# SMAPVEX12

SMAP Validation Experiment 2012

# *Experimental Plan*

***Updated: May 3, 2012***

Revision History

| Revision | Date | Comments |
|---|---|---|
| v1 | Nov 2, 2011 | Draft v1 sent to SMAPVEX team |
| v2 | Nov 14, 2011 | Includes comments from S. Belair |
| v3 | Nov 17, 2011 | Includes vegetation protocols |
| V4 | Nov 29, 2011 | Includes description of in situ network |
| V5 | Feb 8, 2012 | Updated soil and veg protocols based on conference calls |
| V6 | March 7, 2012 | Updates from comments from Sab, RSAT acquisitions included, study site updated, downloading from Pogo from Aaron |
| V7 | March 15, 2012 | Updates from Ramata on roughness; comments from Aaron on soil measurements |
| V8 | April 19 | Updates on vegetation sampling |
| V9 | May 3 | Updates on soil sampling; addition of forest vegetation sampling, update on satellite collection, field selection |

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# 1. Introduction

### *1. 1 Project description*

The Soil Moisture Active Passive (SMAP) mission will provide global soil moisture products that will facilitate new science and application areas, while extending those that have developed as a result of its predecessors. The breakthrough that SMAP will provide is significantly higher spatial resolution on a temporally frequent basis. This will be accomplished by integrating active and passive microwave remote sensing. Passive microwave remote sensing of soil moisture has a long history in soil moisture retrieval but faces limits on spatial resolution. Active microwave techniques can provide much higher spatial resolution data but there are challenges in developing a robust soil moisture retrieval algorithm. SMAP will exploit a combination of both techniques to produce an intermediate accuracy and spatial resolution product. In addition to this “flagship” product, SMAP will also provide a standard passive (radiometer-based) soil moisture product and a research active (radar-based) soil moisture product. Level 4 (combined satellite and model) profile soil moisture and carbon products will also be developed. A radar-based freeze-thaw product is also a standard mission product.

Validation of the suite of SMAP soil moisture and freeze/thaw products is a mission requirement. During the pre-launch phase of SMAP the major concerns related to validation are providing data for the development and evaluation of the SMAP algorithms and establishing the infrastructure to efficiently conduct the post-launch validation in a timely manner. Field campaigns are one of the methodologies that are used for these purposes. In addition to validation, these field campaigns can also be structured to support the development of the SMAP Applications Early Adopters projects.

The SMAP Project Science Definition Team (SDT) and the Cal/Val Working Group provide guidance to the Cal/Val activities of SMAP. As part of a recent SMAP Cal/Val Workshop (May, 2011), the SMAP Algorithm Teams were asked to provide an assessment of what outstanding issues could be addressed with a field campaign. This input was discussed and prioritized by the Workshop participants. Based upon the anticipated launch date of SMAP, it is critical that this campaign be conducted in 2012 in order for the algorithm teams to effectively utilize the results.

The baseline and option soil moisture retrieval algorithms based on radar and combined radar-radiometer measurements exploit the fact that SMAP revisits are at near the same look angle. This is due to the conical scan approach adopted by the instruments that share a common feed and rotating reflector antenna. Radar and radiometer measurements vary according to the soil dielectric constant, vegetation structure and surface soil roughness conditions. Given the varying time-scales associated with each of these factors and near-constant look-angle, the SMAP radar and radiometer measurements can be used to isolate the soil moisture signal. Time-series sequences of measurements need to be of long enough duration to isolate these factors. The purpose and design of SMAPVEX12 is to provide extended-duration measurements that exceed those of any past field experiments. This constitutes the unique and valuable attribute of this field campaign when compared with previous airborne experiments.

Furthermore the SMAP SDT and Algorithms Development Team (ADT) were provided with questionnaires and queries to prioritize the attributes of the pre-launch SMAP airborne field campaign. All of the soil moisture algorithms had two common requirements for a field campaign; an extended time series and diverse vegetation conditions. Data sets that supported the combined active passive algorithm were considered the top priority, which necessitates an aircraft instrument suite that will provide data to simulate the SMAP sensor system.

These requirements discussed above were used to design the SMAP Validation Experiment 2012 (SMAPVEX12). It was decided that SMAPVEX12 would focus only on the requirements for validation of the soil moisture algorithms and products. In response to requirements set out by the SMAP development teams, SMAPVEX12 will be designed such that data acquisitions capture variances in both soil and canopy water content including conditions during peak vegetation biomass. Consequently, the campaign will cover a period of approximately 6 weeks. The site will be located in an agricultural region south of Winnipeg, Manitoba (Canada) which consists of primarily annual cropland with some permanent grassland and mixed forest cover.

Separate field campaigns, taking place in Alaska in cooperation with the CARVE project, will focus on the freeze/thaw algorithm and product. It should be noted that the details provided below are still under discussion and development.

### *1.2 Canadian 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 would provide 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.

The future SMAP mission is expected to become a critical source of improved soil moisture data for Canada. Consequently, the Canadian science community is engaged in pre-launch calibration and validation efforts to ready their operational program and policy counterparts to make full use of SMAP data and data products, once available.

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 campaign supported Soil Moisture and Ocean Salinity (SMOS) validation activities as well as pre-launch validation and algorithm development for SMAP. Some science gaps remain to fully exploit the data, due primarily to the unusually wet conditions in this region of Canadian in the spring of 2010. These conditions led to a reduced variability in soil moisture conditions over space and time. As well, delayed seeding meant minimal crop presence during the 2010 campaign. Consequently, the effect of vegetation on the passive and active retrievals could not be properly assessed.

