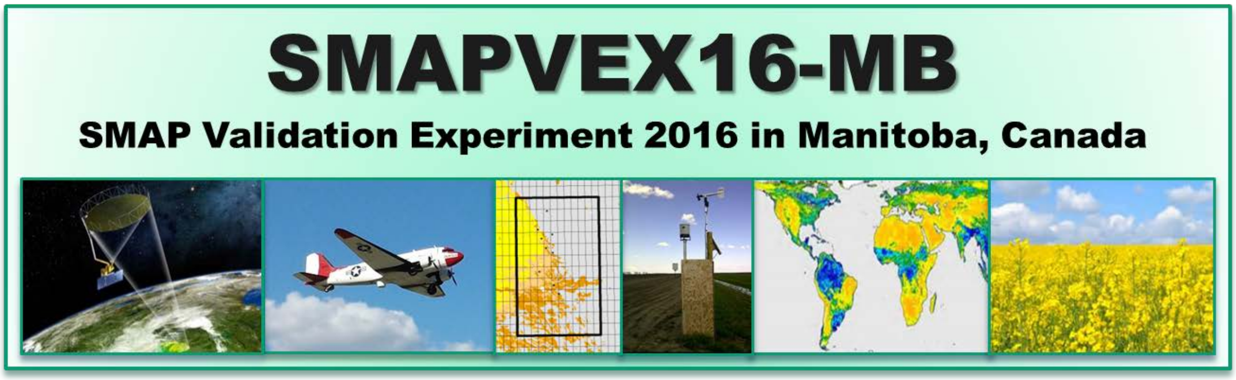

Experimental Plan

May 24, 2016

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1. Introduction

1.1. Overview

The Soil Moisture Active Passive (SMAP) satellite was successfully launched January 31, 2015. The satellite released its first global maps of soil moisture on April 21 of that year (http://smap.jpl.nasa.gov/news/1247/). Level-2 and Level-3 SMAP radiometer data are now available at the NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC). Since its launch, SMAP has captured a number of extreme weather events including the aftermaths of flooding and hurricanes (http://smap.jpl.nasa.gov/news/).

On July 7 2015 SMAP's radar stopped transmitting due to an anomaly involving the radar's high-power amplifier (http://smap.jpl.nasa.gov/news/1247/). With the loss of SMAP's active sensor, NASA is investigating methods to downscale SMAP's coarser resolution radiometer including whether the European Space Agency's Sentinel-1 C-band radar may be used for this purpose.

The mandate of the SMAP calibration/validation team (post-launch) is to: (a) verify and improve performance of the science algorithms, and (b) validate accuracies of the science data products. A number of sources of validation data are being used including in situ observations in addition to truck-, tower- and aircraft-based radiometers and radars. With respect to in situ measurements, these data are being provided by core validation sites, sparse networks as well as intensive field campaigns. Overall, the SMAP L2_SM_P retrieval algorithms (more specifically the V-pol Single Channel Algorithm SCA-V) are meeting SMAP mission requirements with average unbiased root-mean-square difference (ubRMSD) over the core validation sites of 0.038 m^3/m^3 (Chan et al., in press)

1.2. SMAPVEX16-MB objectives

Reducing risk to Canadians and enabling informed decision making, from individual decisions to government policy development, is supported by the availability of timely and accurate information. The impact of improved soil moisture monitoring extends to several areas of Canadian human and economic life and is of enormous value to Canadians. Timely, comprehensive and accurate soil moisture information leads to a better understanding of current and future weather, flood and drought risk, and better management of environmental and health issues. Improved monitoring and prediction of soil moisture conditions provides critical information needed to reduce liability from climate related extremes and target programs towards areas where they are most needed. In the agricultural sector, limited access to spatially detailed and high quality data on soil moisture across Canada significantly impacts the ability to deliver programs and policies to mitigate and respond to risk. Access to accurate and temporally frequent soil moisture data improves response to drought/excess moisture conditions, assists in the development and delivery of water management strategies and agricultural best management practices. Access to spatially distributed surface soil moisture can improve numerical weather prediction and air quality monitoring through an improved characterization of land surface processes. In hydrology, better knowledge of soil moisture can improve model predictions of surface runoff and ground water recharge, enabling better prediction of water availability, transport of contaminants and flood prediction. These improved predictions will bring social, environmental and economic benefits to all Canadians.

In June of 2010, a first field campaign (the Canadian Experiment for Soil Moisture in 2010 or CanEx-SM10) was conducted over sites in Saskatchewan. This was followed in 2012 by the SMAP Validation Experiment 2012 (SMAPVEX12) in southern Manitoba. Data collected during both these campaigns supported pre-launch validation and algorithm development for SMAP.

A post-launch SMAPVEX 2016 campaign will be conducted in Manitoba (SMAPVEX16-MB). This experiment has the following research objectives:

1. To investigate and resolve anomalous observations and products

Despite the encouraging results reported to date by the cal/val team, some discrepancies have been noted:

- SMAP retrievals often underestimate soil moisture as measured in situ;
- For some core validation sites, after rain events and as soils dry, SMAP estimates a faster rate of soil dry down relative to in situ measurements; and
- Errors tend to be higher for sites dominated by annual crops.

Of the core validation sites, the highest errors are observed for the Carman/Elm Creek site in Manitoba. In addition, the discrepancies listed above are all pronounced in the comparisons between SMAP retrievals and in situ observations, at this site. Thus, an important objective of the 2016 experiment will be to investigate and if possible mitigate the sources of these discrepancies. Although this Canadian site has the most pronounced differences, what is learned here will be of use for other calibration sites where annual crops dominant the land cover.

2. To improve up-scaling functions for core validation sites

The Agriculture and Agri-Food Canada (AAFC) Real-time In-situ Soil Monitoring for Agriculture (RISMA) network was installed primarily for validation of soil moisture products from RADARSAT-2. Specific station locations were selected via geostatistical analysis to capture soil texture variances in this region. This site served to capture diverse soil textures (and thus moisture) over a very small footprint with a dramatic break between heavy clays and loams/sandy loams. For the Carman/Elm Creek site, the up-scaling function developed by AAFC is based on a weighted average according to the soil texture fraction present in the SMAP core pixel. RISMA has proven well suited for validation of RADARSAT-2 soil moisture retrievals, yet was not designed with SMAP footprints in mind. SMAPVEX16-MB will provide an opportunity to test whether the AAFC approach to up-scaling is contributing to discrepancies between SMAP soil moisture retrievals and RISMA measured soil moisture and if so, to improve upon the current up-scaling approach.

3. Develop, validate and improve upon SMAP downscaling approaches

With the failure of the SMAP radar, options are being investigated to downscale SMAP passive microwave data. Methods being considered include the use of other active radar satellites (both C- and L-band), visible/infrared/thermal satellites as well as the use of products from land surface models. Data collected during SMAPVEX16-MB will be used to assess and improve upon these downscaling methods.

4. Deployment of ground-based instruments to better understand spatial and temporal variances in soil and crop contributions to microwave responses.

Instruments to be considered include:

- ground based radiometers: these will provide dense temporal measurements of emissions under varying soil and crop conditions; could be used in experiment to incrementally “strip” crops to determine contributions of crop components to emissions and thus potentially contribute to improved modeling of the effect of vegetation on moisture retrievals
- UAV-mounted radiometer: flown over select fields/groups of fields to examine in a relative sense, landscape spatial variances in radiometer response

5. Acquire data for ongoing validation of SMAP Level 2-4 products.

Of specific interest to the Province of Manitoba (a significant potential user of SMAP data) is the validation of root zone soil moisture products.

6. Contribute to broader science/application objectives to prepare for future satellite missions

The scope of soils and crop data expected to be collected during SMAPVEX16-MB could support development of algorithms for information retrieval from future missions including the RADARSAT-Constellation (launch date of 2018), the NASA-ISRO SAR Mission (NiSAR), the Orbiting Carbon Observatory-2 (OCO-2), as examples. The “re-purposing” of SMAPVEX16-MB data for these missions is encouraged.

2. Study site

The Red River Watershed of southern Manitoba provides a mix of land covers, although land use is dominated by annual cropping. This region has been used in decades of soil moisture research, dating back to the early 1990s when JPL flew AIRSAR over the region (1993) and when Altona, Manitoba served as a research site for SIR-C (1994). Subsequently, southern Manitoba has been used extensively to develop and validate soil moisture retrievals using Canada’s RADARSAT satellites. This research led AAFC to install permanent in situ soil moisture stations in the La Salle and Boyne River watersheds, part of the larger Red River basin.

2.1. General description

The Canadian Red River Watershed (Figure 1) is a watershed of extremes in soil moisture. For example, according to the 2008-2009 Annual Report from the Manitoba Agricultural Services Corporation drought and excessive heat have historically (1960-2007) accounted for 37% of reported crop losses, while excessive moisture was responsible for 36% of losses. The watershed is characterized largely by agricultural land use with a wide range of crop and soil conditions. Crops include forage, pasture, canola, flaxseed, sunflower, soybean, corn, barley, spring wheat, winter wheat, rye, oats, canary seed, potatoes, and field peas. The typical crop rotation is a cereal crop alternating with oilseed\pulse crops. Typical field sizes range from 20-

30 to 50-60 hectares. Annual crop type mapping for the entire Red River Watershed, via remote sensing techniques, is completed by AAFC. It is also important to note that this is a shared watershed with the U.S. Three-quarters of the Red River Watershed lies on the U.S. side of the border.

The AAFC RISMA stations were established in two phases in Manitoba. Nine stations were installed near the towns of Carman and Elm Creek, located 80 km southwest of the city of Winnipeg in 2011. Three other stations were installed in the Sturgeon Creek watershed in 2013, located immediately northwest of Winnipeg. The stations in Carman-Elm Creek are situated in the La Salle and Boyne River watersheds which are part of the larger Red River basin. The Sturgeon Creek watershed is part of the larger Assiniboine River basin. These areas are part of Canada's Prairie/Boreal Plain Ecozone and were chosen to capture the diverse soil moisture conditions in the Manitoba portion of the Red River and lower Assiniboine River basins. The Carman-Elm Creek site has an excellent contrast in soil properties from west (fine clay soils) to east (coarser and better drained soils). The watershed is approximately 60 km (east-west) by 10 km (north-south).

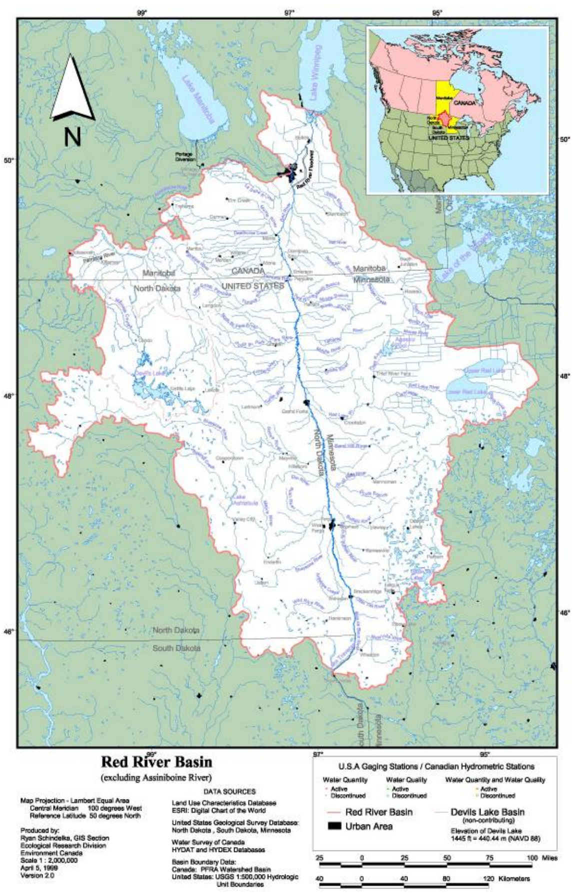


Figure 1. Extent of the Red River Watershed. Approximately 25% of the watershed falls within Canada, with the remainder of the watershed residing within Minnesota, North Dakota and South Dakota, U.S.A

2.2. Intensive sample site description

The SMAPVEX16-MB intensive sample site has been shifted east and south of the location of the 2012 experiment. The 2016 study site corresponds to the 36-km SMAP pixel used in the calibration and validation exercise during the pre- and post-launch of SMAP (Figure 2).

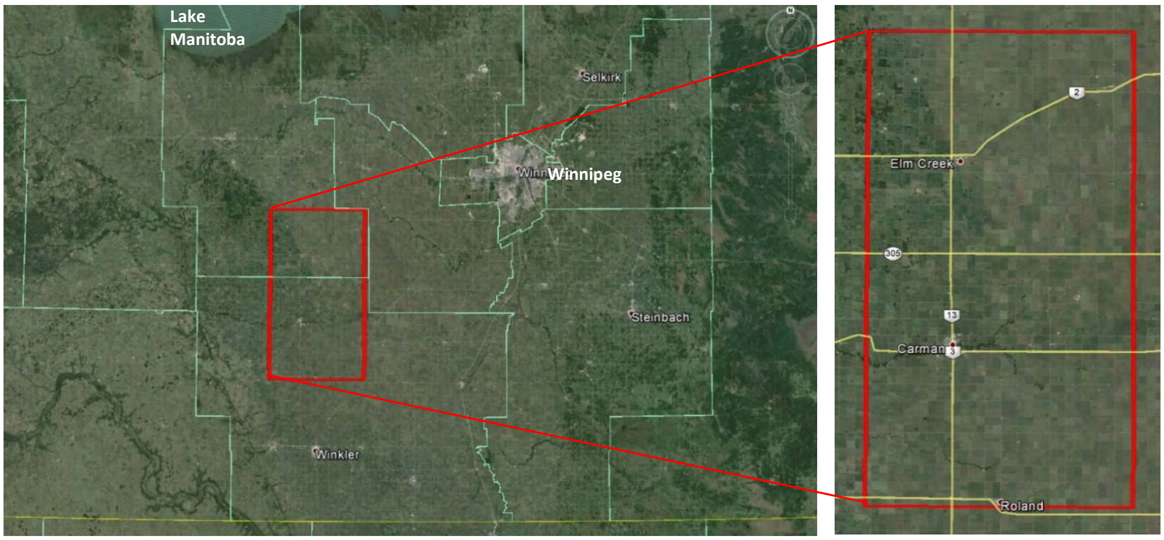


Figure 2. Location of SMAPVEX intensive site relative to Winnipeg

The site dimensions are approximately 26 km x 48 km. According to the Manitoba Agricultural Services Corporation (MASC) Crop Insurance data, more the 85% of the sites is dominated by the following annual crops: canola, soybeans, wheat, corn oats, winter wheat and beans. Only a small fraction (< 5%) is under grassland and pasture. The crop type distribution within the SMAP region of interest is described in Table 1. Figure 3 provides the 2015 crop map.

Table 1. 2015 crop type distribution within the SMAP pixel

Crop Type	Percent Area (%)
Soybeans	29.88
Spring wheat	24.12
Canola/Rapeseed	18.24
Corn	8.28
Oats	6.92
Deciduous Forest	2.29
Grassland	1.96
Beans	1.50
Winter wheat	1.41
Sunflower	1.12
Others	4.28

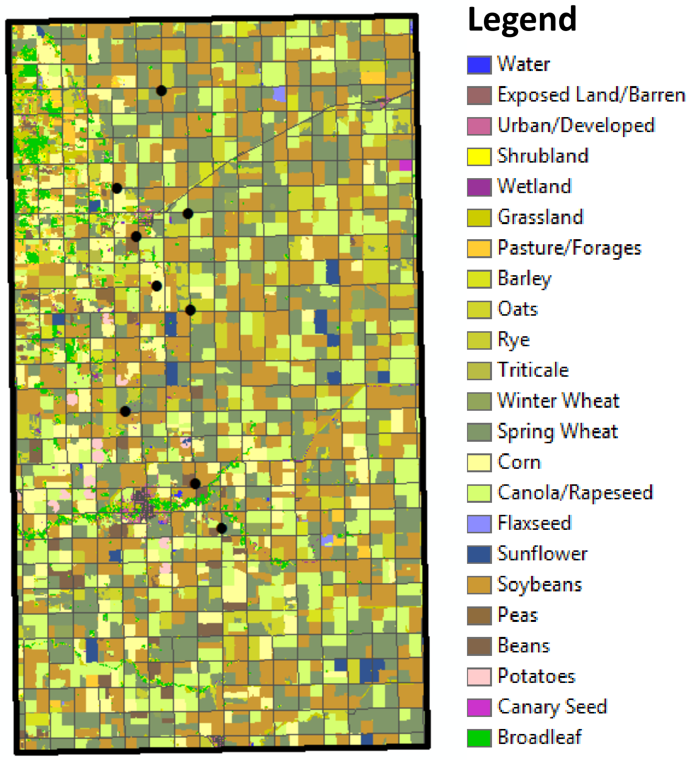


Figure 3. The SMAPVEX16-MB intensive sample site. The land cover and crop types for 2015 are displayed. The AAFC RISMA sites are identified as black dots.

2.3. AAFC In Situ Soil Moisture Network (RISMA)

In 2011, AAFC began installing an in situ soil moisture monitoring network in and around Carman-Elm Creek. The RISMA (Real-time In-situ Soil Monitoring for Agriculture) network, was established to provide a direct source of near-real time information on soil moisture conditions in an agriculturally risk-prone watershed, and to provide a data set that can be used holistically with remotely-sensed and modelled data products for calibration and validation of models. The network was designed to capture the maximum soil variability within the Red River watershed, with the specific location of the sensors established along a gradient of soil texture classes (Figure 4).

The network consists of nine in situ monitoring stations distributed proportionally to be representative of the different soil texture classes. Sites were selected based on soil texture variability, willingness to cooperate from local producers and soil survey by regional soil experts. Each station is instrumented with Stevens' Hydra Probes which measures soil dielectric, soil moisture and soil temperature, with triplicate measurements of the soil properties at each depth. This redundancy was applied to ensure critical variables would continue to be captured in the event of sensor failure, and to provide an indication of the within site variability in moisture conditions. Soil moisture and temperature are measured horizontally at depths of 5, 20, 50 and 100 cm, with an additional three probes place vertically at the surface to capture integrated surface soil moisture over a 6cm depth (Figure 5). Meteorological observations are also captured at each station including liquid precipitation, air temperature, relative humidity, wind speed and wind direction. Sites are instrumented with Hoskin Scientific tipping bucket rain gauges, and Geneq sensors for all other meteorological parameters, and powered by solar panels and batteries (Figure 6). Data are recorded on Campbell Scientific CR1000-XT data loggers and transmitted to AAFC through Raven X modems on the hour mark. Measurements are collected on a 15-minute time frequency for all variables. Data can be viewed and downloaded online in near real-time by accessing the following link: http://aafc.fieldvision.ca./.

All AAFC sites are located within or on the edge of cultivated agricultural fields, with the system set up to capture data (when valid) year round without removal of equipment required due to land management activities. During installation, soil cores were collected at the location of each probe installation and preserved for soil moisture dry down calculation, soil texture and bulk density analysis. Site specific soil moisture dielectric conversion models have been developed using field calibration (Ojo et al., 2015). These calibration models have been applied to each sensor to obtain higher accuracy soil moisture values.

