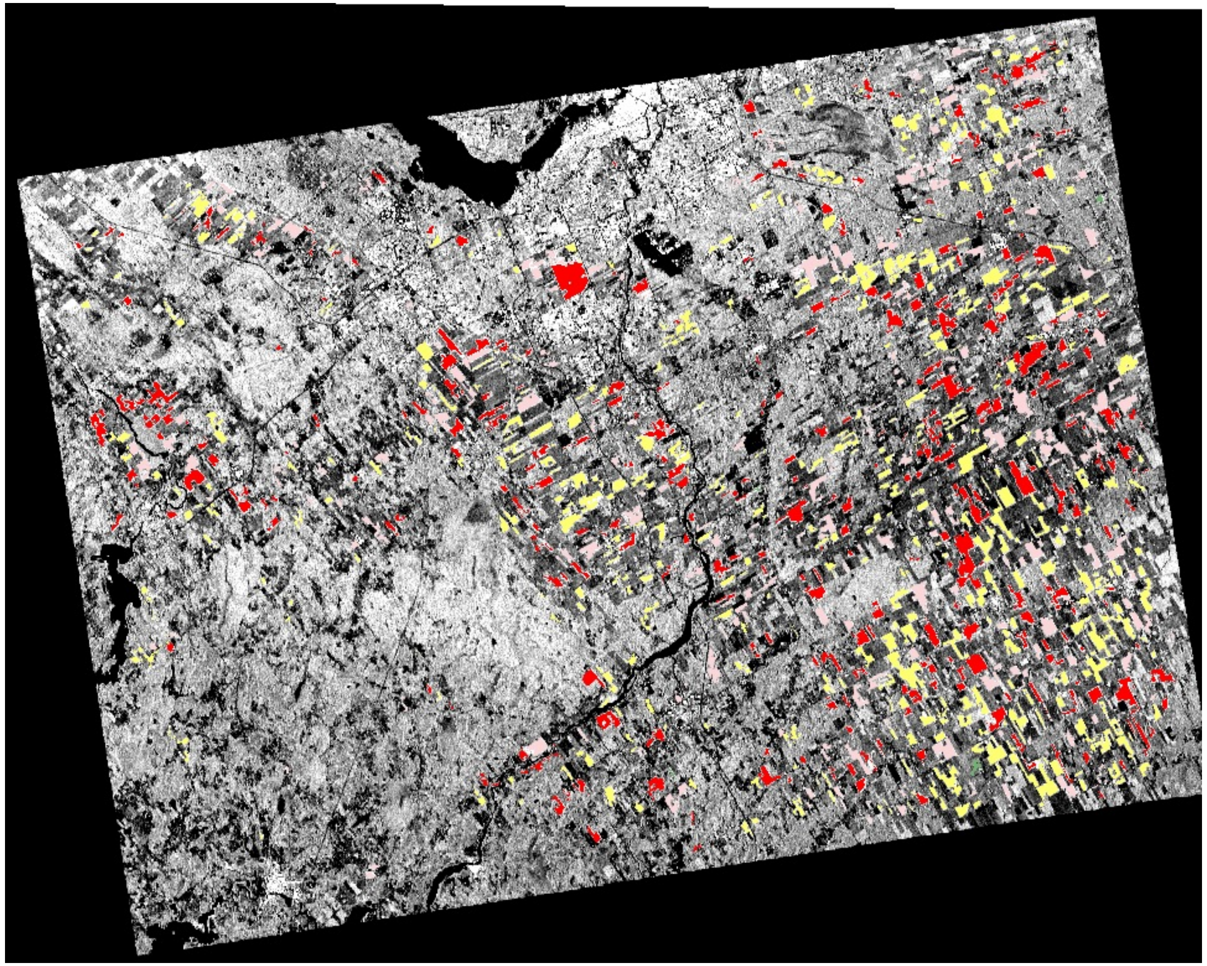


Mapping of crop harvest and tillage



Harvest date

Sept.12 -Sept.24 | Sept.24 - Oct. 6 | Oct.6 - Oct.18 | Oct.18 - Oct.30



Tillage date

Sept.12 -Sept.24 | Sept.24 - Oct. 6 | Oct.6 - Oct.18 | Oct.18 - Oct.30