The overall objectives of the SMAPVEX12 campaign are essentially to gather additional observational data to support the development and validation of the SMAP active and passive soil moisture retrieval algorithms, to support validation of modeling and assimilation of SMAP data sets. These include finding ways to better mitigate low-level RFI effects observed in North America, improve the parameterization of vegetation (and its water content), inter-compare soil dielectric models, gather concurrent active and passive observations to establish relationships, gather SMAP-scale observations to validate all the algorithms, obtain relatively long time series for the radar-based algorithms, and improve transient water body detection.

In addition to supporting these overall SMAP goals, specific Canadian objectives include:

1. To acquire and process data over a Canadian landscape to assess models and algorithms used for retrieving SMAP data products (Level 2 and 3 surface soil moisture and Level 4 root zone soil moisture);

2. To evaluate the accuracy of alternate retrieval models currently used by the Canadian community, to estimate soil moisture from SMAP (Level 1) data;

3. To adapt models for retrieval of soil moisture from microwave brightness temperature and backscatter to the Canadian landscape (using Canadian land use and soils data bases, for example);

4. To evaluate new approaches used in the land data assimilation systems to combine passive and active L-band data for soil moisture analysis (Level 4);

5. To assess the improvement in the representation of the energy, water, and carbon cycles in Canadian environmental analysis and prediction systems using active-passive data;

6. To familiarize operational program and policy users with passive and active soil moisture products, to prepare these users for exploitation and assimilation of SMAP products, once available, and for these users to provide feedback on the suitability of SMAP products for their activities.

7. To train highly qualified personnel (HQP); and

8. To develop, expand and strengthen partnerships between the Canadian and U.S. soil moisture communities.

SMAPVEX is designed to contribute directly to the objectives described in the "Canadian Science and Applications Plan for the Soil Moisture Active and Passive Mission" (August 2011). Specifically, this experiment will assist with Canadian contributions to pre-launch cal/val for soil moisture products. The SMAPVEX site is one of the core Canadian validation sites for SMAP, described in the Canadian SMAP plan.

## 2. Study site

To support the overall SMAP calibration/validation objectives, as well as those specific to the Canadian team, an agricultural domain with a range of crop types and some forest and grasslands was desired. In order to address the algorithm requirements, significant change in the vegetation water content over the study period is required (approximately 45 days).

Another element in the field campaign is the partnership of SMAP with the Canadian Space Agency (CSA). One of the major elements of this cooperation is the CSA support of validation activities, as well as its own applications projects. Initial discussions between the SMAP Cal/Val Team and Canadian scientists involved in SMAP led to a suggested site in the Red River Watershed of southern Manitoba. This region provides the desired mix of land covers and is being developed as a long-term in situ soil moisture network.

### *2. 1 General description*

Agriculture and Agri-Food Canada (AAFC), through the Growing Forward policy framework, is funding a Sustainable Agriculture Environment Systems (SAGES) project to develop a soil moisture monitoring capability to support the Canadian agriculture sector. The project encompasses not only the science, through AAFC's Research Branch, but also establishment of service delivery through the Agri-Environmental Services Branch of the department.

The SAGES implementation site selected is the Canadian Red River Watershed (figure 1). This 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's Agri-Environmental Services Branch. 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.

In situ instrumentation of the watershed will occur incrementally, with respect to the geographic coverage of the network and the number of network stations. Initially a single sub-watershed has been selected based on geostatistical analysis of soil texture and derived soil variables for all of the Red River sub-watersheds. The watershed selected, the Brunkild sub-watershed, has an excellent contrast in soil properties from west (fine clay soils) to east (coarser and better drained soils). The Brunkild watershed is approximately 60 km (east-west) by 10 km (north-south). The Brunkild sub-watershed, as well as the larger Red River Watershed, is one of the GEO Joint Experiment on Crop Assessment and Monitoring (JECAM) international super sites.

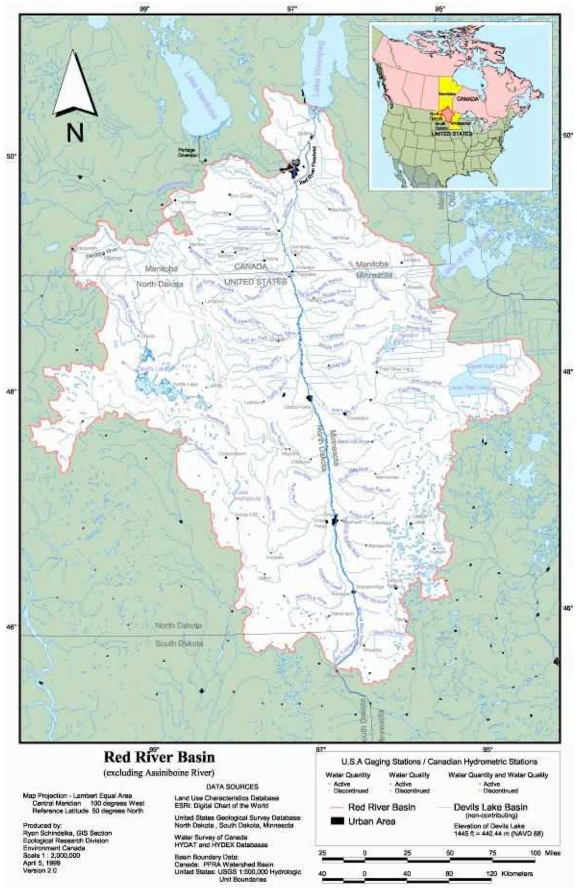



Figure 1. Extent of the Red River Watershed.
Approximately 25% of the watershed falls within Canada, with the remainder of the watershed residing within Minnesota, North Dakota and South Dakota, U.S.A

### *2.2 Intensive sample site description*

The SMAPVEX intensive sample site is located within the larger Red River Watershed (figure 2).