Ojo, E. R., Bullock, P. R., L'Heureux, J., Powers, J., McNairn, H., and Pacheco, A. (2015). "Calibration and Evaluation of a Frequency Domain Reflectometry Sensor for Real-Time Soil Moisture Monitoring", Vadose Zone Journal, Vol. 14 no. 3.

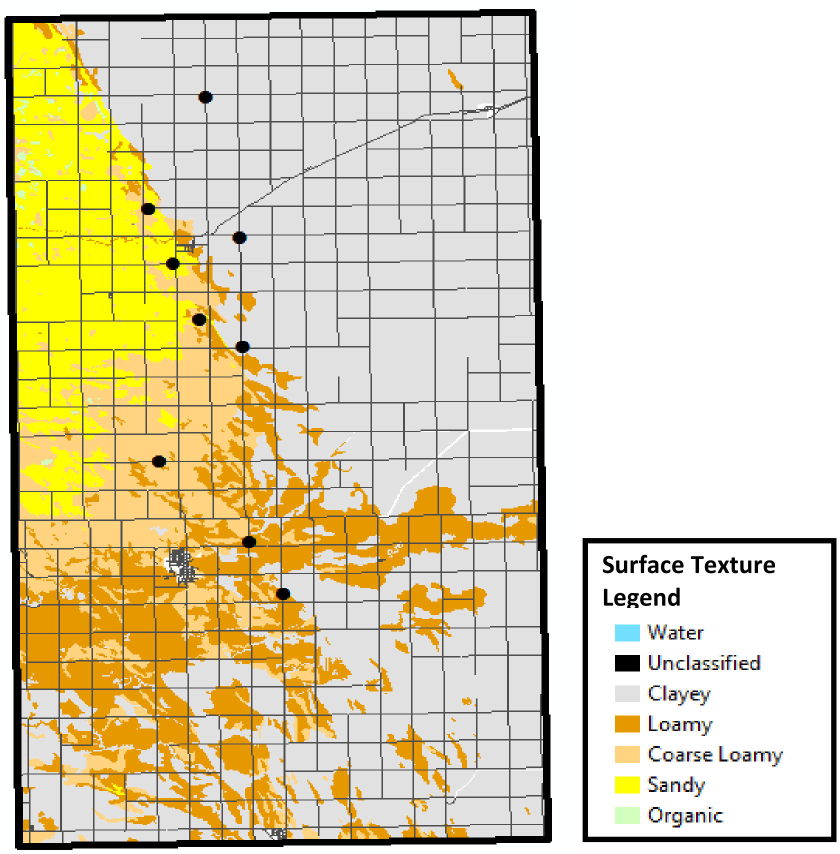


Figure 4. Location of the AAFC RISMA network in Manitoba (black dots). Backdrop image shows clay dominated soils on the eastern portion of the watershed and sandier soils on the western portion of the watershed.

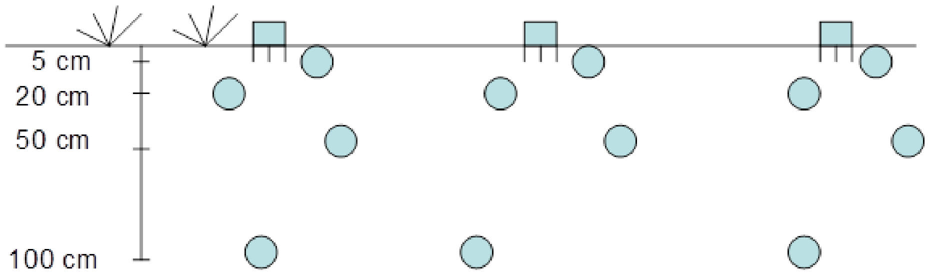


Figure 5. Schematic of probe location within each soil pit for AAFC RISMA sites.

Figure 6. Site installation for AAFC in situ soil moisture sites.

2.4. Temporary In Situ Soil Moisture Network

Previous work has demonstrated the utility of installing short term networks to temporarily increase the spatial resolution of a network. This provides a scaling period which will enable a network manager to provide a more accurate error statistic for the network and scaling functions for improving the representative character of the in situ network. Small soil moisture stations (see Figure 7) will be deployed within field sites throughout the domain in the early summer and record hourly soil moisture and soil temperature data. These stations will be low profile and solar power operated. Approximately 40 stations will be deployed in the region. These will provide a convenient alternative to field sampling which can introduce additional errors.

Figure 7. Example of temporary stations installed with a solar panel and CR206 logger. A Stevens Hydra Probe and a CS655 reflectometer are installed at a depth of 5 cm to mimic the long term in situ station.

2.5. Other Agriculture Weather Networks

2.5.1. Manitoba Agriculture, Food and Rural Development (MAFRD) Agriculture Weather Network

Manitoba Agriculture, Food and Rural Development (MAFRD) provide weather-related information and value-added tools to producers in Manitoba via the Manitoba Agriculture Weather Program (MAWP). The province of Manitoba currently operates approximately 63 automated near real-time weather stations. The program will undergo an expansion in the next several years with the addition of another 30 stations. The expansion will include retrofitting all current stations with soil moisture and temperature monitoring capability at 5 and 20 cm depths. The University of Manitoba, through Dr. Paul Bullock, has contributed Stevens Hydra probes for soil moisture monitoring at the Treherne, Carman and St. Adolphe locations of this network. A map (Figure 8) below demonstrates the distribution of the network in the south central portion of Manitoba.

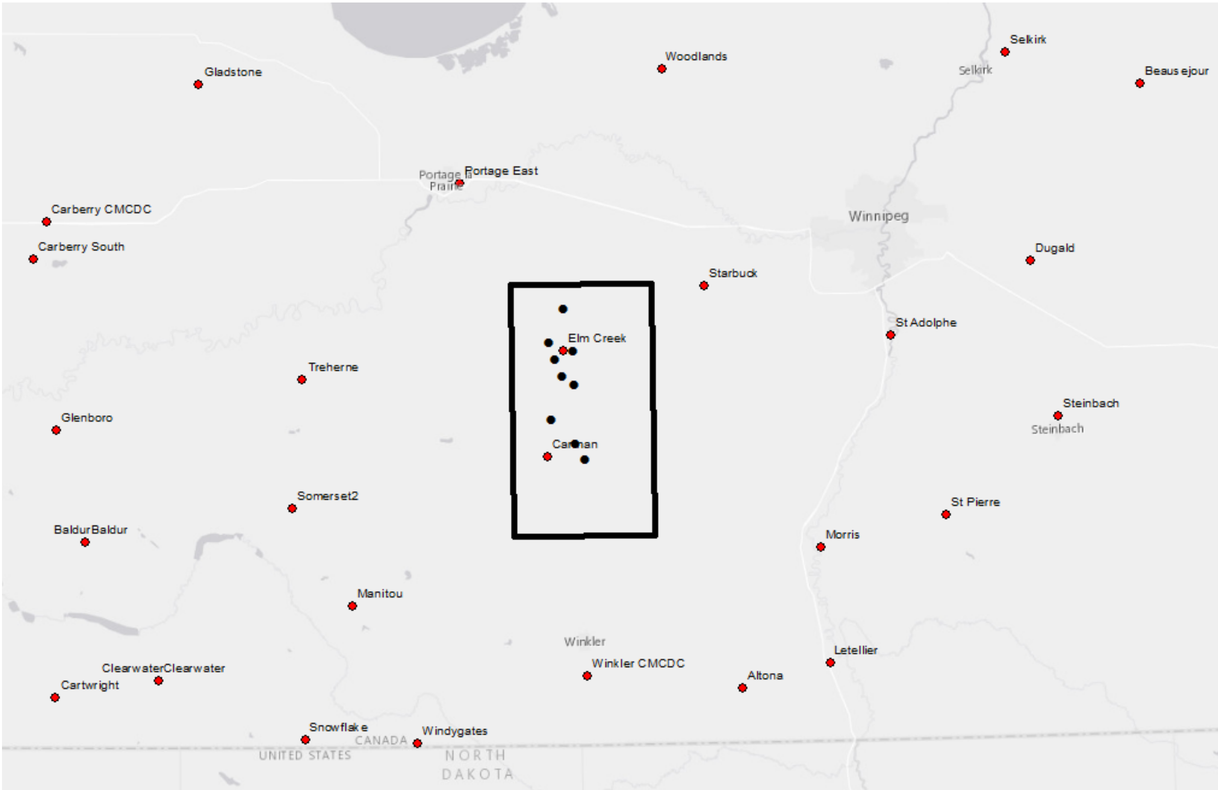


Figure 8. Distribution of the Manitoba Agriculture, Food and Rural Development (MAFRD) agriculture weather monitoring stations in the south central portion of Manitoba.

The Carman (49.498 N, -98.030 W) and Elm Creek stations are of particular interest given that they are located within the SMAP footprint. The Carman station, in particular, collects various meteorological parameters including air temperature, relative humidity, liquid precipitation, solar radiation, and wind speed and direction. This station is also instrumented with single Stevens Hydra probes at various depths: 5-, 20-, 50- and 100-cm depths (Figure 5), which outputs soil moisture (default calibration), soil temperature, imaginary and real dielectric permittivity. Similar to the RISMA network, the Carman station is equipped with a Campbell Scientific CR1000 data logger where data is recorded and sent wirelessly to the server via a modem. The stations' sensors record data every 5 seconds and this data is then processed into 15-minute data, hourly data and daily (24 hour) data. Data from the stations are currently being shared with the public in form of an hourly-updated image file that shows current conditions (http://www.gov.mb.ca/agriculture/weather/current-ag-weather-conditions.html) as well as basic tabular output of a few variables (http://tgs.gov.mb.ca/climate/DailyReport.aspx).

2.5.2. Environment Canada Weather Network

Several meteorological stations are located within the agricultural regions of Manitoba, which are part of the Environment Canada weather network. Most stations record typical meteorological variables including air temperature, total precipitation, wind speed and direction, and relative humidity, with others collecting additional data on dew point temperature, net radiation, snow accumulation and soil temperature. Environment Canada data can be downloaded from their website (http://climate.weatheroffice.gc.ca/climateData/canada_e.html) by locating specific climate stations through their query tool. The map below (Figure 9) illustrates the distribution of the weather stations established by Environment Canada in southern central Manitoba.

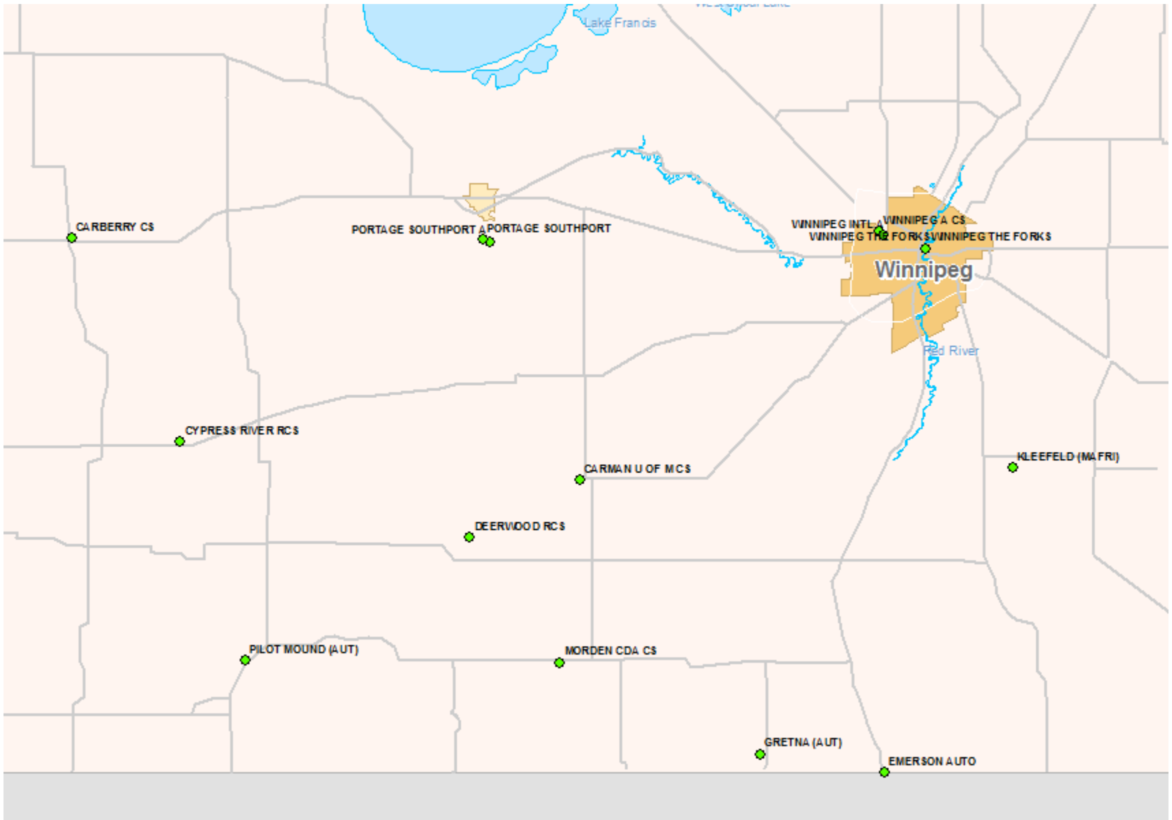


Figure 9. Distribution of the Environment Canada weather stations located in southern central Manitoba.

2.6. Ancillary Datasets

2.6.1. Digital Elevation Modelled Data

Digital elevation model (DEM) data for the area is available from a number of sources including the Natural Resources Canada's (NRCan) products such as the Canadian Digital Elevation Data (CDED) and the Canadian Digital Elevation Model (CDEM). Other DEMs were generated from specific satellite missions including the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) and the Shuttle Radar Topography Mission (SRTM).

The CDED is produced by NRCan and is extracted from the hypsographic and hydrographic elements of the National Topographic Data Base (NTDB). The CDED data is available in 23 metre (1:50 000) and 93 metre (1:250 000) spatial resolutions, with 10m vertical accuracy for the 23-m dataset. Data are freely available and can be downloaded from Natural Resources Canada's GeoGratis portal (http://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/free-data-geogratis/11042). The CDED product is however no longer supported by

NRCan and elevation data users are encouraged to employ the CDEM instead. The CDEM stems from the existing CDED but elevation information were derived from either ground or reflective surface elevations. A mosaic can be obtained for a pre-defined or user-defined extent, where coverage and resolution of the mosaic will vary on the latitude and to the extent of the requested area. Derived products such as slope, shaded relief and colour shaded relief maps can also be generated on demand. Various spatial resolutions can be obtained for the CDEM including 20-, 50-, 90-, 200- and 400-m.

The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) jointly produced the ASTER GDEM V2 dataset. This product was released in 2011 and is an improved version of the original product ASTER GDEM (released in 2009) which was generated using stereo-pair images collected by the ASTER instrument onboard Terra. The GDEM V2 has improved coverage and reduced occurrence of artifacts. The refined production algorithm provides enhanced spatial resolution, improved horizontal and vertical accuracy, and refined water body coverage and detection. The ASTER GDEM V2 is available in GeoTIFF format at 30-m spatial resolution with a 7- to 14-m vertical accuracy (Figure 10). The product can be downloaded free of charge to users worldwide from the Land Processes Distributed Active Archive Center (LP DAAC).

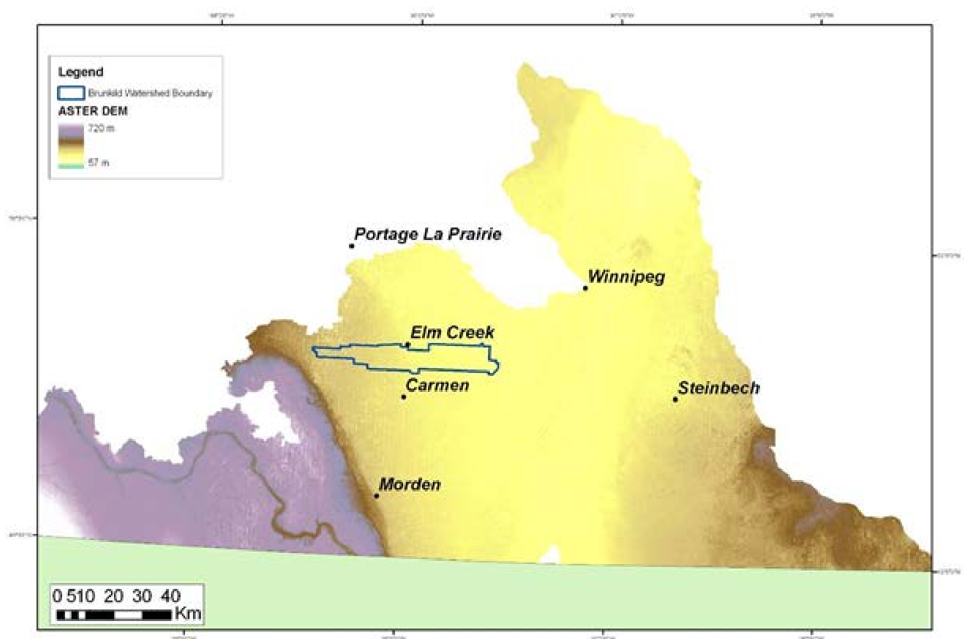


Figure 10. Digital Elevation Model data from the ASTER GDEM project for the Red River Watershed.

The Shuttle Radar Topography Mission has recently released an enhanced 30-m DEM in late 2015. This mission was an international effort led in 2000 by the U.S. National Geospatial-Intelligence Agency (NGA) and NASA. Interferometric synthetic aperture radar was used to obtain elevation data. Lower-resolution elevation data at 90-m were first released in 2003 for several parts of the world. The elevation data are configured into tiles, each covering one degree of latitude and one degree of longitude, labeled according to their south western corners. The absolute accuracy of the DEM is less than 16-m (whereas the relative accuracy is less than 10-m. The data are available for download from the USGS EROS Data Center (http://eros.usgs.gov/).

2.6.2. Soils Data

Soils data for the area are available from the AAFC Soil Landscapes of Canada (SLC) polygon data set. These are based on soil and topographic survey compiled at a 1:1 million scale. Each soil polygon may contain one or more distinct soil landscape components. Each SLC polygon contains information for each horizon on horizon depth, soil texture, soil organic carbon, pH, base saturation, cation exchange capacity, saturated hydraulic conductivity, water retention at saturation, field capacity and wilting point, bulk density, electrical conductivity, calcium carbonate equivalent and decomposition (Von Post). Information on landscape position (slope, aspect), soil drainage class, parent material, and soil classification are also provided for each polygon. These data are currently available through the Canadian Soil Information Service (CanSIS) via AAFC Agri-Geomatics (http://sis.agr.gc.ca/cansis/). AAFC is currently working on converting key soil attribute data from the SLC polygons to a raster data set to facilitate integration into modeling activities. Provincial soil surveys are available at higher spatial resolutions for selected areas within the province.