The location of the intensive site was selected based on the following criteria:

(a) the existing AAFC permanent in situ soil moisture stations fall within this site;
(b) the site covers a range of annual and perennial crops, typical of this region and of interest to the SMAPVEX team;
(c) the site contains some wetland and forest land covers;
(d) the site overlaps with the Brunkild sub-watershed, an on-going AAFC research site;
(e) the soil texture varies across the site and this spatial variability should provide a range of soil moisture conditions; and
(f) the site is relatively close to the home base of Winnipeg.


Figure 2. Location of SMAPVEX intensive site relative to Winnipeg

The site dimensions are approximately 15 km x 70 km. The dominant annual crops in the site include cereals (32.2% of area), canola (13.2%), corn (7.0%) and soybean (6.7%) (figure 3). Approximately 16.4% of the site is occupied by perennial cover (grassland and pasture).

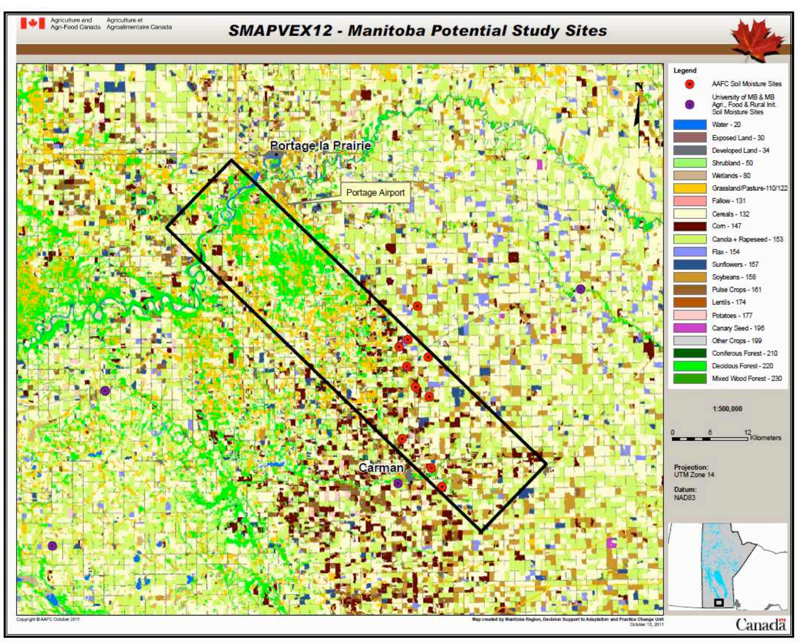



Figure 3. The SMAPVEX intensive sample site
The intensive site is outlined in black. The land cover and crop types are displayed. The AAFC permanent in situ sites are identified as red dots.

### *2.3 Overview of In Situ soil moisture networks*

Several soil moisture networks are present in the agricultural regions of southern Manitoba run by the University of Manitoba, Agriculture and Agri-Food Canada and Manitoba Agriculture, Food and Rural Initiatives (MAFRI). The AAFC network covers a small area in and around the Brunkild sub-watershed, whereas the University of Manitoba sites are more geographical dispersed (figure 4).