For the Carman area, the AAFC soil data is available from the Soil Landscapes of Canada v3.2 map and databases published at a scale of 1:10 km (Figure 4). Each map polygon lists up to 10 different soil types and their proportional occurrence over the area of the polygon. Given that soil attributes are stored in the national soil database by soil horizons of varying thickness, these values were fit to a standardized depth interval of 0–5 cm depth using an equal area spline function as described in. These standardized depth interval values were then downscaled to a 90-m grid by simple polygon weighted averaging based on the proportional occurrence of each soil in the polygon.

2.6.3. Land Cover and Crop Data

AAFC has developed a Decision Tree-based methodology to map crop types over Canadian agricultural landscapes by integrating optical and synthetic aperture radar (SAR) imagery (Figure 11). In 2009, the Earth Observation Team of the Science and Technology Branch (STB) at AAFC began delivering annual crop type digital maps on an operational basis over the Prairies. Starting in 2011, the crop mapping activity has been extended to other provinces in support of a national crop inventory. The approach has consistently generated a crop inventory that meets the overall target accuracy of at least 85% at a 30-m spatial resolution (56m in 2009 and 2010). The annual crop inventories are available in GeoTIF format and typically delivered before April following the growing season. Land cover data are also included in the crop inventory dataset, which includes annual and perennial agricultural land, as well as native grassland, forest, wetland and urban areas within the agricultural extent. The data are available on the Government of Canada Open Portal at the following link: http://open.canada.ca/data/en/dataset/ba2645d5-4458-414d-b196-6303ac06c1c9.

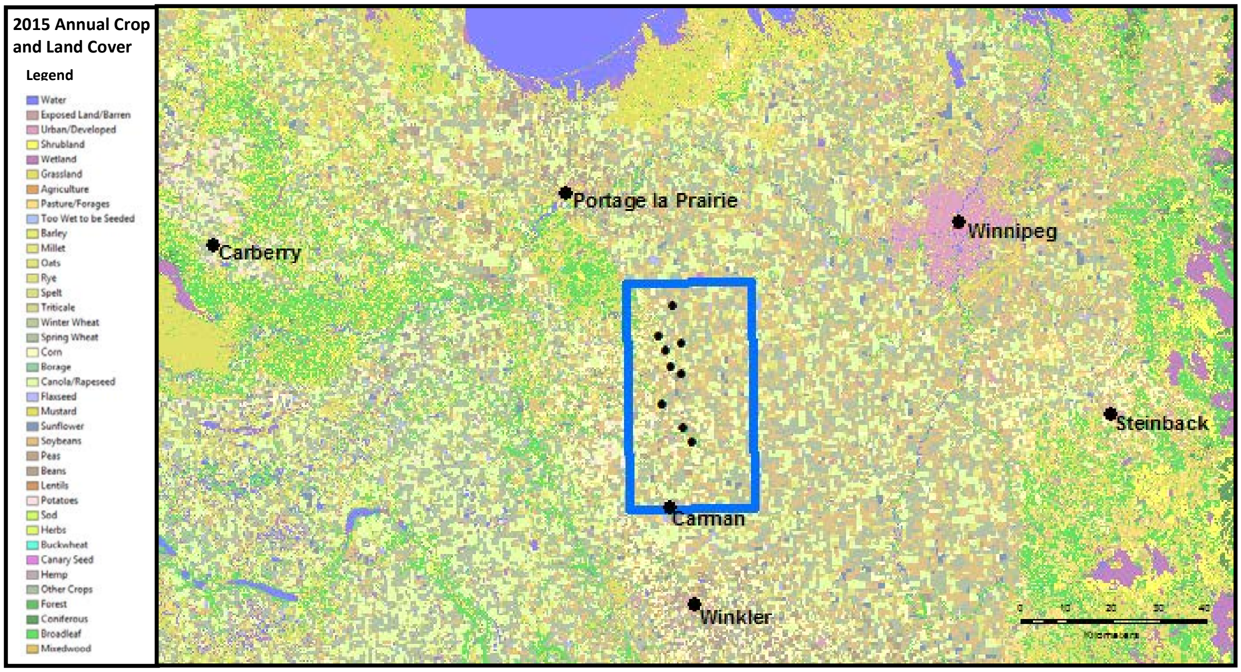


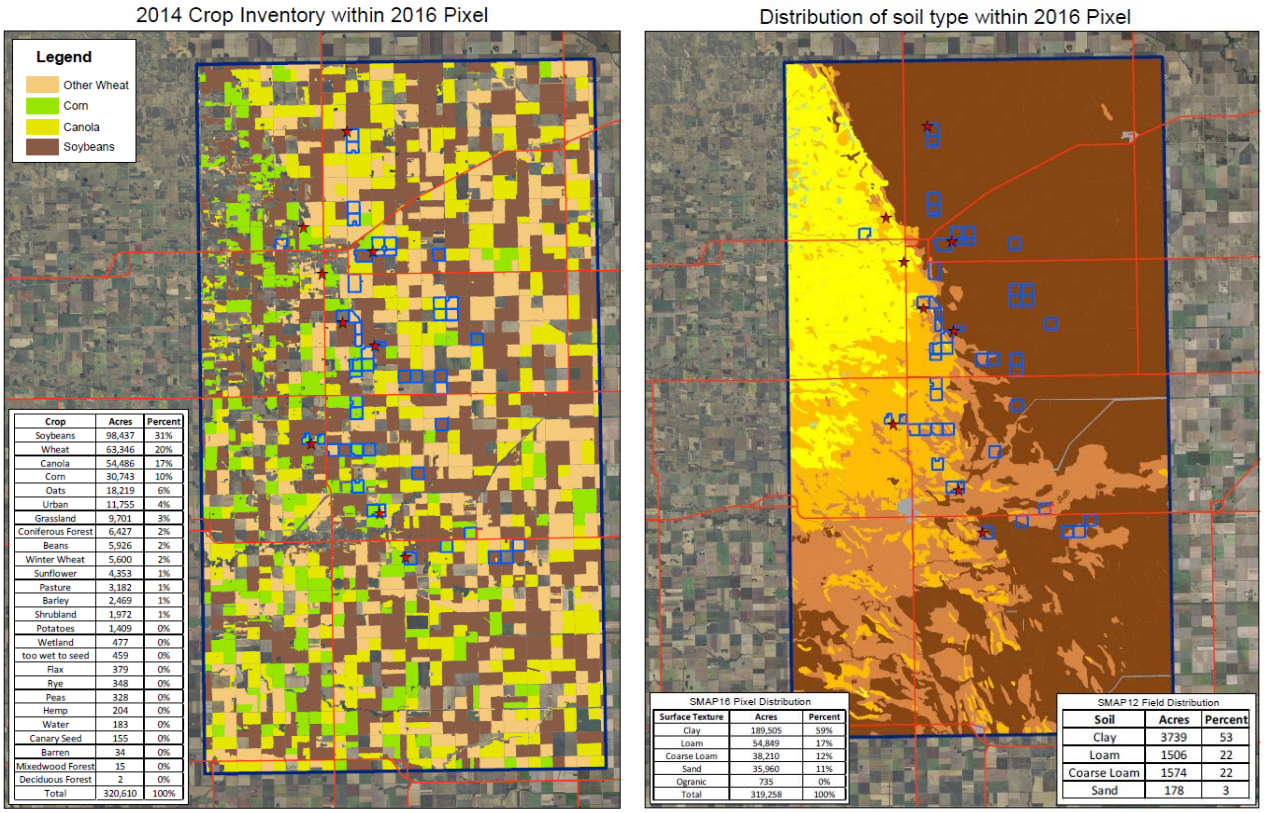
Figure 11. Agricultural land cover/annual crop types for central southern Manitoba. The SMAPVEX16-MB intensive sample site is outlined in blue and the AAFC RISMA sites are identified as black dots.

2.7. Selected sampling fields

In order to ensure field sampling will properly address the research objectives, the selection of fields to be sampled must be representative of surface soil textural conditions and annual crop production within the SMAP pixel (Figure 12). Approximately 50 fields will be selected for sampling during the campaign. The proposed breakdown according to crop type is as follows:

- Soybeans – 15 fields
- Canola – 11 fields
- Wheat – 11 fields
- Corn – 5 fields
- Oats – 3 fields
- Winter Wheat – 2 fields
- Beans – 1 field
- Forage/Grassland – 2 fields

Permissions were secured under contracts with producers, whereby producers will be financially compensated for crop losses as a result of the field sampling. Figure 12 provides the locations of the fields selected for SMAPVEX16-MB. Producers were asked what crops they were planning to seed, and the planned crop types are indicated as well in Figure 13.



Crop	Acres	Percent
Soybeans	98,437	31%
Wheat	63,346	20%
Canola	54,486	17%
Corn	30,743	10%
Oats	18,219	6%
Urban	11,755	4%
Grassland	9,701	3%
Coniferous Forest	6,427	2%
Beans	5,926	2%
Winter Wheat	5,600	2%
Sunflower	4,353	1%
Pasture	3,182	1%
Barley	2,469	1%
Shrubland	1,972	1%
Potatoes	1,409	0%
Wetland	477	0%
too wet to seed	459	0%
Flax	379	0%
Rye	348	0%
Peas	328	0%
Hemp	204	0%
Water	183	0%
Canary Seed	155	0%
Barren	34	0%
Mixedwood Forest	15	0%
Deciduous Forest	2	0%
Total	320,610	100%

SMAP16 Pixel Distribution

Surface Texture	Acres	Percent
Clay	189,505	59%
Loam	54,849	17%
Coarse Loam	38,210	12%
Sand	35,960	11%
Ogranic	735	0%
Total	319,258	100%

SMAP12 Field Distribution

Soil	Acres	Percent
Clay	3739	53
Loam	1506	22
Coarse Loam	1574	22
Sand	178	3

Figure 12. Location of proposed 50 SMAPVEX16 fields (blue boxes) superimposed on 2014 crop map (left) and soil of soil texture (right).

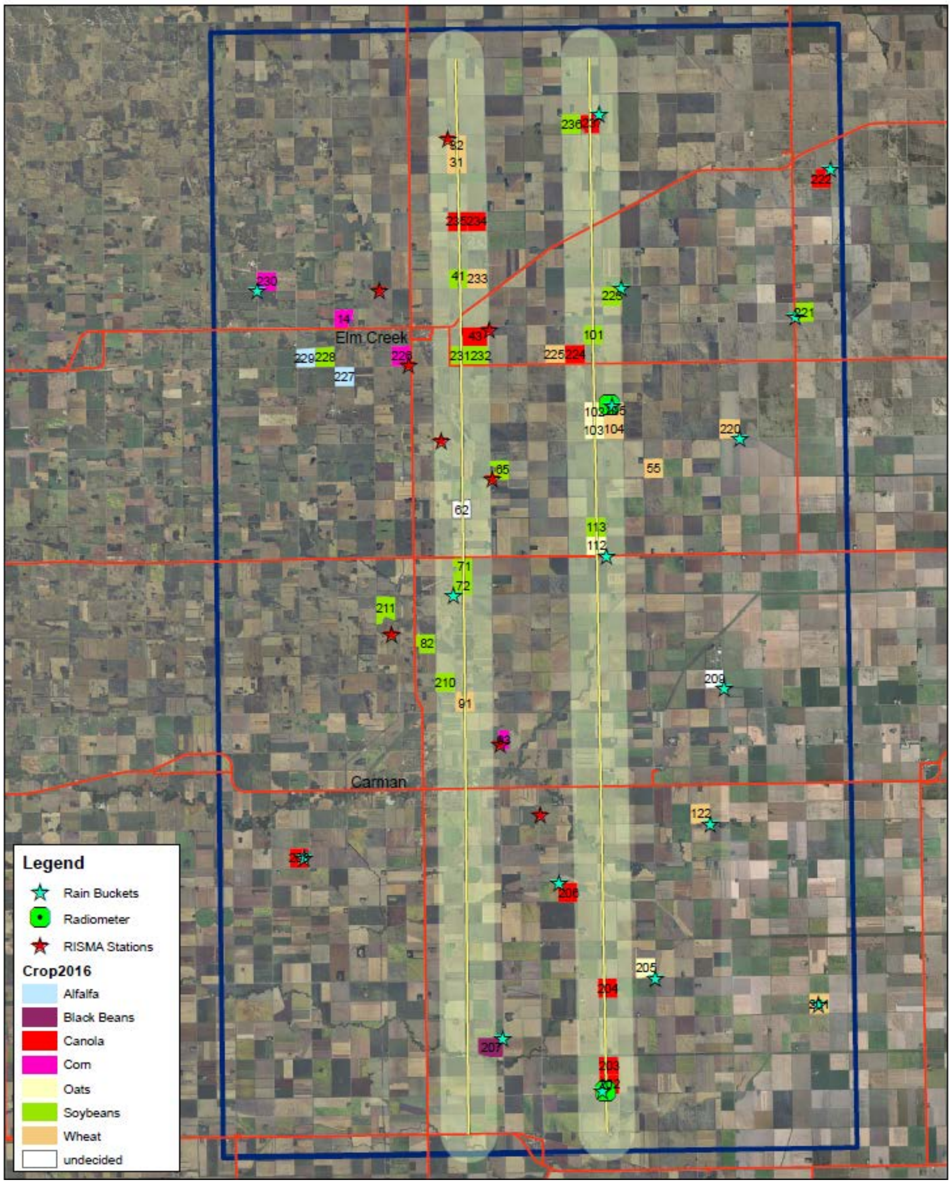


Figure 13. Location of SMAPVEX16 fields with planned crop type for each field

3. Overview of measurement instruments

3.1. Ground instrument specifications

Soil moisture measurements during the campaign will be made continuously through in situ network stations (permanent and temporary), as well as through in field measurements made intensively by field crews during the SMAPVEX campaign.

3.1.1. Description of instruments

Field measurements of soil moisture will be made using the Stephen's Hydra probes (POGO). These probes are based on coaxial impedance dielectric reflectrometry and use an oscillator to generate an electromagnetic signal at 50 MHz that is propagated through three metal tines into the soil. The part of the signal that is reflected back to the unit is measured in volts and is used to solve numerically Maxwell's equations to calculate the impedance and the real and imaginary dielectric permittivities. Real dielectric permittivity can be related to soil moisture using empirical relationships between dielectric and moisture or using physically based dielectric mixing models. Instantaneous measurements can be acquired over a 6 cm depth from the surface when the probe in inserted vertically. A default soil dielectric conversion model is applied based on soil texture classes, with an accuracy of +/- 3% volumetric soil moisture. Improved calibration of instrument soil moisture will be accomplished using site specific texture information. As in SMAPVEX12, custom calibration models will be calculated using reference to gravimetric soil moisture samples collected periodically during the field campaign.

Soil roughness measurements can be made using a portable pin profilometer (Figure 14) that uses surface displacement and post processing techniques to obtain root mean square roughness (rms) and roughness correlation length. These devices are custom built using metal pins with tips coated in red material, a wooden board painted white, a set of legs to support the board and a mechanism to release pins for surface displacement. A retractable metal bar can be mounted to the board to hold a standard digital camera to take a picture of the roughness profile once it is in place. Boards are typically 1 to 2 m in length and typically three measurements are made side by side to capture a longer roughness profile. Roughness measurements can be made to capture oriented surface roughness (perpendicular to tillage structure in agricultural fields) or sensor specific roughness by aligning the profilometer parallel to the look direction of the microwave sensor. Photos obtained in the field can be post-processed using a Matlab routine to obtain the roughness parameters.

Figure 14. Capturing surface roughness with the roughness profilometer.

The Crop Scan instrument is a multi-spectral optical radiometer that measures reflected solar radiation from the crop canopy. The instrument is mounted on a pole and held above the canopy to collect nadir views of reflected solar radiation at spectral bands defined by the instrument model and the filters used. The radiometer has both upward and downward sensors to capture incoming solar radiation to the sensor as well as the energy reflected from the canopy. Measurements must be taken in full sun, ideally within 2 hours of solar noon.

The Crop Scan will provide spectrally detailed measurements at one site in each field. To complement these measurements, the University of Manitoba will also fly a drone-mounted Micasense RedEdge 3 multispectral camera. The drone will be capable of acquiring an image for the footprint of each of the SMAPVEX16 sample fields. These above canopy reflectance measurements will characterize the general crop condition and growth state in a number of optical and infrared wavelengths, over the entire field.

Leaf area index (LAI) can be measured using digital hemispherical photographs. With this technique a wide-angle or fisheye lens captures all sky directions at the same time. When canopies are small, the photos are taken with the lens pointed towards the ground. For tall canopies, the camera is placed on the ground looking skyward. The fisheye photos record the geometry of the plant canopy obstructing the field of view of the soil or sky. An advantage of this method relative to other in situ approaches (such as the LAI2000) is that the data capture is much less sensitive to sky conditions. Plant canopy analyzers such as the LAI2000 require diffuse sky conditions, restricting data capture to early morning or evening collection or collection under consistent overcast conditions. As well, high errors will occur when attempting to capture the LAI of very short vegetation (or early emerging vegetation) as the distance from the lens to the canopy is too small. The fisheye photos are post-processed using the Caneye software to provide an estimate of LAI.

3.1.2. Inventory of ground instruments and laboratory facilities

Table 2 provides a listing of major equipment required for SMAPVEX16-MB. The table also indicates contributions to this equipment by the SMAPVEX team, to date.

Table 2. List of ground instruments available for SMAPVEX

	AAFC (Ottawa + Winnipeg)	Université Sherbrooke	University of Guelph	University of Manitoba	George Masson University	EC	USDA	NASA
Hand held Hydra Probe (Stevens Pogo)	1		3	10				
Temporary in situ stations	12						40	
Cropscan	2		1					
Apogee IR Sensors	4				1			5
Garmin GPS units	14							
LAI camera + FishEye + poles	5							
Digital cameras	3							
Roughness pin profiler	2	2	1			1		
Balance - soils	1			1				
Balance - biomass	1							
Drying ovens for soils	1			2				
Ground-based Radiometer		1				1		
Ground-based Scatterometer		1 (contracted from U. of Calgary)						
Hydrologic Services TB4 precip bucket	12 temporary in situ stations					5		
Extech Pocket FoldUp Thermometer	13							
Reed IR Thermometer	6							

3.2. Aircraft PALS instrument

The Passive/Active L-band Sensor (PALS) provides radiometer products, vertically and horizontally polarized brightness temperatures, and radar products, normalized radar backscatter cross-section for V- transmit/V-receive, V-transmit/H-receive, H-transmit/H-receive, and H-transmit/V-receive. In addition, it can also provide the polarimetric third Stokes parameter measurement for the radiometer and the complex correlation between any two of the polarized radar echoes (VV, HH, HV and VH). Table 3 provides the key characteristics of PALS.

Table 3. Description of PALS

Instrument		Passive/Active L-band Sensor (PALS)
Owner		Jet Propulsion Laboratory (USA)
Platform		DC-3
Passive	**Frequencies**	1.413 GHz
	Polarizations	V, H, +45, -45 polarizations
	Spatial Resolution	20 degrees (3 dB beamwidth in Deg.)
Active	**Frequencies**	1.26 GHz
	Polarizations	VV, HH, VH, HV
	Spatial Resolution	20 degrees
Scan Type		360°
Antenna Type		Microstrip planar antenna with >30 dB polarization isolation
POC/Website		Simon.Yueh@jpl.nasa.gov

The planar antenna consists of 16 stacked-patch microstrip elements arranged in a four by- four array configurations. The measured antenna pattern shows better than 33 dB polarization isolation, exceeding the need for the polarimetric measurement capability. The antenna is shielded by a radome to allow conical scanning during flight.

PALS will be mounted at a 40° incidence angle for a 360° conical scanning operation (Figure 15). The 3dB spatial resolution of the instrument will be ~ 0.35*altitude above ground along-scan. PALS will acquire data at two elevations during SMAPVEX16 (Low and High). The lowest elevation that PALS can operate at is determined by the minimum distance for radar data acquisition, which is 1067 m (3500 feet) AGL. The nominal elevation in this region is 305 m (1000 feet) ASL. Flight altitude for the low altitude flights was chosen to be 1200 m (about 4000 feet) AGL i.e. 1505 (about 5000 feet) ASL. The highest flight altitude for SMAPVEX was determined by the maximum where the instrument has operated without any issues (and for not requiring oxygen use by the flight crew); 3350 m (11000 feet) ASL, i.e., 3050 m (10000 feet) AGL. The spatial resolutions at these two flight altitudes are summarized in Table 4.

Figure 15. The PALS instrument mounted on the DC-3

Table 4. Geometric features of PALS data acquisitions.

Target Altitude (m)	Nominal Ground Elevation (m)	ASL (m)	Along Scan Resolution (m)	Across Scan Resolution (m)	Effective Resolution (m)
1200	305	1505	581	777	**595**
3050	305	3355	1476	1974	**1513**

The PALS flight lines were designed to satisfy the major objectives of SMAPVEX16. Low altitude lines will be used to provide high spatial resolution data for fields/sites with homogeneous vegetation conditions. Sampling sites will be located directly within the swath of these lines, to the degree possible. Since the nominal field size in the region is 800 m by 800 m, flying these at the low altitude (Table 4) should provide the data necessary for algorithm development and validation. Two lines were designed and locations are listed in Table 5; they cover a range of agricultural conditions.

The high altitude lines will map the SMAP grid pixel for investigating SMAP radiometer sub-pixel features. A total of six lines will cover a domain ~27 by 48 km. Lines are spaced ~ 4.5 km apart.

The preliminary flight plan is shown in Table 5. Please note that this plan may change once on site due to local aircraft traffic control, radio frequency interference sources, and refined flight planning to reduce total mission duration.

The PALS will be augmented with additional components designed to detect and mitigate Radio Frequency Interference (RFI).

Table 5. PALS DC-3 Flight Plan

		START		STOP	
	Altitude AGL	**Latitude (Deg.)**	**Longitude (Deg.)**	**Latitude (Deg.)**	**Longitude (Deg.)**
Take off Winnipeg					
MB01	10,000 ft.	49.3618	-98.0881	49.7973	-98.0881
MB02	10,000 ft.	49.7973	-98.0275	49.3618	-98.0275
MB02	10,000 ft.	49.7973	-98.0275	49.3618	-98.0275
MB03	10,000 ft.	49.3618	-97.9668	49.7973	-97.9668
MB04	10,000 ft.	49.7973	-97.9062	49.3618	-97.9062
MB05	10,000 ft.	49.3618	-97.8455	49.7973	-97.8455
MBL01	4,000 ft.	49.7830	-97.9770	49.3700	-97.9770
MBL02	4,000 ft.	49.3700	-97.9870	49.7830	-97.9870
Return to Winnipeg					

3.3. Ground-based Radiometer and Scatterometer Measurements

Two L-band ground based radiometers (one from the University of Sherbrooke and one from Environment Canada) will be deployed during SMAPVEX16-MB. As well, Dr. Chris Fuller will be contracted to deploy a ground based C-band scatterometer owned by the University of Calgary. Of the 50 SMAPVEX16-MB fields, two have been selected for radiometer and scatterometer measurements – one field of canola and one field of wheat. These crop types were selected to complement a sister SMAPVEX16 campaign occurring in Iowa where radiometer and scatterometer measurements are being collected over soybeans and corn.

3.3.1. Radiometer measurements

The University of Sherbrooke radiometer will be installed in one field, while the EC radiometer will be installed in the other. Both instruments will be left in place from the beginning of the first SMAPVEX16-MB window to the end of the second window. However, measurements will not be collected during the period between window 1 and window 2.

Daily multi-angular observations of TBH and TBV from .30 to 60° with an increment of 5° (~ 1h30 per field) will be collected on the canola and wheat fields and then the instruments will be left to measure at only 40°. Calibration will occur every 2-3 days or before the multi-angular observations (for a few minutes). A temporary in situ station will be installed inside the radiometer footprint (Figure 16 and Figure 17) to collect soil moisture, soil temperature and air temperature measurements. These will be supplemented with additional hand-held measurements during soil moisture sampling days. Soil roughness (once) and vegetation (twice per week) will also be collected around the footprint.

When SMOS PM acquisitions are available, multi-angular measurements will be collected in order to analyze the diurnal variation of surface characteristics (vegetation, soil moisture) on the signal. This will require the collection of soil moisture, soil temperature and vegetation water content at the same time. Dates for the first window include: June-08, June-10, June-11, June-

13, June-14, June-16, June-18, June-19, and June-21; for the second window: Jul-11, Jul-12, Jul-14, Jul-16, Jul-17, Jul-19, Jul-20, Jul-22 21.

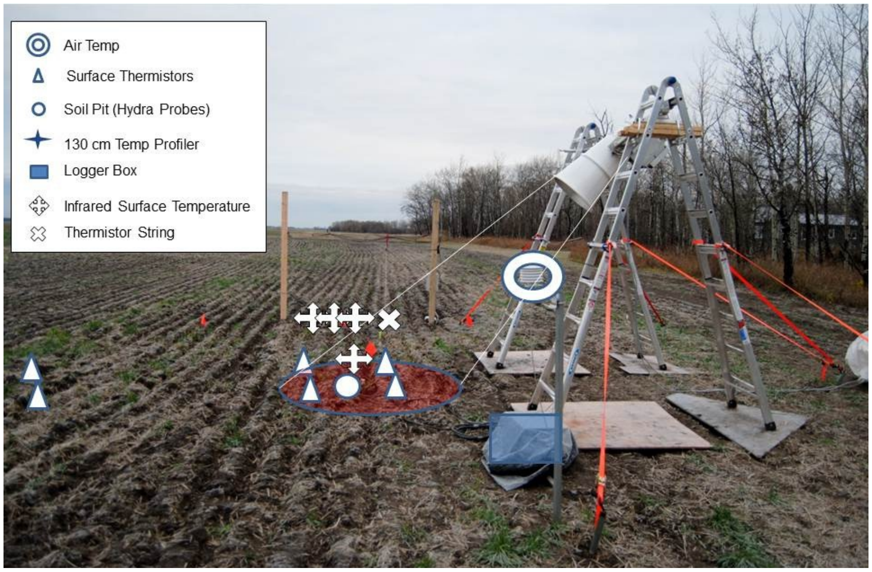


Figure 16. University of Sherbrooke radiometer site photo with approximate location of the instruments/sensors recording the soil and meteorological conditions in and around the footprint. The approximate footprint size of the -3 dB 40 degree footprint is illustrated with the red shaded ellipse. Source : SLAP Freeze/Thaw Validation Experiment 2015 Surface-Based Radiometer Data Documentation (P. Toose and A. Roy, 2015)

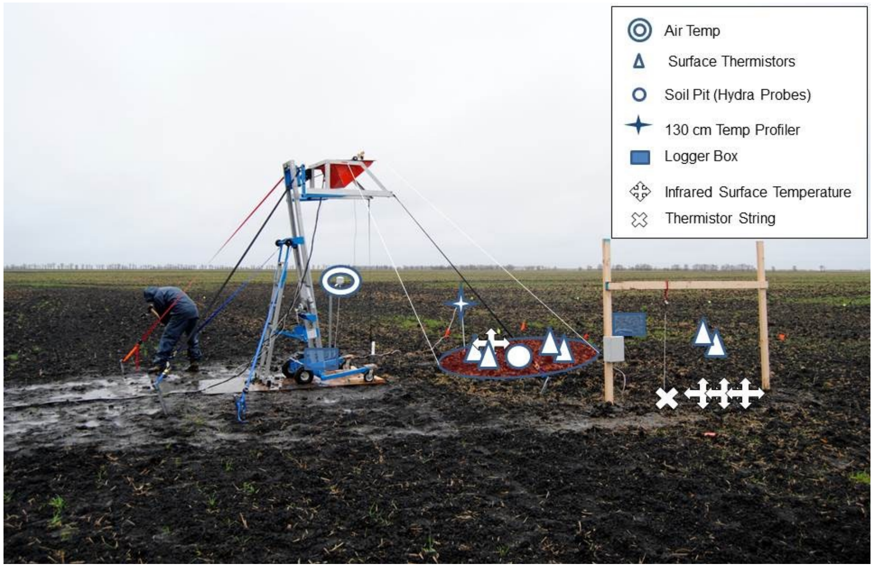


Figure 17. Environment Canada radiometer site photo with approximate location of the instruments/sensors recording the soil and meteorological conditions in and around the footprint. The approximate footprint size of the -3 dB 40 degree footprint is illustrated with the red shaded ellipse. Source : SLAP Freeze/Thaw Validation Experiment 2015 Surface-Based Radiometer Data Documentation (P. Toose and A. Roy, 2015)

The radiometer footprint varies with incidence angle and the variation in size and location are captured in Table 6 and Figure 18.

Table 6. EC Radiometer footprint size (meters) at various angles of incidence. The 40 degree incidence used for the long term continuous data acquisition is highlighted in yellow. Source : SLAP Freeze/Thaw Validation Experiment 2015 Surface-Based Radiometer Data Documentation (P. Toose and A. Roy, 2015)

Measured Angle (degrees)	Height Above Ground (meters)	Width	Depth
30	2.75	1.7	2.0
35		1.9	2.3
40		**2.0**	**2.6**
45		2.3	3.2
50		2.6	4.0
55		3.0	5.3
60		3.8	7.5

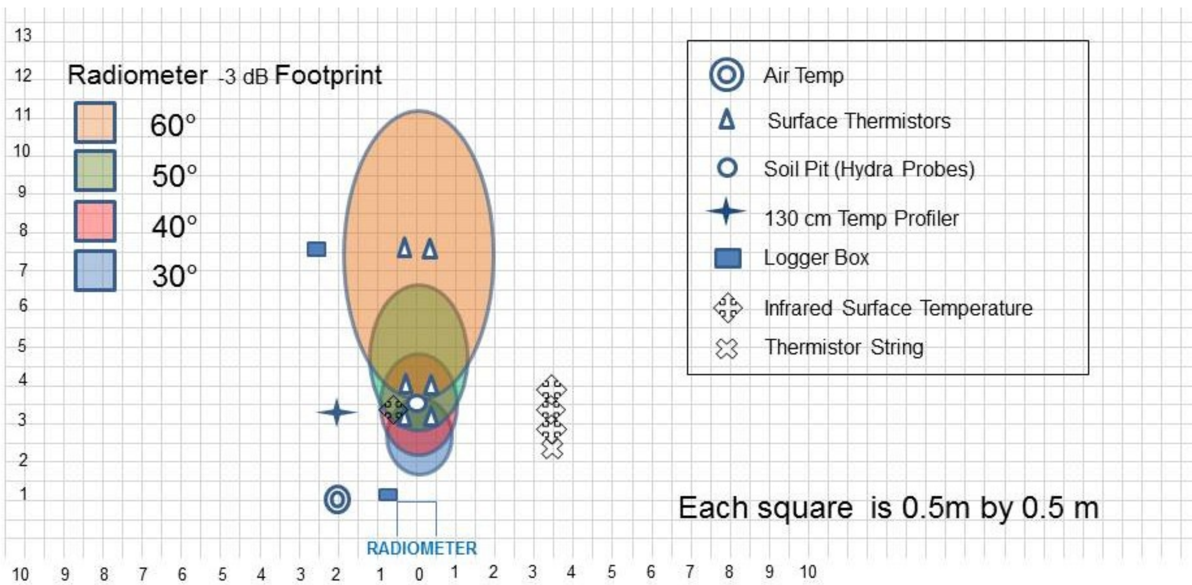


Figure 18. The EC and UdeS surface-based radiometer approximate footprint sizes at multiple incidence angles and the approximate location of the instruments/sensors recording the soil and meteorological conditions in and around the footprint. Source : SLAP Freeze/Thaw Validation Experiment 2015 Surface-Based Radiometer Data Documentation (P. Toose and A. Roy, 2015)

3.3.2. Scatterometer measurements

Dr. Chris Fuller will be contracted to collect data using the University of Calgary scatterometer. This instrument is a frequency modulated continuous-wave radar, which can be oriented in both azimuth and elevation by an automated positioner. Selected specifications for the scattero meter are provided in Table 7. The instrument is mounted on a truck and is thus portable. As only one scatterometer is available, once measurements are made on one field, the scatterometer will be driven to the second field for data collection. The scatterometer will collect data during both of the two-week SMAPVEX16-MB windows. Between these windows, the scatterometer will be removed from the truck and stored at the University of Manitoba.

Table 7. University of Calgary scatterometer specifications (C. Fuller, 2015)

RF output frequency	5.5 GHz ± 2.50 MHz
Antenna type	0.61-m parabolic reflector, dual linear polarization
Antenna beamwidth	5.4^0
Cross polarization isolation	>30 dB, measured at the peak of the beam
Transmit power	12 dBm
Bandwidth	5–500 MHz, user adjustable
Range resolution	0.30 m
Polarization mode	Polarimetric (HH, VV, HV, VH)
Noise floor	Co ~ −36 dBm, cross ~ −42 dBm
External calibration	Trihedral corner reflector

RF, radio frequency.

Window 1
First date of scatterometer measurements : June 9, 2016 (or June 8, 2016 if possible)
Last date of scatterometer measurements : June 20, 2016

Window 2
First date of scatterometer measurements : July 10, 2016
Last date of scatterometer measurements : July 21, 2016

Scatterometer measurements (backscatter) will be collected at HH, VV, HV and VH polarizations at a time described below. Incidence angles will range from 20° to 60°, at 3° incident angle increments. Thus, measurements will be taken at 20°, 23°, 26°, 29°, and so on up to 60°.

Measurements will be made every day during the campaign when weather and access permits. Measurements will not be collected on days when rain is occurring or highly probable to occur. Dew is often present on the crop canopy in the early morning and it is undesirable to acquire measurements under these conditions. As such, measurements will only commence once dew has dissipated. The exception will be on days of RADARSAT-2 overpasses (see below).

On the canola field, scatterometer measurements will be taken at three degree incident angle increments as described above. The scatterometer will then move to the wheat field where the three degree incident angle increments will be repeated. After this is completed, the scatterometer will be fixed at a 25° incident angle on this wheat field. Measurements will continue until late afternoon (time TBD).

Several RADARSAT-2 AM and PM acquisitions are planned. When RADARSAT-2 PM acquisitions are available, scatterometer measurements will be acquired in both the morning and late afternoon, as close in time to the RADARSAT-2 passes as possible. These acquisitions will capture the diurnal differences in backscatter, including the impact of dew on the radar response. For the other dates, the scatterometer multi-angular measurements will be only be acquired in the morning.

The calendar below summarizes the scatterometer data collection plan:

June 2016						
S	M	T	W	T	F	S
29	30	31	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	1	2

July 2016						
S	M	T	W	T	F	S
26	27	28	29	30	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

Green:	Assembly of the platform and scatterometer; calibration of the scatterometer.
Red boxes:	Morning and afternoon multi-angle scatterometer measurements (RADARSAT-2 Days) on canola and wheat fields.
Blue:	Late morning multi-angle scatterometer measurements on canola and wheat fields, and fixed angle scatterometer measurements on the wheat field.
Orange:	Disassembly of the platform and scatterometer; calibration of the scatterometer.

The scatterometer will be positioned as close to the radiometers as possible, yet ensuring no interference from the radiometer structures. The scatterometer should be placed as close as possible to the edge of the field, without driving onto the field. It is hoped that part of the scatterometer footprint will overlap that of the radiometers (if possible).

A maximum height above the canopy is desired. This suggests a height of the scatterometer (above the terrain) of 2.5-3.0 metres, which would provide a footprint in range of 4-by-4m. It is important that the same footprint is revisited each measurement day. Thus the location of the scatterometer truck will be flagged such that the truck position is replicated.

The scatterometer will be calibrated prior to and after the campaign, using external calibration targets and as per normal procedures for calibration of this scatterometer.

Fuller, M.C., Geldsetzer, T., Gill, J.P.S., Yackel, J.J., Derksen, C. (2014). C-band Backscatter From a Complexly-Layered Snow Cover on First-Year Sea Ice. Hydrological Processes, Vol. 28, pp. 4614-4625.

4. Satellite acquisitions

Both passive (SMAP and SMOS) and active (RADARSAT-2, Sentinel-1A/B and TerraSAR-X) microwave data will be collected during SMAPVEX16-MB. Landsat-8 and Sentinel-2 imagery is expected to be available, and AAFC has programmed acquisitions of RapidEye. The technical characteristics of these satellites are summarized in Table 8 and Table 9. For detailed descriptions, the reader is referred to the individual sensor web sites.

Table 8. Technical specification of satellites

Satellites	Frequency (GHz)	Polarization	Incidence angle (°)	Resolution
SMAP	1.41	V, H and U	40	40 km
SMOS	1.4	H and V	0 -55	30 km
Sentinel-1	5.405	VV+ VH, HH+HV, HH and VV	20 to 45	5-20 m
RADARSAT-2	5.4	Single Dual Quad	20-49	3-100 m
TerraSAR-X	9.65	Single Dual Quad	15 to 60	1-16 m
RapidEye				6.5 m
Sentinel-2				10-60 m

Table 9. Technical characteristics of optical sensors

Satellites	Spectral Band	Wavelength nm	Resolution
Landsat-8	Band 1 - Coastal/Aerosol	433 - 453	30
	Band 2 - Blue	450 - 515	30
	Band 3 - Green	525 - 600	30
	Band 4 - Red	630 - 680	30
	Band 5 - NIR	845 - 885	30
	Band 6 - SWIR	1560 - 1660	30
	Band 7 - SWIR	2100 - 2300	30
	Band 8 - Panchromatic	500 - 680	15
	Band 9 - SWIR - Cirrus	1360 - 1390	30
	Band 10 - LWIR	10300 -11300	100
	Band 11 - LWIR	11500 -12500	100
RapidEye	Band 1 - Blue	440 - 510	5
	Band 2 - Green	520 - 590	5
	Band 3 - Red	630 - 685	5
	Band 4 - Red Edge	690 - 730	5
	Band 5 - NIR	760 - 850	5
Sentinel - 2	Band 1 - Coastal/Aerosol	443-453	60
	Band 2 - Blue	458-523	10
	Band 3 - Green	542-578	10
	Band 4 - Red	650-680	10
	Band 5 - Vegetation Red Edge	697-712	20
	Band 6 - Vegetation Red Edge	732-747	20
	Band 7 - Vegetation Red Edge	773-793	20
	Band 8 - NIR	784-900	10
	Band 8A - Vegetation Red Edge	855-875	20
	Band 9 - Water Vapour	935-955	60
	Band 10 - SWIR - Cirrus	1360-1390	60
	Band 11 - SWIR	1565-1655	20
	Band 12 - SWIR	2100-2280	20

4.1. Calendar of satellite acquisitions

Passive and active microwave acquisitions will occur before, during and the intensive periods of data collection during SMAPVEX16-MB. The calendar of passive and active acquisitions are listed in Table 10 and Table 11.