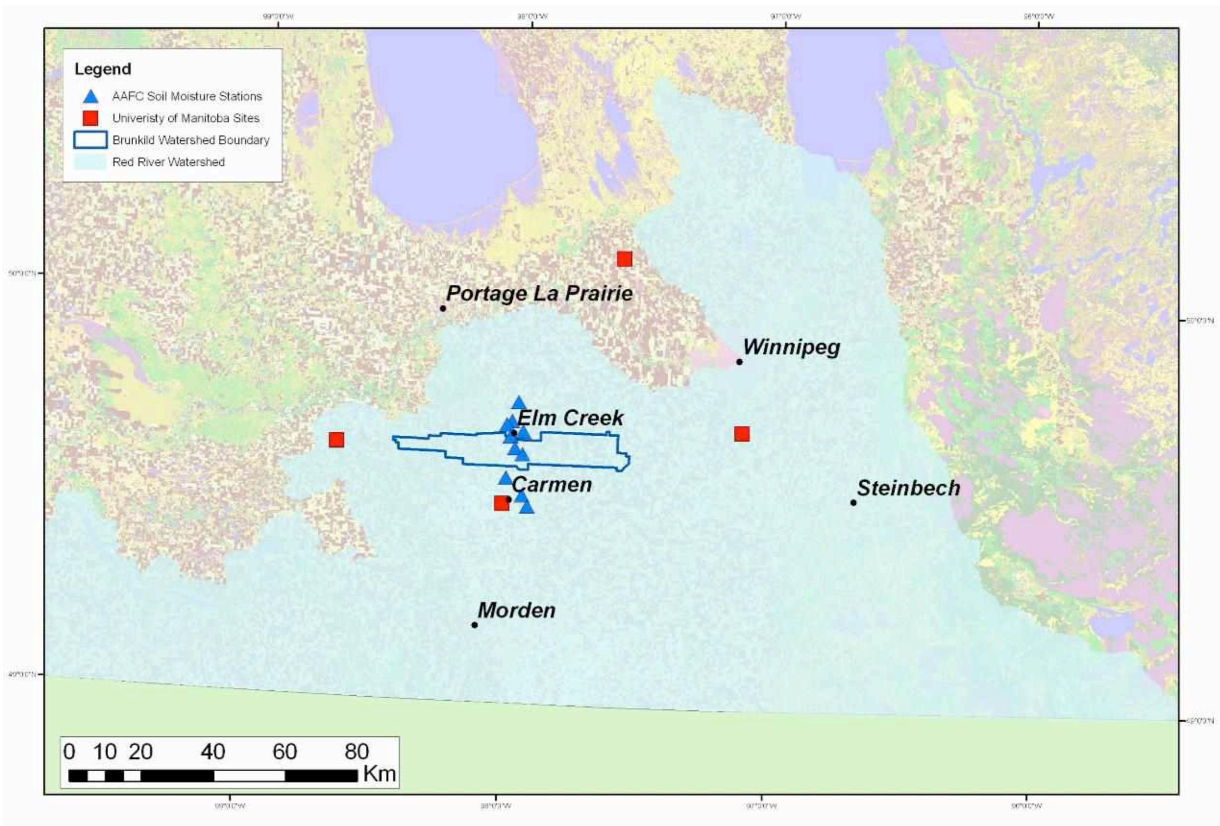



Figure 4. Location of Manitoba in situ soil moisture sensors within the Canadian portion of the Red River watershed.

In 2011, Agriculture and Agri-Food Canada (AAFC) began piloting an in situ soil moisture monitoring network in and around the Brunkild watershed. The 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 is soil texture classes (figure 5). 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 measures soil moisture, soil temperature and liquid precipitation, with triplicate measurements of the soil moisture and soil dielectric at each depth, and duplicate measurements of soil temperature. 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 6). Each site is instrumented with Stephen's Hydra Probes and a tipping bucket rain gauge (Campbell Scientific 700) powered by solar panels and batteries (figure 7). Data is logged using an Adcon A755 telemetry unit which transmits measurements to a base station in Ottawa, Ontario at 30 minute intervals. Measurements are collected on a 30 minute time scale for all variables, which include soil moisture percentage (using Stephen's default dielectric conversion model), soil temperature in Celsius and real soil dielectric permittivity. 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 and soil texture and bulk density analysis. Site specific soil moisture dielectric conversion models will be developed by using soil moisture and dielectric values calculated using a dry down process in a laboratory. These will be applied to each sensor to obtain higher accuracy soil moisture values.

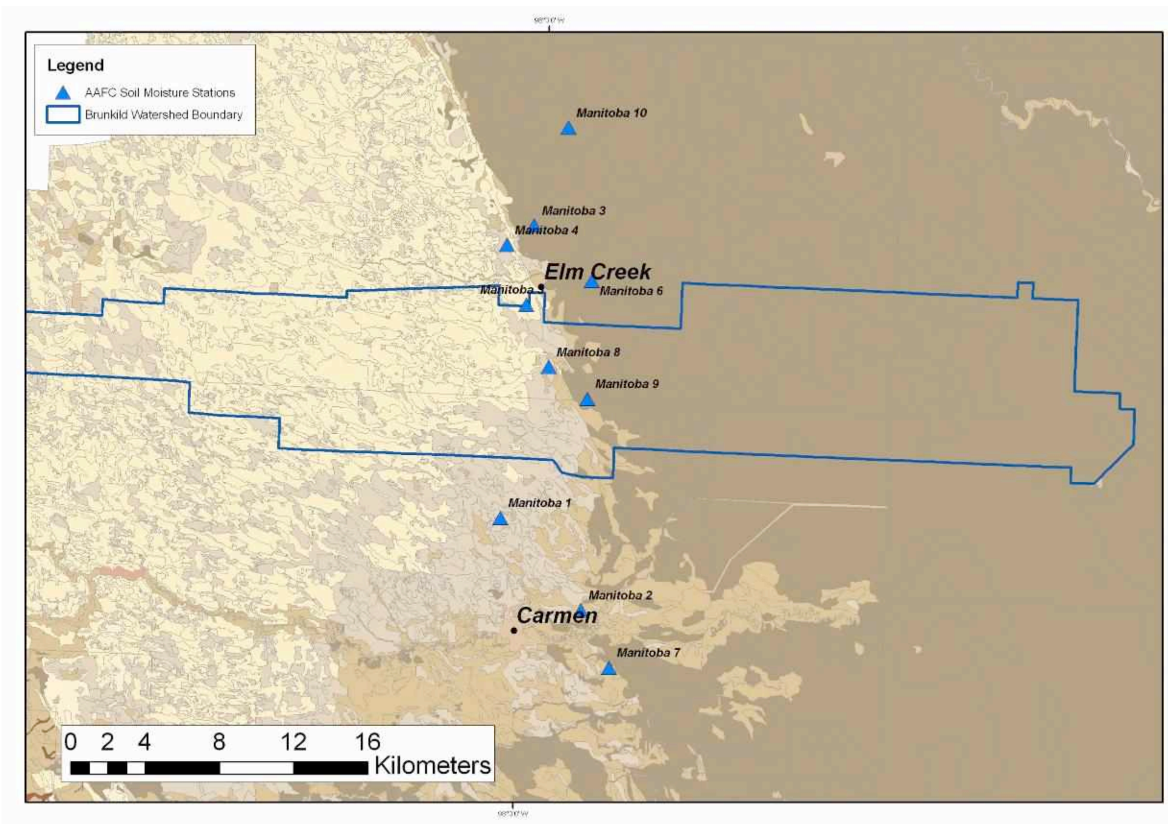



Figure 5. Location of the AAFC Manitoba in situ soil moisture network.
Backdrop image shows clay dominated soils on the eastern portion of the watershed and sandier soils on the western portion of the watershed.

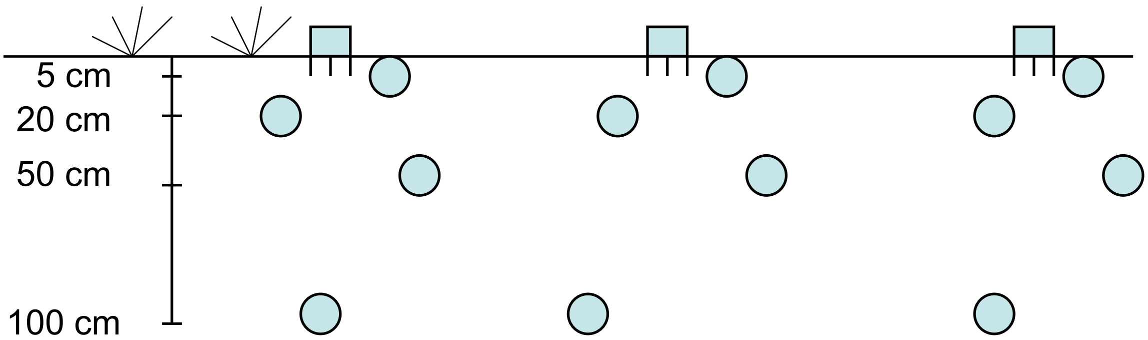



Figure 6. Schematic of probe location within each soil pit for AAFC in situ monitoring sites.

Figure 7. Site installation for AAFC in situ soil moisture sites.

As part of this soil moisture piloting, advances in wireless communications technology are being assessed through a sensor web approach. Sensor webs integrate three aspects: sensing, communication and computing. This approach seeks to create networks that can capture and distribute data in near real time and work interoperably with other networks to create a 'network of networks'. This approach can maximize scarce resources to optimize collection of critical agricultural variables. For this pilot, wireless communications are being piloted through the use of remote telemetry units (RTUs) equipped with subscriber identity module (SIM) cards to collect the data and communicate this to a centralized data base for quality control processing. Options for open geospatial dissemination of the data via various web-based platforms are being explored. Data will be disseminated publicly once a data quality control assessment has been made.

The University of Manitoba soil moisture network is run by Dr. Paul Bullock of the Department of Soil Science. This network consists of five in situ soil moisture stations (one dormant) with associated meteorological station equipment (figure 8). Stations were installed in the spring of 2009 and 2010 in both cropland and pasture sites. Data are collected via Campbell data loggers and are manually downloaded for use in academic research.

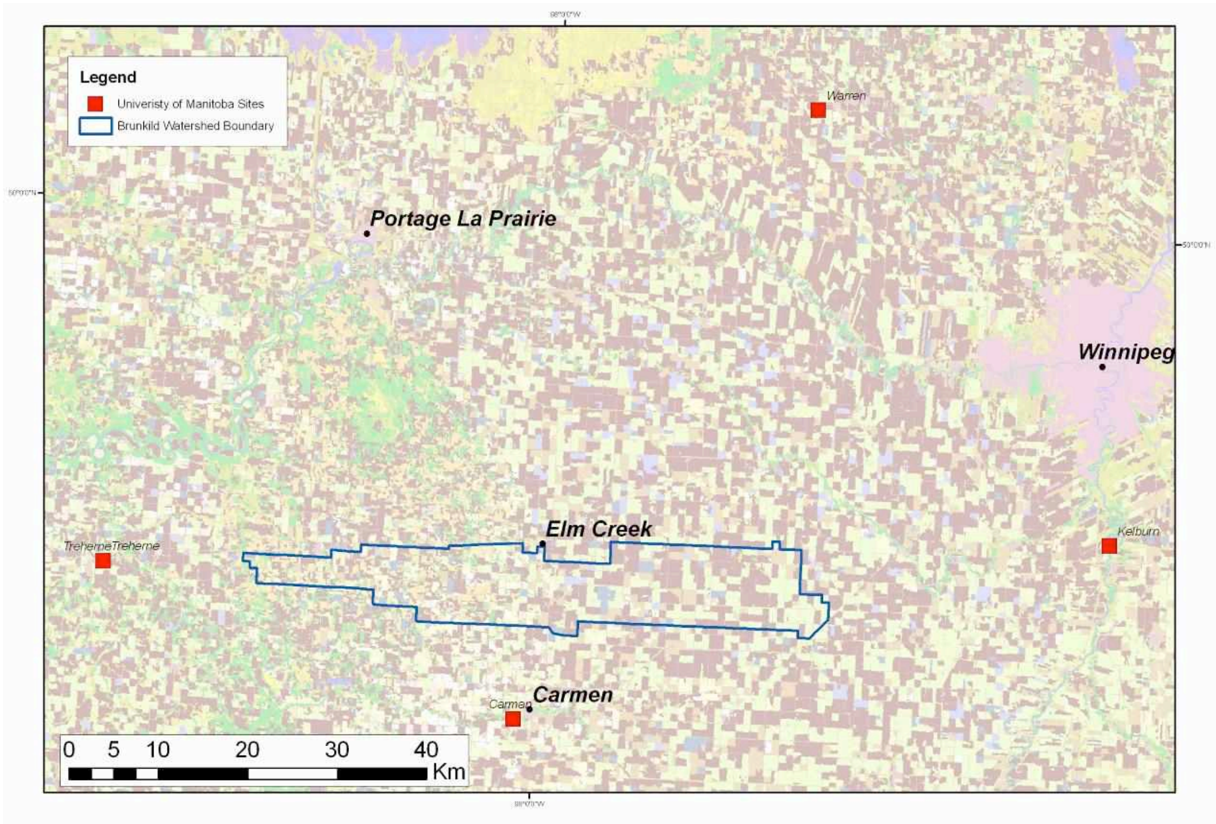



Figure 8. Location of the University of Manitoba in situ soil moisture monitoring sites and meteorological stations.