Table 10. Timing of SMAP and SMOS overpasses

	SMAP ASC		SMAP DES		SMOS ASC		SMOS DES	
Date	**Hour**	**Min**	**Hour**	**Min**	**Hour**	**Min**	**Hour**	**Min**
6			8	14			19	54
7	19	20			7	12		
8	18	57	7	54	6	34	20	16
9			8	26				
10	18	32			6	56	20	38
11			8	2			20	0
12	19	9	8	37	7	18		
13	16	44			6	39	20	22
14			8	14			19	43
15	19	20			7	1		
16	18	57	7	49	6	23	20	5
17			8	26				
18	18	32			6	47	20	27
19			8	2			19	48
20	19	9	8	37	7	6		
21	18	44			6	28	20	10
22			8	14				
23	19	21			6	50	20	32
24	18	57	7	49			19	54
25			8	26	7	12		
26	18	32			6	33	20	16
27			8	2				
28	19	9	8	38	6	55	20	38
29	18	44					19	59
30			8	14	7	17		
1	19	20			6	39	20	21
2	18	57	7	49			19	42
3			8	26	7	1		
4	18	32			6	22	20	4
5			8	2				
6	19	9	8	37	6	44	20	26
7	18	44					19	48
8			8	14	7	6		
9	19	20			6	27	20	10
10	18	57	7	49				
11			8	26	6	49	20	32
12	18	32					19	53
13			8	2	7	11		
14	19	9	8	37	6	33	20	15
15	18	44						
16			8	14	6	55	20	37
17	19	20					19	58
18	18	57	7	49	7	16		

19			8	26	6	38	20	20
20	18	32					19	42
21			8	2	7	0		
22	19	9	8	37	6	21	20	4
23	18	44						
24			8	14	6	43	20	26

Table 11. Timing of RADARSAT-2 and TerraSAR-X Ascending and Descending Acquisitions

	TerraSAR ASC		TerraSAR DES		RADARSAT - 2 ASC		RADARSAT - 2 DES	
Day	**Hour**	**Min**	**Hour**	**Min**	**Hour**	**Min**	**Hour**	**Min**
6								
7								
8							7	57
9					19	19		
10								
11	00	11						
12			12	54	19	03	7	40
13								
14								
15					19	15	7	53
16	00	19						
17								
18			12	45	19	28		
19								
20								
21								
22	00	11			19	11	7	48
23			12	54				
24								
25					19	24	8	01
26								
27	00	19						
28								
29			12	45	19	07	7	44
30								
1								
2					19	19	7	57
3	00	11						
4			12	54				
5								
6					19	03	7	40
7								
8	00	19						
9					19	15	7	53
10			12	45				
11								
12					19	28	8	05
13								
14	00	11						
15			12	54				
16					19	11	7	48
17								
18								
19	00	19			19	23	8	01
20								
21			12	45				
22								
23					19	07	7	44
24								

4.1.1. SMAP and SMOS coverage

SMOS: The Soil Moisture Ocean Salinity (SMOS) mission was launched in late 2009 by ESA. SMOS provides multiple polarization L-band brightness temperatures at multiple incidence angles. The mission also provides a soil moisture product. Spatial resolution of SMOS data is ~40 km. Products are posted on a 16 km grid (with 40 km resolution). Overpasses occur in the morning and evening with 16 ascending acquisitions and 16 descending acquisitions occurring during the intensive field campaign. The coverage during SMAPVEX is summarized in Table 10. Note that this has been restricted to passes with coverage closer to the center of the swath to improve data quality. Times are in local time. Details on SMOS and SMOS data can be found in Kerr et al. (2012).

Kerr, Y.H.; Waldteufel, P.; Richaume, P.; Wigneron, J.P.; Ferrazzoli, P.; Mahmoodi, A.; Al Bitar, A.; Cabot, F.; Gruhier, C.; Juglea, S.E.; Leroux, D.; Mialon, A.; Delwart, S. The SMOS Soil Moisture Retrieval Algorithm, IEEE Trans. Geoscience and Remote Sensing, 50, pp. 1384 – 1403, 2012.

SMAP: The Soil Moisture Active Passive (SMAP) mission is one of the first Earth observation satellites developed by NASA in response to the National Research Council's Decadal Survey. The SMAP satellite uses a combined L-band radiometer and radar instruments sharing a rotating 6-m mesh reflector antenna to provide high-resolution global maps of soil moisture at multiple spatial resolutions of 1 – 3 km. The incidence angle is 40 degrees. During SMAPVEX16-MB there will be 16 ascending acquisitions, which will occur during the evening of the intensive field campaign and 16 descending acquisitions during the morning of the intensive field campaign. On July 7 2015, the SMAP radar stopped transmitting and was officially announced unusable on 2 September 2015. The mission continues with data being returned only by the radiometer. The coverage during SMAPVEX is summarized in Table 10 (O'Neill, Entekhabi, Njoku, & Kellogg, 2013).

O'Neill, P., Entekhabi, D., Njoku, E., & Kellogg, K. (2013). The NASA Soil Moisture Active Passive (SMAP) Mission: Overview. *NASA*, 1-4.
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110015242.pdf

4.1.2. C-Band SAR satellite coverage

RADARSAT-2: More than 90 RADARSAT-2 Wide Quad-Polarimetric acquisitions have been programmed from April to September of 2016 (Table 12). A sub-set of these (7) overlap with each of the SMAPVEX16-MB intensive field campaigns. Both orbits (ascending and descending) were programmed. Ascending acquisitions occur at approximately 7:00 PM local time; descending acquisitions at approximately 8:00 AM local time. For many acquisitions, multiple frames of 2 or 3 were programmed to maximize the coverage of the SMAP cal/val pixel.

Table 12. RADARSAT-2 programming (April-September 2016). Shaded entries are acquisitions which occurring during intensive field campaign.

Date	Local Time	Orbit	Mode	Date	Local Time	Orbit	Mode
Apr-01	19:03:19	ASC	WideFQ (FQ1W)	Jul-02	7:57:13	DES	WideFQ (FQ3W)
Apr-04	7:53:03	DES	WideFQ (FQ8W)	Jul-02	19:19:48	ASC	WideFQ (FQ15W)
Apr-04	19:15:41	ASC	WideFQ (FQ10W)	Jul-06	7:40:28	DES	WideFQ (FQ19W)
Apr-07	8:05:33	DES	WideFQ (FQ1W)	Jul-06	19:03:19	ASC	WideFQ (FQ1W)
Apr-07	19:28:20	ASC	WideFQ (FQ18W)	Jul-09	7:53:04	DES	WideFQ (FQ7W)
Apr-11	7:48:47	DES	WideFQ (FQ10W)	Jul-09	19:15:39	ASC	WideFQ (FQ11W)
Apr-11	19:11:37	ASC	WideFQ (FQ9W)	Jul-12	8:05:33	DES	WideFQ (FQ1W)
Apr-14	8:01:24	DES	WideFQ (FQ5W)	Jul-12	19:28:20	ASC	WideFQ (FQ18W)
Apr-14	19:24:10	ASC	WideFQ (FQ14W)	Jul-16	7:48:54	DES	WideFQ (FQ11W)
Apr-18	7:44:43	DES	WideFQ (FQ17W)	Jul-16	19:11:29	ASC	WideFQ (FQ7W)
Apr-18	19:07:22	ASC	WideFQ (FQ2W)	Jul-19	8:01:24	DES	WideFQ (FQ5W)
Apr-21	7:57:12	DES	WideFQ (FQ4W)	Jul-19	19:23:58	ASC	WideFQ (FQ20W)
Apr-21	19:19:50	ASC	WideFQ (FQ15W)	Jul-23	7:44:45	DES	WideFQ (FQ16W)
Apr-25	7:40:28	DES	WideFQ (FQ19W)	Jul-23	19:07:20	ASC	WideFQ (FQ2W)
Apr-25	19:03:19	ASC	WideFQ (FQ1W)	Jul-26	7:57:13	DES	WideFQ (FQ3W)
Apr-28	7:53:03	DES	WideFQ (FQ8W)	Jul-26	19:19:48	ASC	WideFQ (FQ15W)
Apr-28	19:15:41	ASC	WideFQ (FQ10W)	Jul-30	19:03:19	ASC	WideFQ (FQ1W)
May-01	8:05:33	DES	WideFQ (FQ1W)	Aug-02	7:53:04	DES	WideFQ (FQ7W)
May-01	19:28:20	ASC	WideFQ (FQ18W)	Aug-02	19:15:39	ASC	WideFQ (FQ11W)
May-05	19:11:37	ASC	WideFQ (FQ9W)	Aug-05	19:28:20	ASC	WideFQ (FQ18W)
May-08	8:01:24	DES	WideFQ (FQ5W)	Aug-09	19:11:29	ASC	WideFQ (FQ7W)
May-08	19:24:10	ASC	WideFQ (FQ14W)	Aug-12	19:24:10	ASC	WideFQ (FQ14W)
May-12	7:44:45	DES	WideFQ (FQ16W)	Aug-16	19:07:20	ASC	WideFQ (FQ2W)
May-12	19:07:20	ASC	WideFQ (FQ2W)	Aug-19	19:19:48	ASC	WideFQ (FQ15W)
May-15	19:19:48	ASC	WideFQ (FQ15W)	Aug-23	7:40:28	DES	WideFQ (FQ19W)
May-19	19:03:19	ASC	WideFQ (FQ1W)	Aug-23	19:03:19	ASC	WideFQ (FQ1W)
May-22	19:15:39	ASC	WideFQ (FQ11W)	Aug-26	19:15:39	ASC	WideFQ (FQ11W)
May-25	8:05:33	DES	WideFQ (FQ1W)	Aug-29	8:05:33	DES	WideFQ (FQ1W)
May-25	19:28:20	ASC	WideFQ (FQ18W)	Aug-29	19:28:20	ASC	WideFQ (FQ18W)
May-29	19:11:29	ASC	WideFQ (FQ7W)				
				Sep-02	7:48:47	DES	WideFQ (FQ10W)
Jun-01	19:24:10	ASC	WideFQ (FQ14W)	Sep-02	19:11:38	ASC	WideFQ (FQ9W)
Jun-05	19:07:20	ASC	WideFQ (FQ2W)	Sep-05	8:01:24	DES	WideFQ (FQ5W)
Jun-08	7:57:14	DES	WideFQ (FQ3W)	Sep-05	19:24:10	ASC	WideFQ (FQ14W)
Jun-08	19:19:48	ASC	WideFQ (FQ15W)	Sep-09	7:44:43	DES	WideFQ (FQ17W)
Jun-12	7:40:35	DES	WideFQ (FQ20W)	Sep-09	19:07:22	ASC	WideFQ (FQ2W)
Jun-12	19:03:19	ASC	WideFQ (FQ1W)	Sep-12	7:57:12	DES	WideFQ (FQ4W)
Jun-15	7:53:04	DES	WideFQ (FQ7W)	Sep-12	19:19:50	ASC	WideFQ (FQ15W)
Jun-15	19:15:39	ASC	WideFQ (FQ11W)	Sep-16	7:40:28	DES	WideFQ (FQ19W)
Jun-18	19:28:20	ASC	WideFQ (FQ18W)	Sep-16	19:03:19	ASC	WideFQ (FQ1W)

Jun-22	7:48:54	DES	WideFQ (FQ11W)	Sep-19	7:53:03	DES	WideFQ (FQ8W)
Jun-22	19:11:29	ASC	WideFQ (FQ7W)	Sep-19	19:15:41	ASC	WideFQ (FQ10W)
Jun-25	8:01:24	DES	WideFQ (FQ5W)	Sep-22	8:05:33	DES	WideFQ (FQ1W)
Jun-25	19:24:10	ASC	WideFQ (FQ14W)	Sep-22	19:28:20	ASC	WideFQ (FQ18W)
Jun-29	7:44:45	DES	WideFQ (FQ16W)	Sep-26	7:48:47	DES	WideFQ (FQ10W)
Jun-29	19:07:20	ASC	WideFQ (FQ2W)	Sep-26	19:11:37	ASC	WideFQ (FQ9W)
				Sep-29	8:01:24	DES	WideFQ (FQ5W)
				Sep-29	19:24:10	ASC	WideFQ (FQ14W)

Sentinel-1: The Sentinel-1 mission is a joint initiative of the European Commission (EC) and the European Space Agency (ESA). The payload of the satellite consists of a C-band SAR instrument with four exclusive imaging modes with different resolutions. Sentinel-1 provides dual polarization capability, very short revisit times and rapid product delivery. The use of Sentinel-1A and Sentinel-1B will assist with land monitoring of forests, water, soil and agriculture (Agency, Sentinel-1 User Handbook, 2013).

Both Sentinel-1A and 1B acquisitions will be made for the summer growing season in Manitoba. These will be obtained in Interferometric Wide swath (IW) mode VV-VH polarization. The Interferometric Wide swath (IW) mode allows combining a large swath width (250 km) with a moderate geometric resolution (5 m by 20 m). Three ascending tracks will be obtained (12, 63 and 165) at a nominal overpass time of 0:15 UTC. Observations from either satellite are on a 12-day repeat offset by 6-days. This results in the following days (red=1B).

Track 12; Dates July 9, 21; August 2

Track 63; Dates June 1, 13, 25; July 7, 13, 19, 25, 31; August 6, 12, 24

Track 136; Dates May 25; June 6, 18, 30; July 12, 18, 24, 30; August 5, 11

Note that the first repeat of track 165 on 08 June is currently not part of the Sentinel-1A observation scenario due to a conflict in the observation scenario. In addition, 1B data will become available after the completion of various post-launch procedures and will not begin until July. Additional tracks will be provided by 1B that include for Manitoba 12 descending and 136 ascending.

Agency, E. S. (2013). *Sentinel-1 User Handbook.*
https://sentinel.esa.int/documents/247904/685163/Sentinel-1_User_Handbook

4.1.3. X-Band satellite coverage

TerraSAR-X: A TerraSAR-X proposal was approved by DLR. DLR has agreed to provide 30 ascending and descending acquisitions of the TerraSAR-X dual stripmap mode. There will be 9 acquisitions which occur during intensive field campaign. Initially launched on 15 June 2007 TerraSAR-X is a German Aerospace Center and EADS Astrium joint venture created to provide more accurate SAR data in X-band. TerraSAR-X has multiple resolutions from 1m to 16m with an incidence angle of 15 to 60 degrees.

TerraSAR - X - Germany's radar eye in space. (2009, 07 08). Retrieved May 11, 2016, from DLR:
http://www.dlr.de/eo/en/desktopdefault.aspx/tabid-5725/9296_read-15979/
http://www.dlr.de/eo/en/desktopdefault.aspx/tabid-5725/9296_read-15979/

4.1.4. Optical data programming

RapidEye: Acquisitions of RapidEye are being programmed by AAFC for the SMAPVEX16-MB site, as a background mission. RapidEye is equipped with a 5 band, jena-optonik multi-spectral imager able to provide optical data from 440 – 850 nanometres.

LANDSAT: Landsat 8 is a joint NASA/USGS program that provides continuous acquisition and availability of Landsat data utilizing a two-sensor payload (operational land imager and thermal infrared sensor). Launched on February 11, 2013, it is the eighth satellite in the Landsat program. Landsat 8 measures Earth's surfaces in the visible, near-infrared, short wave infrared and thermal infrared, with a resolution of 15 to 100 metres. There will be 2 acquisitions which occur during intensive field campaign.

http://www.nasa.gov/mission_pages/landsat/overview/index.html

SENTINEL-2: Sentinel-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. Sentinel-2 carries an optical instrument payload which samples 13 spectral bands. There are four bands at 10m resolution, six bands at 20m and three bands at 60m. The wavelength for the bands is from 443-2280nm. (Agency, Sentinel - 2 User Handbook, 2015)
Agency, E. S. (2015). Sentinel - 2 User Handbook.

https://earth.esa.int/documents/247904/685211/Sentinel-2_User_Handbook

4.2. Field measurement strategies

4.2.1. Soil physical properties

The following soil physical (SP) properties will be measured during SMAPVEX:

SP1: Soil Moisture
SP2: Soil and Vegetation Temperature

SP1: Soil Moisture

Objective: Surface soil moisture will be measured at the SMAP scale to assess passive and active radar retrieval approaches and to assess field-scale variability in soil moisture to assist in scaling issues. The overall goal of the soil moisture sampling should be to maximize the number of fields from which representative field-scale soil moisture determinations can be acquired.

General description of agricultural fields in Manitoba:
Over the Manitoba study sites, agricultural fields are often a quarter-section in size (160 acres) with dimensions of 0.5 miles by 0.5 miles. Most fields in the area are annually cropped and

seeded in rows, mainly in the spring or sometimes in the fall. Depending on the seeding equipment, crop rows are separated by 15 to 35 cm for most crops with wider spacings for the row-seeded crops such as corn or soybeans. After a field is seeded, the seed rows are normally located along the top of a small ridge of soil created by the seeding equipment. In some cases, the rows may not be as clearly defined such as behind air-seeding equipment using sweep openers that spread seed across 3 to 4 inches within each row or if harrows or packers were pulled behind the seeding equipment. In these fields, the rows can be more difficult to discern, especially when the crop has reached full biomass and the canopy has closed.

Hand-held Soil Moisture Sensor Measurements:
Surface soil moisture measurements will be acquired over selected agricultural fields coincident in time to flight overpasses. Field crews will use Stevens POGOs (Figure 19) to measure soil moisture at near surface depths (5.7 cm) at 16 locations in each field.

Figure 19. Illustration of a Stevens POGO soil moisture sensor system.

Each crew will consist of 2 members. One member will carry a POGO sensor and an iPod with the Hydramon app installed (Figure 19). This person will record readings electronically using the app, which will provide a complete set of sampling data (POGO serial number, sample time, soil moisture, EC, temperature, real and imaginary dielectric). The other team member will carry a GPS for navigation to each sampling point and a data sheet to record each real dielectric reading in hard copy as a backup. Each crew will be given 5 fields to sample. The crew members will work together on each field following a prescribed pattern of sample locations (Figure 20) and a specific sampling protocol at each sample point (Figure 21). Up to fifty fields will be sampled on each sample date (10 field crews, 5 fields each).

There will be 16 sampling points in each field arranged as two parallel transects, one at 100 m from the road and the other another 200 m further into the field (Figure 20). The transects are oriented parallel to the seed row direction to make it easier to walk between points. Seeding direction will be confirmed no later than the end of May so that the sample point locations can be preloaded into each GPS prior to the sampling campaign. The end points of each transect will be a minimum of 100 m from the field edge. Sampling points along each transect will be 75 m apart. The samplers will move together from site to site, entering and exiting the field at site 1.