The MAFRI Ag Weather program supports soil moisture collection through the University of Manitoba stations as well as through a gravimetric survey of soil moisture conditions across the agricultural regions of the province during the last week of October of each year. This survey was started in 2004 and collects auger samples from 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm and 90-120 cm. These are weighed and oven dried and matched against a soil properties database of bulk density, wilting point, field capacity and available water holding capacity to obtain measures of available soil moisture (mm) and percent available water holding capacity for root zone (0 – 120 cm), top zone (0 to 30 cm) and sub zone (30 – 120 cm). The locations of these sample points for the Red River watershed are given in figure 9.

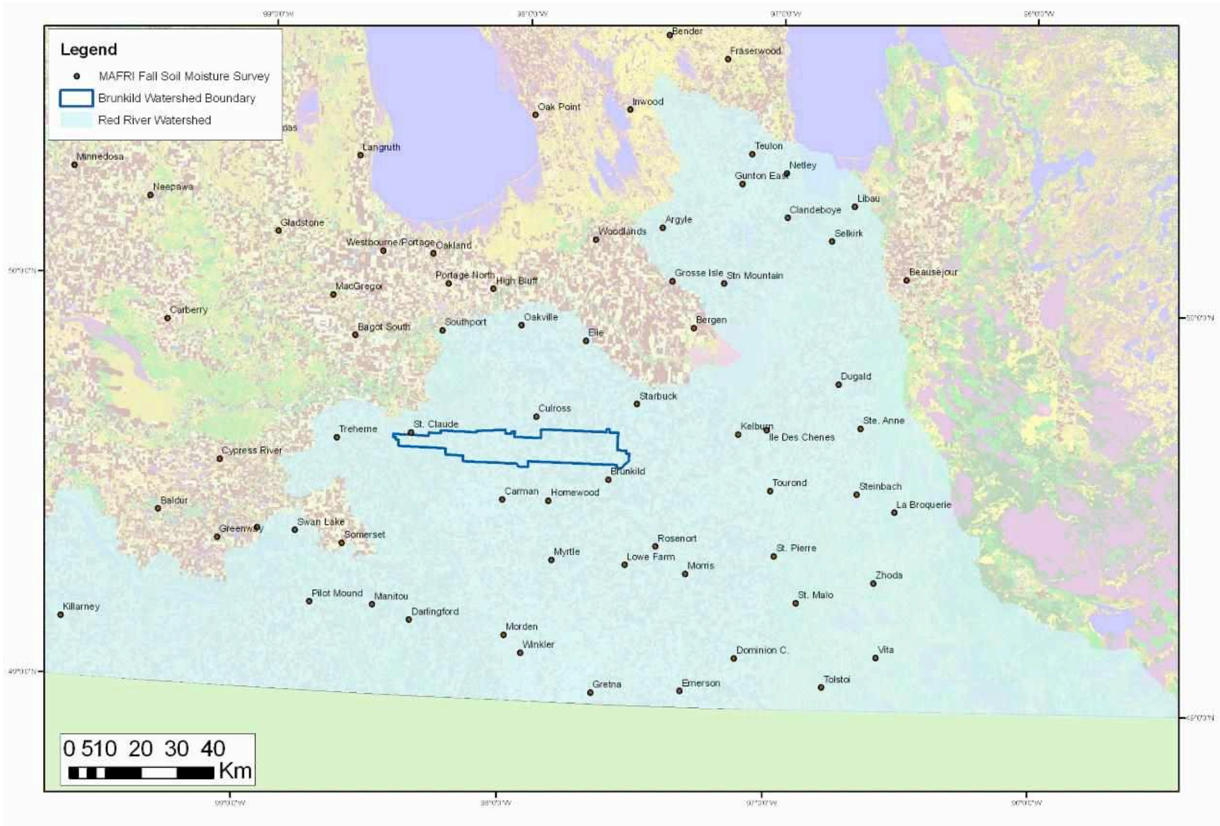



Figure 9. Location of MAFRI fall gravimetric soil moisture survey sampling

### 2.4 Availability of other supporting data

Several meteorological stations are located within the agricultural regions of Manitoba, established through provincial government agencies such as MAFRI and Manitoba Water Stewardship, the University of Manitoba, federal government agencies such as AAFC and Environment Canada and private companies such as Weather Farm, Weather Bug and Weather Innovations (figure 10). Most stations record typical meteorological variables including air temperature, total precipitation, wind speed and relative humidity, with some having additional data on net radiation, snow accumulation and soil temperature. Data from Environment Canada can be downloaded station by station from their website (http://climate.weatheroffice.gc.ca/climateData/canada_e.html). Data from AAFC networks are distributed internally within AAFC. Current conditions data from MAFRI stations can be displayed on the MAFRI website (http://tgs.gov.mb.ca/climate/CurrentConditions.aspx). Note that many stations are shared between the University of Manitoba, MAFRI, AAFC and EC. Private weather networks are available through a subscription service (see figure 11 for example).