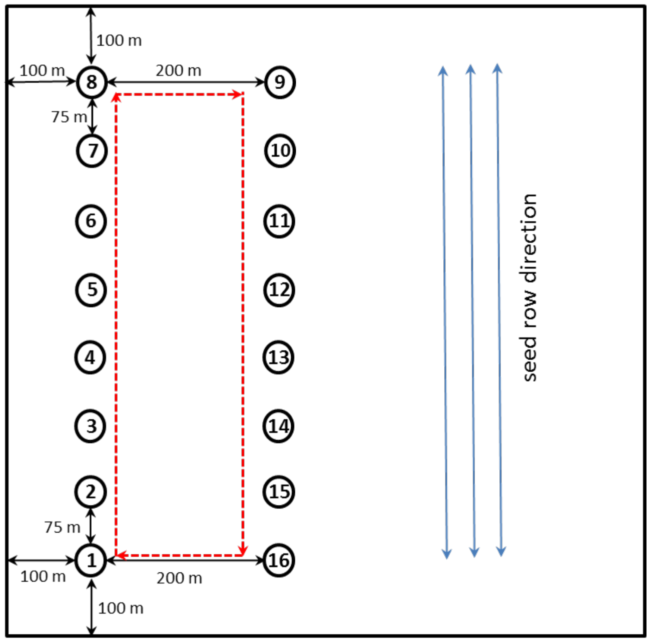


Figure 20. Soil moisture sampling strategy for SMAPVEX

All sample points will be pre-loaded into handheld GPSs to allow easy navigation to the sample sites. This will be particularly important in fully developed canopies where navigation can be difficult and flags are often lost as the crop grows. To avoid confusion, data labeling will be standardized as follows: Field # - Site # - Replicate #

At each sample location, a total of 3 readings will be taken with the 1st reading between the crop plants at the top of a ridge, the 2nd reading in the middle of a ridge and the 3rd reading at the bottom of the depression between ridges (Figure 21). If there are no discernible ridges, all three readings will be taken and a note made on the sampling sheet that there were no ridges. Always insert the probe perpendicular to the soil surface as shown in the figure below.

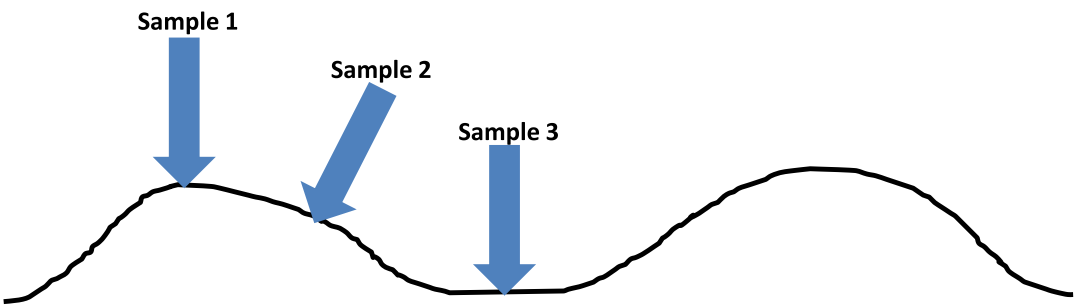


Figure 21. Location of replicate soil moisture measurements at each site

Each sample location will avoid large cracks, dry clods or areas that have been heavily compacted by tractor wheels or foot traffic. Samplers must take care not to push the moisture probe in too far and cause compaction, especially if the soil is loose.

At the completion of soil moisture sampling of their 5 fields on each date, the 2 team members will bring the iPod and the data sheet back to the base. The electronic data will be downloaded and backed up. The hard copy data sheet will be scanned to an electronic file for backup and then filed.

High-resolution soil moisture sampling (optional if sufficient resources are available):
High-resolution ground measurements of soil moisture can provide data to evaluate variability in soil moisture within an area equivalent to a RADARSAT-2 standard mode (30 m) pixel. This intensive sampling will be conducted on a limited number of fields within the main sampling grid. The number of fields measured and the number of times the measurements are taken will be dictated by availability of field personnel. The intensive sampling should be targeted to the earlier part of the sampling campaign when crops are still in their early stages of growth and the variation in soil moisture will be a more significant factor affecting the microwave signatures.

The high-resolution pattern will be a 50-point grid at a 15 m spacing centered on Sample Points 3 and 4 (Figure 22). Three readings per sample point will be taken as shown in Figure 21. All sample points will be pre-loaded into handheld GPSs to allow easy navigation to the sample sites. To avoid confusion, data labeling will be standardized as follows: Field # - Intensive Sample Site # - Replicate #.

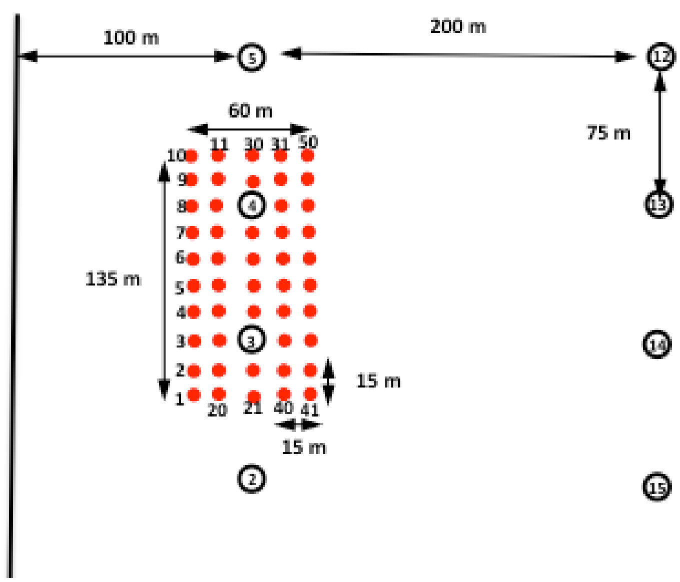


Figure 22. Sampling grid for high-resolution soil moisture sampling.

Each sample location will avoid large cracks, dry clods or areas that have been heavily compacted by tractor wheels or foot traffic. Samplers must take care not to push the moisture probe in too far and cause compaction, especially if the soil is loose.

At the completion of soil moisture sampling the 2 team members will bring the iPod and the data sheet back to the base. The electronic data will be downloaded and backed up. The hard copy data sheet will be scanned to an electronic file for backup and then filed. No calibration samples will be taken during high-resolution sampling.

Temporary and Permanent Soil Moisture Sensors:
A temporary soil moisture station will also be installed on each field at either site 1 or site 16. These will be installed as soon as possible after seeding and the hand-held sampling locations are finalized. The temporary stations will record surface soil moisture (5.7 cm) preceding, during and after the aircraft measurement campaigns.

In addition to the surface soil moisture collected by field crews and the temporary soil moisture stations, soil moisture readings at discrete depths of 5, 20, 50 ad 100 cm will be acquired by the AAFC permanent in situ network stations. The location and data collected by these stations is described in previous sections of this document.

Soil Moisture Sensor Calibration:
It is essential to provide a solid basis for assessing sensor accuracy for the 2016 campaign. The calibration of surface soil moisture readings using Stevens hydraprobes and ML2x theta probes in 2012 will be used as a basis for establishing calibrated soil moisture values from the hand-held probes as per Rowlandson, T.L., Berg, A.A., Bullock, P.R., Ojo, E.R., McNairn, H, Wiseman, G. and Cosh, M.H. 2013. Evaluation of several calibration procedures for a portable soil moisture sensor. Journal of Hydrology 498:335-344. This analysis revealed minimal variability in real dielectric versus soil moisture between individual sensors. It also revealed that a field-based calibration provided the lowest amount of absolute error in the sensor readings and that on most fields, the accuracy fell within the 0.04 m^3 m^{-3} target. Therefore, the approach in the 2016 campaign will be to create a field-based calibration to convert the real dielectric readings to volumetric soil moisture.

There are approximately 10 different soil moisture sampling dates planned during the field campaign. If each team brings back two volumetric soil moisture samples from each of their 5 fields on each sampling date, there will be a dataset of 20 measured values for each field on which to develop a field-based calibration. It is important that the samples collected represent a range of soil moisture conditions (from wet through to dry), which would be expected over the course of two separate 2-week sampling campaigns (one in mid-June and one in mid-July).

The volumetric core samples will be taken within 2 meters from two specified sample locations in each sample field and in a spot where the soil has not been trampled or disturbed. The two sample locations will be specified on each sampling date, during the morning briefing. The calibration sample locations will be rotated on each sampling date so that all 16 sample sites will have been sampled by the end of the 2016 campaign.

Volumetric soil moisture samples will be taken using 5 cm aluminum rings (Figure 23). The ring is covered with a cloth membrane cap and then pushed vertically down into the soil until fully inserted (Figure 24). Once the ring is fully inserted, the POGO will be used to take 3 readings from the undisturbed soil surrounding the inserted ring. The POGO should be carefully pushed in approximately 10 cm from the ring taking care to fully insert the probe but not to push it in too hard and compact the soil. The POGO should not come in contact or too close to the ring. The three real dielectric readings from around the ring will be recorded using the app and also on the data sheet along with the number of the nearby field sample location.

Figure 23. Aluminum sampling ring ready to be inserted at a volumetric soil moisture calibration sample location.

Figure 24. Aluminum sampling ring fully inserted. Three POGO samples can be taken surrounding the ring approximately 10 cm away.

The aluminum ring is then gently removed by inserting a trowel underneath to loosen the soil (Figure 25). Once removed, the soil sample is trimmed on the bottom end to ensure an exact volume of soil has been removed (Figure 26). The sample in the ring is then carefully transferred to a sample container ensuring that soil is not spilled during the transfer and that none is left sticking to the outside of the sample ring. The membrane cap is removed from the aluminum ring. The lid is placed on the sample container and the container is put inside a Ziploc bag, which is marked with the date, field number, sampling site, sample position and replicate number.

Figure 25. Loosening a sample ring to remove the sample from the soil.

Figure 26. A sample that has been trimmed to size and now ready to be transferred to the sample container.

At the laboratory, the lab crew will remove the sample tin from the Ziploc bag and remove the lid. The wet weight of the sample will be the total weight of the soil in the core plus the aluminum ring plus the sample container base. The labeled Ziploc bag will be set aside for reuse to hold the oven-dried soil when it is cleaned out of the ring. The sample container base with the ring and the soil will be placed in a drying oven for a minimum of 48 hrs at 105^{o}C then re-weighed. The sample container base and aluminum ring will be pre-weighed prior to use so they can be subtracted from the total to determine the wet and oven-dry weight. The height, diameter and volume of each aluminum ring will be pre-determined for the purpose of bulk density determination.

Once the dry weight of the sample has been recorded, the sample will be returned to the Ziploc bag. Two samples of soil per field will be retained for any further required soil analysis.

The gravimetric moisture content will be determined for each individual sample as the mass of water divided by the mass of oven-dry soil. In addition, the bulk density of each individual sample will be determined as the oven-dry mass of soil divided by the aluminium ring volume. The average bulk density of all 20 calibration samples for each field will be averaged to determine an average bulk density of the surface soil for the entire field. The average bulk density will be multiplied by the gravimetric moisture content of each individual sample to calculate the volumetric moisture content of each core sample. The average bulk density per field follows the 2012 protocol in Rowlandson et al 2013 which documented more accurate field-based calibrations using this method as opposed to using each individual bulk density with each individual gravimetric soil moisture content.

The volumetric soil moisture content for each core sample will be used with the adjacent hydraprobe reading to create a calibration. Volumetric water content is a linear function of the square root of real dielectric permittivity. As per Rowlandson et al. 2013, linear regression analysis will be used to determine the equation of best fit between the volumetric moisture content and the square root of the dielectric permittivity from the hydra probe as below:

$$\theta_V = a\,(\varepsilon_{TC})^{0.5} + b$$

SP2: Soil and Vegetation Temperature

Field Protocols:
On soil moisture sampling days, the temperature of the soil and vegetation will be measured during the collection of hand-held soil moisture sensor readings. Soil temperatures will be recorded using a simple digital pocket thermometer. For each sample field, four sites will be selected to measure soil temperature (Table 13). These will be sites 1, 8, 9, and 16 as per Figure 20. The digital thermometer will be inserted to two depths – 5 cm and 10 cm. These depths will be indicated on the thermometer to facilitate insertion to the correct depth. The thermometer should be left in place until the temperature reading stabilizes. Temperatures will be recorded on data sheets. At these same 4 sites (1,8,9,16), surface temperatures for soil and vegetation will be measured using a thermal infrared thermometer. Temperatures will be recorded for sunlit vegetation and sunlit soil, as well as for shaded vegetation and shaded soil. These measurements will also be recorded on data sheets.

Table 13. Temperature Sampling Summary

Property	Locations	Depth	Instrument	Measurement technique
Soil Temperature	4 Sites 1,8,9,16	5 and 10 cm	Digital pocket thermometer	insert to 5 cm, take reading then push to 10cm, take reading
Soil and Vegetation Temperature	4 Sites 1,8,9,16	Surface	Thermal infrared thermometer	measure sunlit soil, sunlit vegetation, shaded soil, shaded vegetation

4.2.2. Soil roughness

The roughness measurement protocol used during the SMAPVEX12 campaign will be replicated here, given that field conditions will be very similar to the 2012 campaign. Macro and micro surface roughness are known to effect microwave emission and scattering. For agriculture fields, this roughness is primarily due to land management activities, modified over time by the effects of erosion by water and wind. Although the effects of land management on roughness can vary due to soil characteristics, large roughness variations across a field are small. Consequently roughness will be measured at only two sites in each field. In addition, the SMAPVEX16-MB campaign will begin after seeding and further effects due to management activity are not expected. As well, canopy closure reduces the influence of erosion forces. Thus roughness will be measured only once during the campaign.

Information on surface roughness will be gathered with a portable pin profilometer that uses surface displacement and post-processing techniques to obtain root mean square roughness (rms) and roughness correlation length (ℓ). Before taking the photo, if vegetation obstructs the view of the board the vegetation will be flattened.

For each field, roughness measurements will be collected at two sites. To adequately measure the correlation length, roughness measurements must be taken over long profiles (typically several metres). To achieve a longer 3-metre profile, once one profilometer measurement is taken, the instrument will be moved such that the end of the first measurement becomes the start of the second measurement. This will be repeated a second time to achieve a 3-metre profile comprised of three 1-metre profiles. The photographs of the three separate profiles will be joined into a single profile using a matlab application, post data collection, to provide the two roughness parameters per site. For each site, the board will placed parallel to the look direction of the SAR instruments (Sentinel-1 (descending), RADARSAT-2 (descending), TerraSAR-X (descending) and PALS flight) (Figure 27). The look direction is the direction perpendicular to the orbital track or flight line. For RADARSAT-2, Sentinel-1 and TerraSAR-X this is perpendicular to the descending orbital track. For PALS this is perpendicular to the flight track.

For each site a total of 6 photos (3 adjacent photos x 2 look directions) will be taken. This will lead to 12 photos (3 adjacent photos x 2 sites x 2 look directions) for each field.

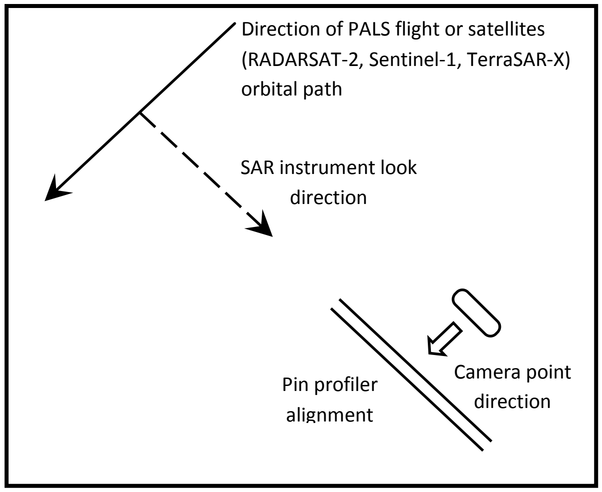


Figure 27. An example of the placement of the profilometer.

A summary of the approach to measuring roughness is provided in Table 14.

- 1-m long profilometer will be used to estimate the surface roughness, the profiler is placed end to end 3 times to give a 3 m long profile measurement per replicate,
- One replicate consists of a 3-m profile in the clockwise look direction of PALS flights (~90 degrees) and RADARSAT2 (descending mode ~ 282 degrees).
- 2 sites per field,
- Vegetation is removed (or flattened by using a long cardboard) along this transect so that it doesn't interfere with the soil roughness measurement and so that a photo (10 megapixel camera) of the pins can be taken,

Table 14. Summary of surface roughness measurement strategy

	Acquisitions	
	PALS	**RADARSAT-2**
Instruments	Needle profilometer	Needle profilometer
Number of sites per field	2 (same sites as RADARSAT-2)	2 (same sites as PALS)
Number of replicates per site	1	1
Number of profiles per site	3 (placed end-to-end)	3 (placed end-to-end)
Number of field visits	1	1

Measurement time estimates:
A survey of those previously involved in soil roughness measurements resulted in a consensus that a soil roughness team (2 people) could spend 40 minutes per site, to collect measurements

in the 2 look directions. Thus, 1 hour 20 min (40 min x 2 sites) will be required for a field. It could take up to 30 minutes of drive between each field. In one day we will aim to sample 3-4 fields per day per team.

Daily time estimates to cover the 3-4 fields:
(1 hour 20 min + 0.5 hour)*3 fields = 5.5 hours and
(1 hour 20 min + 0.5 hour)*4 fields = 7 hours 20 min
Travel time: 1.5 hours x 2 = 3 hours
Total daily time estimate for 3-4 fields: = 8.5 hours- 10 hours 20 mn per day and per team of 2 people.

There will be two soil roughness teams. If each team covers 3-4 fields per day, 15- 20 fields per team per week (5 days) will be covered. With two teams, we could sample on average 35 fields during the 1st week of the campaign. Therefore, all the 50 fields could be sampled during window 1 of the campaign.

4.2.3. Vegetation properties for cropland

Objective: To measure biomass and canopy water content to assess the effectiveness of vegetation parameterization associated with soil moisture retrieval models for both passive and active microwave sensors, at the SMAP scale.

Measurement approach:
A number of vegetation (VG) properties will be measured during SMAPVEX16-MB. Some of these properties are static (measured only once). Others are dynamic (require repeated measurements). Characterization of the vegetation is an important aspect of the SMAPVEX campaign and the level of effort to collect these measurements and samples will be significant.

The variety of crops grown in southern Manitoba is substantial. The number of different crops to be sampled will be largely determined by the prevalence of each crop in the region, modified by access granted by the land owners. The focus should be placed on major crops. Major annual crops to be targeted will include winter and spring wheat, canola, oats, corn and (soy)beans. Two fields of pasture/forage will likely also be selected.

The following static and dynamic vegetation properties will be measured.