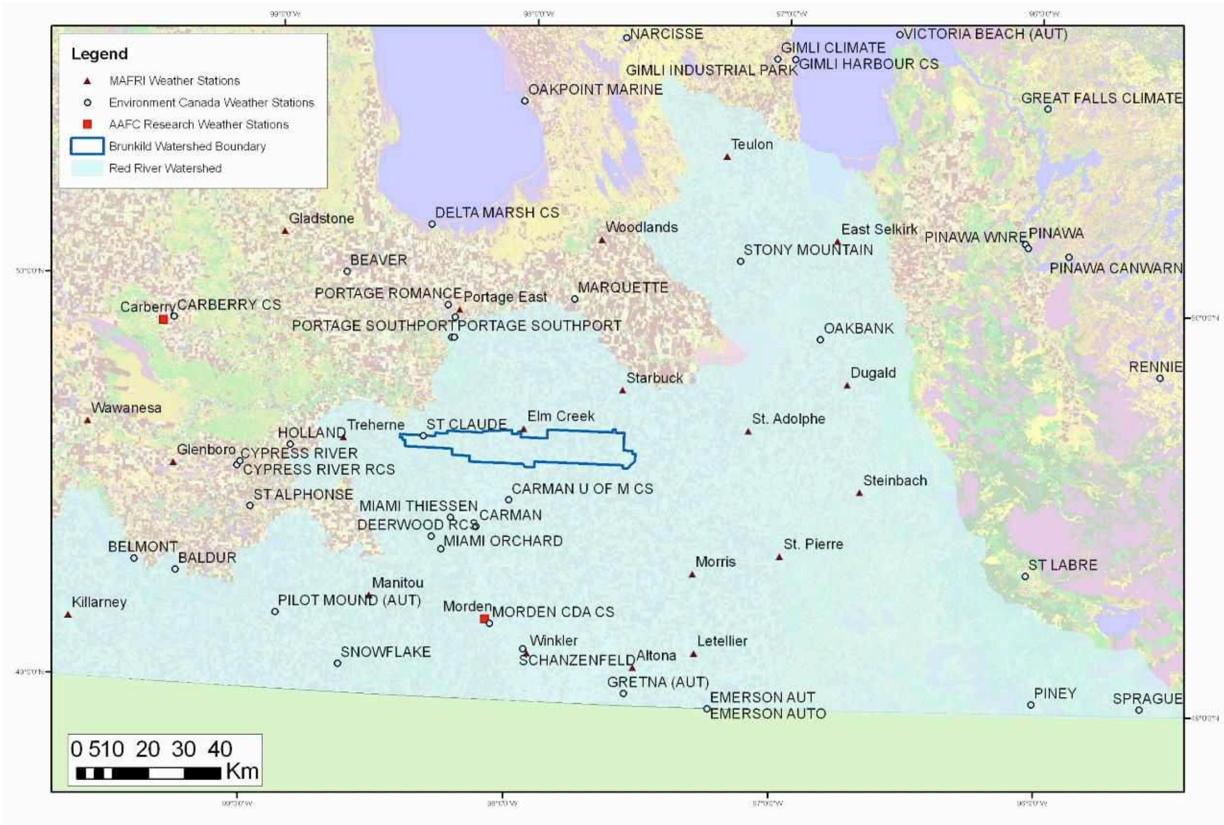



Figure 10. Location of AAFC, EC and MAFRI meteorological stations.


Figure 11. Location of Weather Innovation (WIN) meteorological stations supported by the Manitoba Potato Growers Association.

Carbon flux measurements are potentially available through individual research stations in the area. A portable carbon flux tower will be made available for the duration of the 2012 SMAPVEX campaign through AAFC and Environment Canada.

Digital elevation model (DEM) data for the area is available from a number of sources. The Canadian Digital Elevation Data (CDED) is available at 23 and 93 m spatial resolution and 10m vertical accuracy for the 23m data set and can be downloaded freely from Natural Resources Canada's GeoBase system (www.geobase.ca). The DEM from the ASTER Global-DEM project is available at a 30m spatial resolution with a 7-14m vertical accuracy (figure 10). Coarser resolution DEMs are available from the Shuttle Radar Topography Mission (SRTM) at 90m spatial resolution and 10m vertical accuracy.