Static Properties
VG1: Plant Count
VG2: Row Spacing
VG3: Row Direction

Dynamic Properties
VG4: Leaf Area Index (LAI)
VG5: Biomass and Canopy Water Content
VG6: Height
VG7: Phenology
VG8: Point Canopy Reflectance
VG9: Field Scale Canopy Reflectance

The sampling strategy will consist of collecting vegetation data at three sites per field, at least once per week. The change in vegetation structure, biomass and water content is significant during this period of peak growth and thus weekly measurements are warranted. Three of the 16 soil moisture sites will be selected for vegetation sampling. In 2012, sites 2 (on transect #1), 11 and 14 (both on transect #2) were selected. This worked well in 2012 as transit time through the field was optimized and yet the distance between sites ensured that a range of vegetation conditions were sampled. It is proposed that the same general approach will be followed in 2016. However, the effect of trampling of vegetation around the soil moisture sampling sites by the vegetation teams must be considered. Several options were considered to minimize this disturbance; however the team opted to move the sampling site by one during the second week of each campaign window. As such, sites 2, 11, and 14 will be sampled the first week of each campaign window whereas sites 3, 10, and 13 will be sampled the second week of each campaign window (Table 15).

Table 15. Location of the vegetation sampling sites for each week of the two field campaign windows.

Campaign Window		Week	Dates	Sampling Sites
1	June 8 – 20	Week 1	June 8 – 13	2, 11, 14
		Week 2	June 14 – 20	3, 10, 13
2	July 10 – 22	Week 1	July 10 – 16	2, 11, 14
		Week 2	July 17 – 22	3, 10, 13

In addition, vegetation teams will be asked to take their samples 2-3 m away from the soil sample location to minimize disturbance at these sites. The number of replicates required for each vegetation parameter will also vary. These are detailed in the summary table (Table 19) at the end of this section.

VG1: Plant Count

The density of plants will be determined by counting the number of emergent plants in a row along a fixed distance of 1 meter. For each field, a small tennis ball will be lobbed towards a random location on the field. At the spot where the tennis ball lands, the center of the meter stick will be set down parallel to the closest row. The number of plants from one end of the meter stick to the other will be counted. This will be replicated for a total of 10 counts per field by moving perpendicular to the rows at each throw. Counts will be recorded on data sheets and used with row spacing to calculate plant density.

VG2: Row Spacing

Row spacing will be determined by measuring the distance between rows at each location where the plant counts are made. At each location, after the plant counts are made, the meter stick will be turned perpendicular to the row direction. At the soil level, the total distance will be measured between the centers of the two plant rows immediately adjacent on either side of the row on which the plants were counted. The distance will be divided by 2 to calculate average row spacing. Row spacing will be recorded on data sheets.

VG3: Row Direction

The direction of planting will be recorded (in degrees) using a compass, and using magnetic North as a reference. Thus, you will need to line up your N direction to the magnetic needle and record the direction of the row based on that reference. Correction of these readings to true North can be done afterwards.

VG4: Leaf Area Index
LAI will be captured using hemispherical digital photos. Seven photos will be taken along two transects (14 photos in total) at each of the three vegetation sites. These photos will be post-processed to estimates of LAI.

Some confusion in the collection of LAI led to errors in the 2012 campaign. As such, some modifications to the instrumentation and better training will be implemented in 2016. AAFC is fabricating telescopic light-weight aluminum poles upon which the camera is mounted. With these poles, cameras are suspended well above the crop canopy and thus only downward facing photos are necessary. The fixed pole also helps to maintain the camera lens level to the surface of the field. In this configuration, field crews no longer have to decide on upward or downward facing photos. For all crops (corn, soybeans, canola and wheat), all photos will be taken above the canopy during the first window in June. In July, the same configuration is used for all crops except for corn, where photos will be taken upward instead. If resources permit, photos will be more closely reviewed following measurement dates to correct any problems during the data capture.

VG5: Biomass and Canopy Water Content
Vegetation biomass will be collected via destructive sampling. Canopy water content is derived from the biomass samples. One biomass sample will be collected per measurement site.

The approach to sample collection will be determined by the crop (Table 16). For canola, wheat, oats, barley, grassland and tame hay, a 0.5 m x 0.5 metre square will be placed over the canopy. All above ground biomass will be collected by cutting all vegetation at the soil level. This approach is also well suited for crops which are broadcast seeded, or which have very dense planting. For corn and soybeans fields, 5 plants along two rows (10 plants in total) will be collected. Knowledge of the density of the crop will permit scaling of these measurements to a unit area (m^2). Any weeds that are collected in the sampling plot are discarded in the field but should be noted on the data sheets if the amount is significant. Photos should also be taken for documentation purposes.

On vegetation sampling dates, three samples in total will be removed from each field (one biomass sample per sampling site). The specific samples sites will differ based on the sampling week for each of the field campaign windows. Please refer to Table 15 for specific dates and site locations. The goal will be to sample each field at least once per week.

Table 16. Biomass sampling strategies for each crop type.

Biomass Sampling Strategy	**Crop Types**
0.5 m x 0.5 m square	canola, wheat, oats, barley
5 plants along two rows	corn and soybeans

Samples will be first placed first in a mesh bag, and then a plastic bag to minimize water loss prior to weighing the wet sample. The mesh bag must be labeled with the date, field and site numbers on a label and then attached to the mesh bag with a zip tie. Vegetation will degrade rapidly (within a few hours) and thus weighing of the wet sample must be completed quickly. Thus during vegetation sampling days, the lab crew will have a temporary weighing station located on site. Crews are to bring their vegetation samples to the lab station when possible and convenient. To facilitate standardization and reduce errors, one team of two people will be assigned to weigh all samples. Wet weights are taken with the mesh and plastic bags (size of bags used and average bag weight must be pre-recorded). Following wet weighing, plastic bags are removed. If the samples are heavier than 1 kg, the vegetation plants must be subsetted to create a subsample of no more than 1 kg. The subsample will be left in the mesh bag and weighed immediately. Thus, it is important to try and keep the plants as intact as possible during the collection. Plants can be folded into the bag and broken as long as plant tissues are still connected. The mesh bag and subsetted sample will be placed in the air drying facilities at the U of M for a maximum of two weeks. The weight of the air-dry sample is then taken. For each field, one of the air-dry samples (from site 14 on week 1 and site 13 on week 2) will be placed in a plant drying oven at 60^{o} C for 48 hours to determine the oven-dry weight. The average ratio of oven-dry weight to air-dry weight for each crop will be multiplied by the air-dry weight for each sample to correct the biomass to oven-dry basis. The oven-dry plant biomass will be used to determine plant canopy water content.

The lab crew will segment a specific sample by plant organs, i.e. from the sample at site 2 for week 1 and site 3 for week 2 of each field campaign window. There is an exception to this rule which is that all wheat biomass samples will be segmented into (a) stems+leaves and (b) heads. After segmentation, labels for mesh bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. The level of segmentation will depend on the crop and is described in Table 17.

Table 17. Segmentation of the biomass sample required for each crop type.

Segmentation / Crop Type	**Sample A**	**Sample B**	**Sample C**	**Sample D**
Wheat, oats, barley	Leaves / Stems			Heads
Corn	Leaves	Stems	Tassels	Cobs
Canola, soybeans	Leaves	Stems		Seeds / Pods

VG6: Height

Crop height can vary significantly and increasing the number of measurements will help to improve the accuracy of the average crop height. Plants that are collected from the biomass sample are used for this measurement. In total, 10 heights will be measured, 5 in each of two rows. For narrow-row crops such as wheat, oats, and barley, the height will be measured to the top of the upper most part of the canopy, whether leaf or fruit. Leaves are to be left in their natural orientation, and not extended, for this measurement. Heights can be measured before or after biomass sampling (whatever is easiest) and recorded on data sheets.

VG7: Plant Phenology

One lab crew (2 people) will be responsible for weighing the wet and dry biomass samples. The lab crew will also be tasked with recording the phenology of each biomass sample for a total of 3 phenology records per field. This determination will take place during the weighing process and recorded on data sheets. The BBCH scale will be used.

VG8: Point multi-spectral crop scans

Above canopy reflectance measurements will be collected in order to characterize the general crop condition and growth state in a number of optical and infrared wavelengths.

A Crop Scan multi-spectral instrument will be used to capture reflectance of the crop canopy. These reflectance data will only be collected on the first vegetation sample site (site 2 or 3 depending on the week) in each field. The crop scan measurements will be taken at approximately the same points at which the LAI photos are captured. This will yield 14 crop scan measurements (7 in each of two rows) for one vegetation site in each field.

VG9: Field-scale multi-spectral crop scans

A drone-mounted Micasense RedEdge 3 multispectral camera (Figure 28) will be used to acquire an image for the footprint of each field from which the soil moisture and vegetation samples are gathered. The camera acquires 5 spectral bands (Table 18). The drone schedule will be managed to facilitate the capture of a weekly image at each sample field during the two-week June and July field campaign windows. In addition, a sample will be gathered once during the intervening 2 weeks, once prior to the June sampling period and once after the July sampling period (i.e. approximately 7 images per field over the growing season for a total of 350 images).

Figure 28. Micasense RedEdge 3 multispectral camera.

Table 18. Spectral Bands captured by the Micasense RedEdge 3 camera.

Band Number	Band Name	Center Wavelength (nm)	Bandwidth FMHM (nm)
1	Blue	475	20
2	Green	560	20
3	Red	668	10
4	Red Edge	717	10
5	Near Infrared	840	40

The spatial resolution of the camera images will be less than 10 cm. The drone carries a downwelling radiation sensor that senses the radiation in each of the 5 bands. These readings will be used to correct the measurement of the reflectance in each band. In addition, a Before-Flight Reflectance Panel will be used to capture a calibrated surface reading immediately before and after the flight on each field. The images will be captured in the 5-hour period bracketing solar noon (approximately 1:30 p.m. Central Daylight Time) which is from 11:00 a.m. to 4:00 p.m. When possible, the drone will be deployed just ahead of physical vegetation sampling on some fields on vegetation sampling days. On those dates, high resolution Normalized Difference Vegetation Index (NDVI) and enhanced vegetation index (EVI) values will be extracted from the vegetation sample locations to develop a calibration between the vegetation indices and the vegetation wet biomass and vegetation water content for each crop type.

For each date on which the drone is deployed at a given field, an area average NDVI and EVI will be calculated for the entire soil sampling footprint to provide a field-scale biomass and vegetation water content. However, this can be subsampled to any spatial resolution required.

A summary of the details for the vegetation sampling is included in Table 19

Table 19. Summary of vegetation sampling strategies.

VegetationProperty	Number of sites per field	Replicates per site	Instrument	Temporal frequency	Description of approach	Assigned Team
Static Vegetation Parameters						
Plant Count	1	10	Meter stick, tennis ball	once	Count number of plants along 1 metre	AAFC students prior to campaign
Row Spacing	1	10	Meter stick	once	Measure the distance of the two rows adjacent to the plant density count	AAFC students prior to campaign
Row Direction	1	1	Compass	once	Measure row direction using magnetic north as a reference	AAFC students prior to campaign
Dynamic Vegetation Parameters						
Leaf Area Index	3	14	Camera and fish eye lense	once per week	7 photos taken along 2 transects (14 in total)	Biomass Team
Biomass and Canopy Water Content	3	10 plants for corn and soybean, 0.5 x 0.5m sample for every other crop	0.5 x 0.5 m square	once per week	For canola, wheat, oats, barley, grassland, tame hay collect all biomass within square; For corn and soybeans collect five plants along each of 2 rows (10 in total)	Biomass Team
Height	3	10 plants	Meter stick/tape measure	once per week	Measure height of plants that are collected from the biomass samples (10 plants, 5 in each row)	Biomass Team
Phenology	3	1	BBCH scale	once per week	Determine phenology for all three biomass samples	Lab Team
Point canopy reflectance	1	14	CropScan	once per week	One Crop Scan measurement for each LAI site (on site 2 or 3 of the field).	Biomass Team
Field scale canopy reflectance	Entire field	1	Drone-mounted Micasense RedEdge 3 camera	once per week, from May 30th to July 29th		U of M. Team

Appendix – Ground measurement protocols

A.1. Overview of daily activities

Schedule 1 – Soil moisture sampling days.

PALS flights are planned to begin at 7 AM and end at 9 AM local time, to match with SMAP's overpass at 8:00 AM. Thus, field crews will need to begin sampling at 6 AM.

Weather Briefing, by phone Inform team of Go-No/Go	4:30 a.m.
Departure from U of M to field if "Go" No/Go days – vegetation/roughness Rain days – down days for crews	5:15 a.m.
Arrival at site and start sampling • **5 fields per team, sampled in order of priority**	6:00 a.m. – 11:00 p.m.
Overpass time	7:00 a.m. – 9:00 p.m. (PALS)
End of sampling and start to U of M	11:00 p.m.
End of day time and activities	12:00 p.m. o Truck cleanup and organization for next day (field crew) o Data sheets photocopied and filed (lab crew) o Data downloaded from Hydra Probes (TBD) o Pass soil samples to lab technician for weighing o Check in with Coordinator (Jarrett)
Weather Briefing, lead personnel only	4:45 p.m.
Announcement of tentative GO/NOGO decision for next day	6:00 p.m. or sooner

Schedule 2 – Biomass and roughness sampling days

Departure from U of M to field	8:00 a.m.
Arrival at site and start sampling	9:00 a.m.
End of sampling and start to base	3:00 p.m.
End of day time and activities	4:00 p.m. o Truck cleanup and organization for next day (field crew) o Download field photos (field crew) o Download LAI photos (field crew) o Data sheets photocopied and filed (lab crew) o Place vegetation samples into drying ovens (lab crew) o Download crop scans (TBD) o Check in with Coordinator (Jarrett)
Weather Briefing, in person (lead personnel only)	4:45 p.m.
Announcement of tentative GO/NOGO decision for next day	6:00 p.m. or sooner

A.2. Soil moisture measurements protocols

A.2.1. Soil moisture sampling instructions

1. Please be sure to indicate your reader or unit number, field ID, crop type and start date/time on your sheet. Set your recording device (iPOD) to the loam setting.

2. Using your pre-supplied GPS coordinate, walk to the first point in the field.

3. At each point (1, 2 …8) in each transect, take three measurements. Ensure that you have good contact with the soil. You may need to brush aside or scrape away any surface debris to get good contact.

4. Take a soil moisture reading (store and mark on data sheet) three times - top, bottom and side of furrow.

5. At points 1, 8, 9 and 16, record a soil temperature reading (make good contact and allow the device to equilibrate for 1 minute). A measurement is taken at 5 cm then the thermometer is pushed down to the 10 cm mark and a second reading is taken once the temperature equilibrates.

6. At points 1, 8, 9 and 16, take a TIR measurement and record the temperature of sunlit vegetation, shaded vegetation, sunlit ground and shaded ground.

7. At a pre-determined site (announced at the start of the sampling day), take one bulk density soil core alongside one hydra probe reading. Each core should be taken within 15 cm of the hydra probe reading. Two soil cores will be taken in each of your fields (1-5) each day such that at the end of each sampling day, you will provide 10 cores to the lab crew. On sample day 1, take two soil cores at site 1, on sample day 2 take one core at site 1 and a second core at site 2, on day 3 take one core at site 1 and a second core at site 3 and so on.

    a. Push the aluminum ring pushed vertically into the soil until fully inserted (Figure 29).

Figure 29. Aluminum sampling rings fully inserted alongside a POGO reading location

    b. The aluminum ring is then gently removed by inserting a trowel underneath to loosen the soil (Figure 30). Once removed, the soil sample is trimmed on both ends to ensure an exact volume of soil has been removed (Figure 31). The sample in the ring is then carefully transferred to the sample container ensuring that soil is not spilled during the transfer and that none is left sticking to the sample ring. The lid is placed on the sample container and the container is put inside a Ziploc bag, which is marked with the date, field number, sampling site, sample position and replicate number.

Figure 30. Loosening a sample ring to remove the sample from the soil

Figure 31. A sample that has been trimmed to size and now ready to be transferred to the sample container

8. Please record any pertinent details such as if the field is wet with dew and when it dried, if there were any small showers, if there was evidence of recent tillage or spray, (there will be widely spaced tracks in the field).

9. Record your end time on your data sheet.

10. At one point in the field, take a photo of the completed field diagram from the soils data sheet and then take a photo of the field in the direction of the crop row or tillage direction.

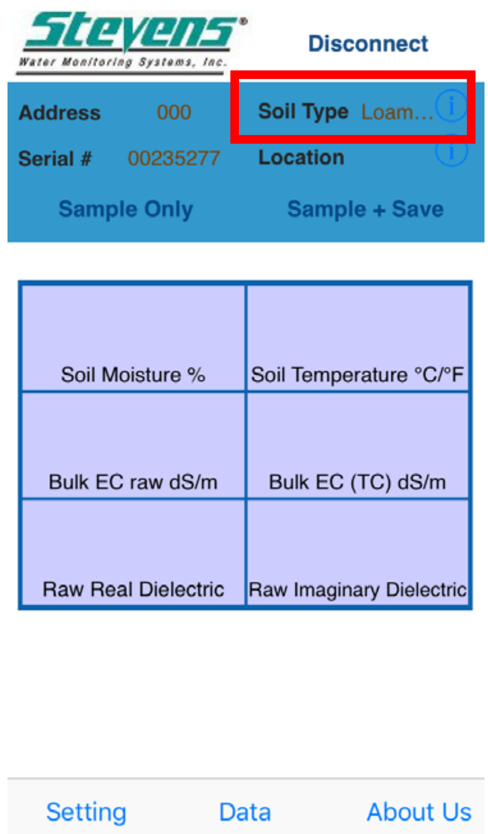
A.2.2. Using the POGO Hydra Probe and downloading data

INSTRUCTIONS FOR SAMPLE TEAM

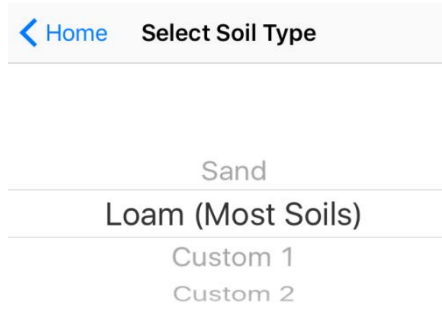
1. Turn POGO power on and open the “**Hydramon**” App on the Ipod (or alternative device)

2. Click “**Connect**” on the Ipod. If device does not connect, go into Ipod “**Settings**” under Wi-Fi and select the WiFi associated with the POGO (will either start with Stevens or POGO). If you still have issues connecting to the device, please check to see if there are instructions in the Ipod “**Notes**” and see if there is information regarding changes in IP addresses.

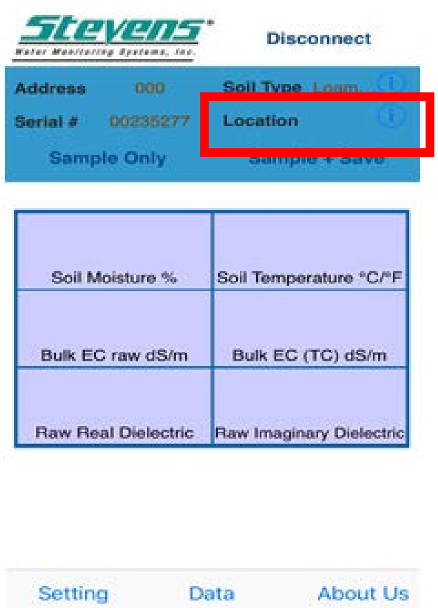
3.

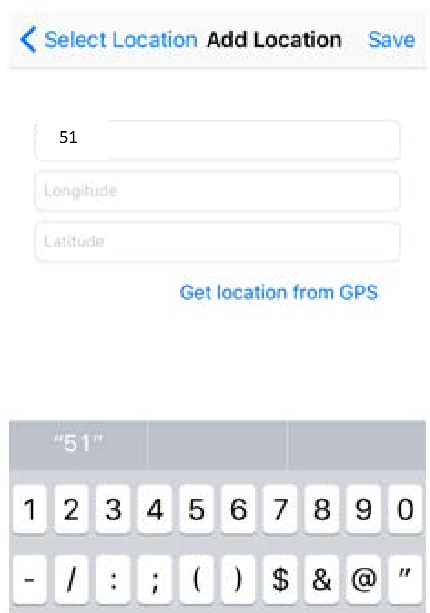


4. Next press on “**Soil Type**” and ensure that it is set to “**Loam**”. If it is not, change this to loam by tapping on or next to “**Soil Type**”



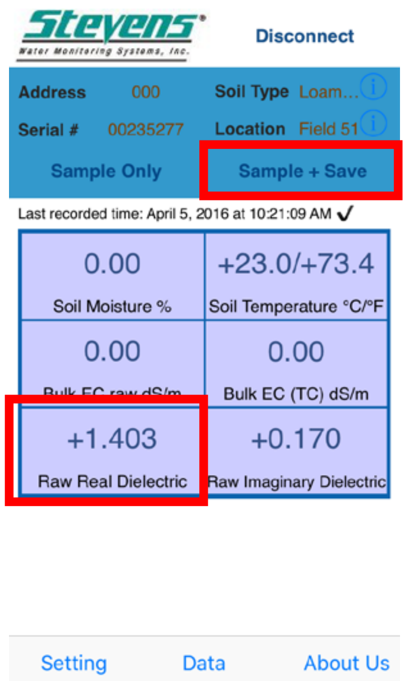
5. Click on “**Location**” and then “**Add**” and under “**Name**” enter the field number (e.g. 51) that you are currently sampling or select this field from the list if already present and click “**Save**”. Latitude and Longitude are not necessary. It is also not necessary to change it at every point.





6. Insert the POGO vertically into the ground until the plate is flush with the ground. Do not push it so hard that you cause soil compression.

7. Click “**Sample and Save**”. This will provide a reading of Soil Moisture % and Raw Real Dielectric (along with temperature and bulk EC information). This measurement has now been recorded, but the Raw Real Dielectric should be recorded on the sampling sheets (e.g. in this example, 1.403).



8. Remove the POGO from the ground and remove ALL soil that is attached to the tines of the probe and on the plate. Failure to do so can cause error in future readings.

9. If an erroneous measurement is taken (e.g. probe wasn’t properly inserted), note this on the sampling sheet. These data can be later removed from the POGO files.

10. At the end of the day, return POGO to equipment team. **DO NOT CLEAR THE DATA.**

INSTRUCTIONS FOR DOWNLOAD TEAM

11. When connected to WiFi, click “**Data**” and at the bottom, select “**Send by Email**” and enter the specified email address. Also, please change the subject line to “POGO data Team __ June __” and enter team number and the date.

A.3. Soil roughness

The surface roughness is measured using a pin profiler and digital camera. The use of a compass is necessary to place the pin profiler in the same direction as the look direction of the following sensors:

RADARSAT 2 perpendicular to descending orbital track: 282 degrees clockwise.

PALS perpendicular to flight track: 90 degrees clockwise.

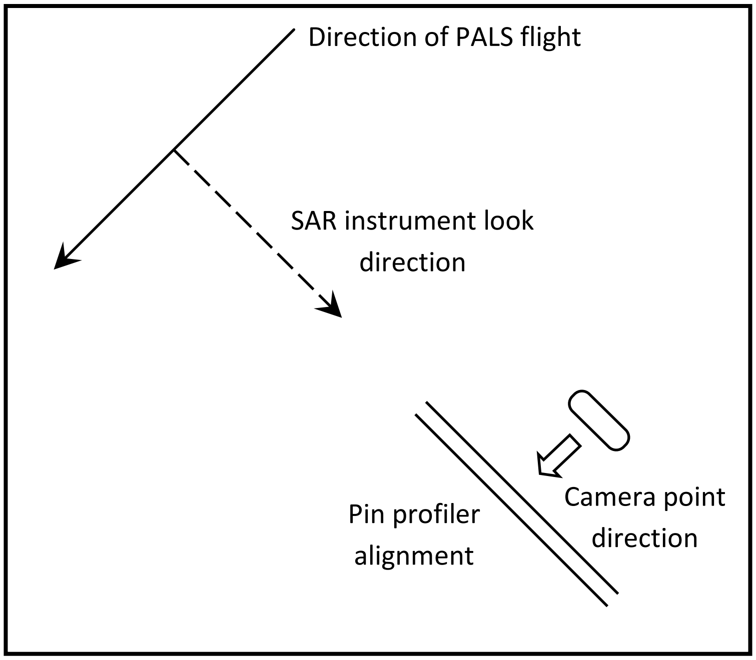
NOTE: The look direction is the direction perpendicular to the orbital track or flight line as the SAR is side looking.

For each field, roughness measurements will be collected at two sites. For each site, a set of measurements consists of three, 3 m replicates in the look directions of RADARSAT2 (descending) and PALS flights. One replicate is represented as a surface roughness measurement of 3-m length. The 3-m profile is created by taking three 1-metre profile photos immediately adjacent to each other (i.e. take one photo, move pin profiler so that the end of profile photo 1 is the beginning of profile photo 2, and so on). Thus for each site a total of 6 photos (3 adjacent photos x 2 look directions) will be taken in the look directions of the SAR sensors (RADARSAT2 (descending mode) and PALS). This leads to 12 photos (3 adjacent photos x 2 sites x 2 look directions) for each field. If the surface roughness is considered very smooth with no row structure, the roughness team can opt to take the roughness measurements in the look direction of one sensor (i.e. 6 measurements, 3 per site) to represent the roughness viewed by the three SAR sensors. The pin meter traces the variation of surface height and the information is recorded in a photograph taken with a digital camera (see the figure below). The photographs of each 3-m profile measurement will be processed with software to derive the values of the roughness parameters s and l, corresponding to the standard height and the correlation length of the site as observed in the look direction of the satellites and of the PALS. Then, the mean and the standard deviation values of the parameters s, l are computed to determine the field roughness.

- 1-m long profilometer will be used to estimate the surface roughness. The profiler is placed end to end 3 times to give a 3-m long profile measurement,
- One replicate consists of a 3-m profile parallel to the look direction of RADARSAT2 (descending mode) and PALS sensors,
- 2 sites per field,
- Before taken the photo (10 megapixel camera) of the pins, vegetation is removed (or flattened by using a long cardboard) along this transect so that this vegetation doesn't interfere with the soil roughness measurement,

Pin Profiler and Camera Protocols:

1. With the compass find the look direction of the sensor (account for the magnetic declination of the study area ~ 4°20'E),
2. Install the profiler in the look direction of the sensor, as shown:



3. Place the metallic bars of 61-cm long at left and right sides of the profiler to identify its location,
4. Place the digital camera on the metallic bar of 127-cm long fixed at the top of the profiler and perpendicularly to it; the distance between the camera and the profiler is ~ 118 cm,
5. Remove the vegetation along the profiler (or flatten it by using a long cardboard) to avoid interference with roughness along the profiler,
6. Use the legs fixed on the back of the profiler to level the profiler (check with the bubble level).
7. Use the hook to slide down the pins,
8. Take the photograph of the tops red pins (see figure below),
9. Record the photograph number on the worksheets,
10. Turn off the camera and remove it from the 127-cm long metallic bar,
11. Handle horizontally the profiler, one people at each side, and use the hook to replace the pins as they were before they slid down,
12. Use the previous location of the profiler (marked with the 61-cm long metallic bars) to place it end to end, for the next measurement,
13. Repeat the process 3 times to obtain a 3-m long profile measurement.

Notes

- The above mentioned dimensions referred to the profilometer used during CanEx-SM10,
- Do not install the profiler on a soil surface that is trampled
- To avoid damage, handle the device carefully,
- Withdraw the damaged pins and replaced them,
- Keep a space on both sides of the profiler. This is very important for the photographs processing,
- If need, help the pins to slid down,
- To avoid interference between the red tops pins and the clothes color during the photographs processing, do not wear red clothes.

A.4. Vegetation

A.4.1. Cropland vegetation sampling protocols

VG1: Plant Count

Plant spacing will be determined by counting the number of plants which have emerged in a single row, over a 1-meter distance, replicated 10 times.

- Lob a tennis ball towards a random location in the field
- At the spot where the tennis ball lands, place a meter stick parallel to the closest row
- Count the number of plants along the 1 meter stick
- Record number of plants on data sheet
- Move perpendicular to the rows, and replicate 10 times in each field

**Timing: Plant spacing should be completed prior to commencement of field campaign.

VG2: Row Spacing

Row spacing will be determined by measuring the distance between rows replicated for 10 rows.

- At each location after the plant count is taken, turn the meter stick perpendicular to the row direction that was just counted.
- At the soil level, measure the distance in centimeters between the centers of the two plant rows immediately adjacent on either side of the row on which the plants were counted.
- Divide this number by 2 to calculate the average row spacing; record on data sheet.
- Repeat 10 times, at each location of the plant spacing measurements.

Plant density (PD) will be calculated as follows:

$$Plant\ Density\ (PD) = \frac{Average\ \ number\ of\ \ plants\ in\ 10m}{Average\ \ row\ width\ in\ 10m} = \frac{Average\ \#\ Plants}{m^2}$$

**Timing: Plant spacing should be completed prior to commencement of field campaign.

VG4: Leaf Area Index (LAI)

Seven hemispherical photos will be taken every 5 meters, along two parallel transects on sites 2, 11 and 14 for Week 1 of each window, and sites 3, 10, and 13 for Week 2 of each window (Table 15). Thus for each site, a total of 14 photos are taken.

- The LAI pole will be already mounted with the camera and fisheye lens. All photos will be taken downward, except for corn during the second window where photos will be taken upward facing. Record orientation on the datasheet (which should be similar throughout the same field).
- Upon arrival to a site, extend the arm with the camera and tighten the hinge. Turn on the camera and ensure settings are correct (see below). Expand the telescopic pole to its maximum (175 cm) length and tighten the screw.
- In the case of row crops, photos will be taken in the middle of the crop row.
- Take the first photo. Take photos 2-7 at 5 meter increments along first transect.
- Cross over to second row, and take photos 8-14 at 5 meter increments along this second transect.
- When walking back on this second transect, be sure to offset the location of photos as shown in Figure 32.
- When taking the photo, the operator should always face the sun.
- Record the photo numbers on the data sheet.
- Mark the sun direction on the data sheet.

Camera setup:

1) Exposure Mode set to P (programmed).
2) Frame Release Mode (top left dial of body) set to Single.
3) Auto Focus Mode (front of body) set to Manual.
4) Metering (top right) set to Matrix.
5) AF Area Mode set to Matrix.
6) Image format (using menu) set to NEW RAW HIGH + JPEG fine.
7) Image quality (using menu) set to 14 bit.
8) White balance (using menu) set to sun or shadow.
9) Active D Lighting (using menu) set to Auto.
10) Hand held (using menu) set.
11) Noise reduction (using menu) set to hand held.
12) Image display (using menu) set to histogram + details.
13) Set local time (using menu)

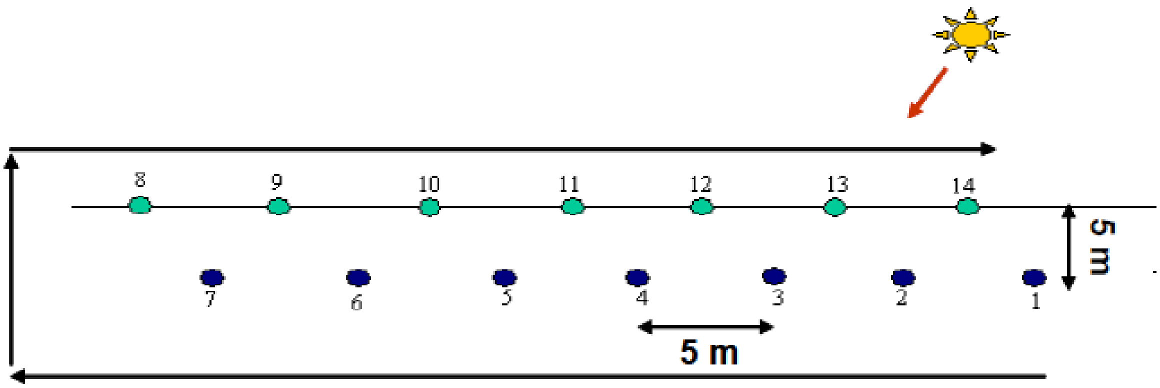


Figure 32. Sampling transect for hemispherical photos to measure LAI

VG5: Biomass and Canopy Water Content

1. Wider-spaced row crops (corn, soybeans)

For larger biomass and wide-spaced row crops, biomass will be determined on a per plant basis and scaled to total biomass using the plant density calculations. At each sample location, 10 plants (total) will be harvested from 2 consecutive rows (5 plants x 2 rows).

- With a knife, cut the crop at the base of each plant. Do not include residue or weeds in the sample.
- Place the crop in a labeled paper biomass bag. The top of the bag can simply be rolled down. Then place the paper bag inside a plastic bag. Secure the plastic bag with a firm knot.
- The paper bag should be labeled as follows:
  Field # - Site #
  Date (Year-Month-Day)
- If the plants are large, it may be necessary to use more than one paper bag. In this case, place each paper bag inside a separate plastic bag and add the following additional label to the paper bag:
  Sample x of y (for example: Sample 1/3)
- If the plants are wet with dew, gently shake the vegetation prior to bagging.

<u>At the lab</u>

Lab personnel should:

- For the sample gathered from the first vegetation site (site 2 or 3 depending of the week) of each field, the biomass sample will be segmented. The level of segmentation will depend on the crop and is described in the table below:

Table 20. Segmentation of the biomass sample required for each crop type.

Segmentation / Crop Type	Sample A	Sample B	Sample C
Wheat, oats, barley	Leaves / Stems	Heads	
Corn, canola, soybeans	Leaves	Stems	Seeds / Pods and Cobs
Grassland and tame hay	No segmentation required		

- Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. For example,
  Field # - Site # - Leaves
  Date (Year-Month-Day)

2. Narrow-spaced row crops (wheat, barley, oats, canola)

For low biomass and narrow-spaced row crops, biomass will be collected from within a standardized 0.5 m x 0.5 m area, using a quadrat. At each sample location, one sample will be gathered.

- Place the quadrat over the top of the crop.
- With a knife, cut all plants within the quadrat, at the base of each plant. Do not include residue or weeds in the sample.
- Place the crop in a labeled paper bag. The top of the bag can simply be rolled down. Then place the paper bag inside a plastic bag. Secure the plastic bag with a firm knot.
- The paper bag should be labeled as follows:
  Field # - Site #
  Date (Year-Month-Day)
- If the plants are wet with dew, gently shake the vegetation prior to bagging.

<u>At the lab</u>

Lab personnel should:

- From the first vegetation site (site 2 or 3 depending of the week) of each field, the biomass sample will be segmented. The level of segmentation will depend on the crop and is describe in Table 20 above. All wheat biomass samples will be segmented.
- Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. For example,
  Field # - Site # - leaves
  Date (Year-Month-Day)

- If the plants are large, it may be necessary to use more than one paper bag. In this case, place each paper bag inside a separate plastic bag and add the following additional label to the paper bag:
  Sample x of y (for example: Sample 1/3)

3. Lab procedures and calculation of biomass and canopy water content

The lab crew will be stationed on site with a portable weighing scale. The plant samples will be returned to the University of Manitoba for drying and determination of dry biomass weights. Canopy water content will be derived from these weights. One team of two will be tasked with weighing and drying all the samples.

Wet weights should be taken as soon after biomass collection as possible, as plant matter can degrade quickly. To slow this process, field crews should keep samples in a cool shaded place if possible until samples can be weighed at the temporary lab station.

- Tare (zero) lab scale.
- Leave plant sample in paper and plastic bag. Place sample on scale and record weight in grams.
- If plant sample is too large for the scale a larger flat surface (pan, cardboard) can be placed on the scale before it is zeroed.
- Determine the size of the plastic bag used and weigh 10 plastic bags. Record the weight of these 10 bags.
- Back at the University of Manitoba, remove the plastic bag and place paper bag in drying room.
- Dry at about 30^{o}C for 1 week.
- Before re-weighing crop samples, verify that sample has been completely dried. If uncertain, place crop sample back in drying room until re-weighing establishes that dry weight is constant.
- Tare (zero) lab scale.
- Leave plant sample in paper bag. Place sample on scale and record weight in grams.

Plant water content (PWC) will be calculated as:

$$Plant\,Water\,Content\,(PWC)\,(g) = \left(Wet\,Weight\,(g) - Plastic\,Bag\,Weight\,(g)\right) - Dry\,Weight\,(g)$$

For wider spaced row crops (corn, soybeans, sunflower, etc.), plant water content will be scaled to an area basis (grams of water per m^2) according to:

$$Area\,PWC\,(gm^{-2}) = \frac{Total\,PWC\,(g)}{Number\,of\;\,plants\,collected}\,x\,PD\,(plants\;\,per\;\,m^2)$$

Narrow spaced low biomass crops are already collected on an area basis (0.25 m^2). Thus the total plant water content is easily scaled to g/m^{-2} by applying a factor of 4.

VG6: Height

The plant height of ten plants will be recorded at each site.

- Plants that are collected from the biomass sample are used for this measurement. Heights can be measured before or after biomass sampling.

- Use a tape measure to measure the distance from the soil to the highest point of the plant. Do not extend leaves. Leaves should remain in their naturally occurring position/orientation during measurement.
- Take 5 height measurements in one row. The second set of 5 measurements should be taken in the adjacent row.
- Record in centimeters all 10 measurements on the data sheet.

VG7: Plant Phenology

Plant phenology will be determined by the lab technician in charge of weighing the samples.

- Phenology is recorded for every sample
- After weighing the sample take crop out of bag.
- Refer to the BBCH scale and determine the crop growth stage. Record this on the data sheet.
- Segment the crop as previously described (for site 2 or 3) and place organs in separate labeled bags.
- Place samples in drying room.

A.4.2. Reflectance data collection protocol

VG8: Point multi-spectral crop scans

Reflectance data will only be collected on the first vegetation sample site (site 2 or 3 depending on the week) in each field. One reflectance measurement will be taken at the location of each of the 14 LAI measurements (see Figure 32).

- Hold the radiometer so that it is well above the plant canopy.
- Take a reading.
- Move up 5 meters to the next LAI site and take another reading until you have 7 measurements in the first LAI transect.
- Move over 5 meters to the second LAI transect and repeat.
- In total, you will have collected 14 spectra at each field.

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