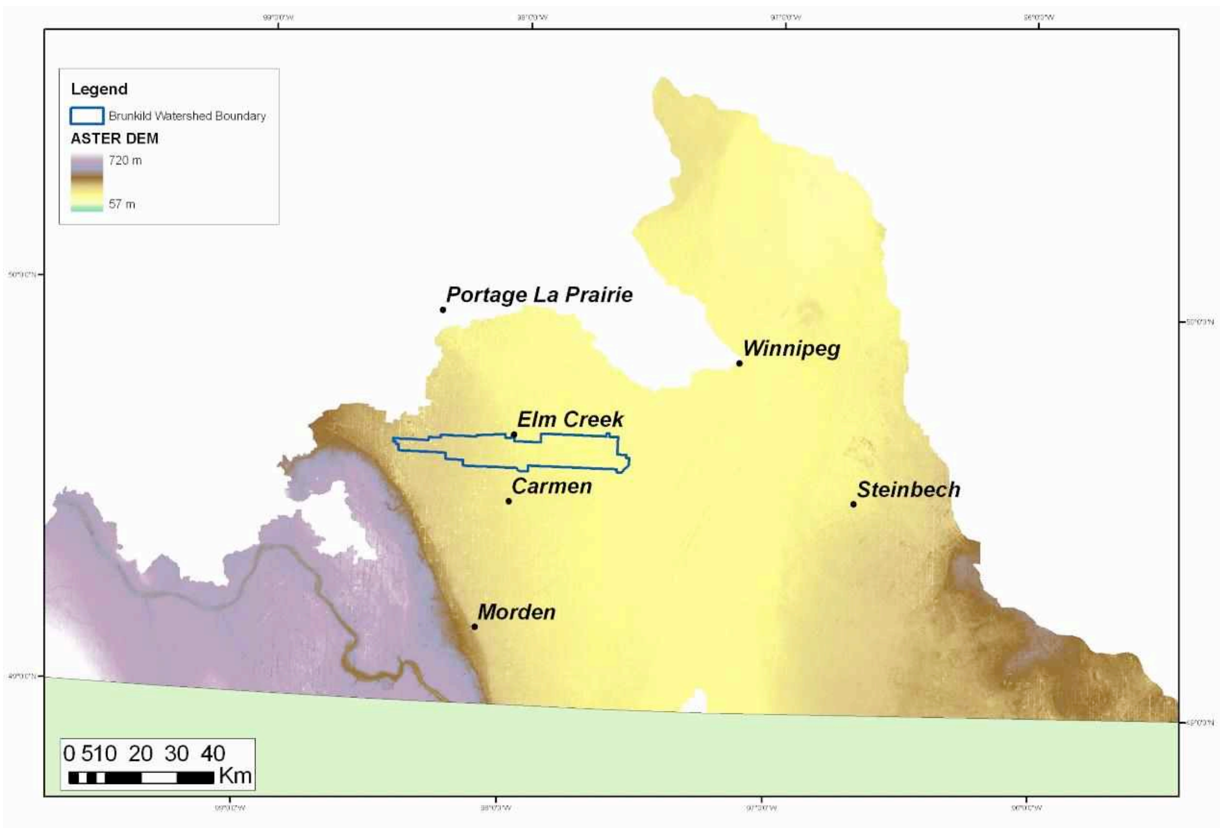



Figure 12. Digital Elevation Model data from the ASTER GDEM project for the Red River Watershed

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 compiles 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. Work is currently being done to convert 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.

Land cover data are available for circa 2000 at a 30m resolution derived from Landsat-TM data for the agricultural extent of the province through the AAFC Earth Observation Service. This land cover data set provides an indication of annual and perennial agricultural land, as well as native grassland, forest, wetland and urban areas within the agricultural extent. National land cover data derived from this data set and others from the forested and northern regions is available on a polygon basis through GeoBase (http://www.geobase.ca/geobase/en/data/landcover/index.html). Annual crop type maps are available for Manitoba from the AAFC Earth Observation Service at a 50 m spatial resolution, classifying cropland into specific crop classes for each growing season (figure 13). This data set is available for 2008, 2009 and 2011 (2010 was not completed due to a lack of ground truth data to support the classification). These maps are derived based on a combination of optical and radar data collected throughout the growing season and use a supervised decision tree classifier to obtain the final maps. Maps for a typical growing season are completed in the late fall for each year.

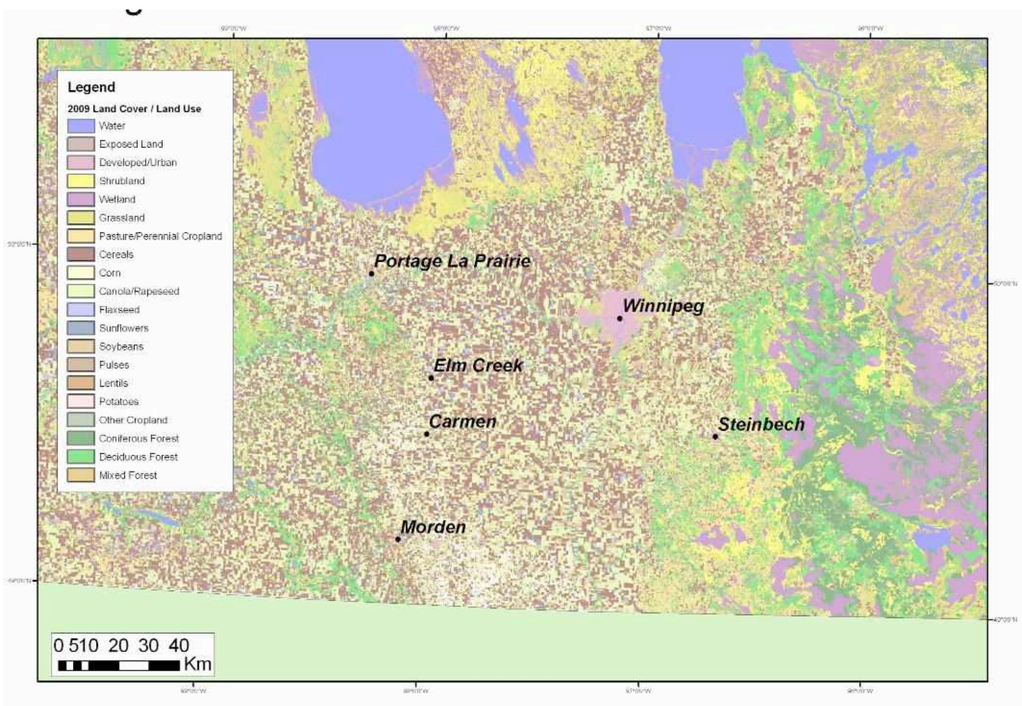



Figure 13. Agricultural land cover/land use for Red River Watershed

### *2.5 Selected sampling fields*

Permissions have been granted to 60 quarter section fields (800 x 800 m) where annual crop and pasture land cover is present (figure 14). Access has been secured under a contract with producers, and under which producers are being financially compensated for crop losses as a result of the field sampling. Permission to access 5 forested sites has been also been granted (figure 14).

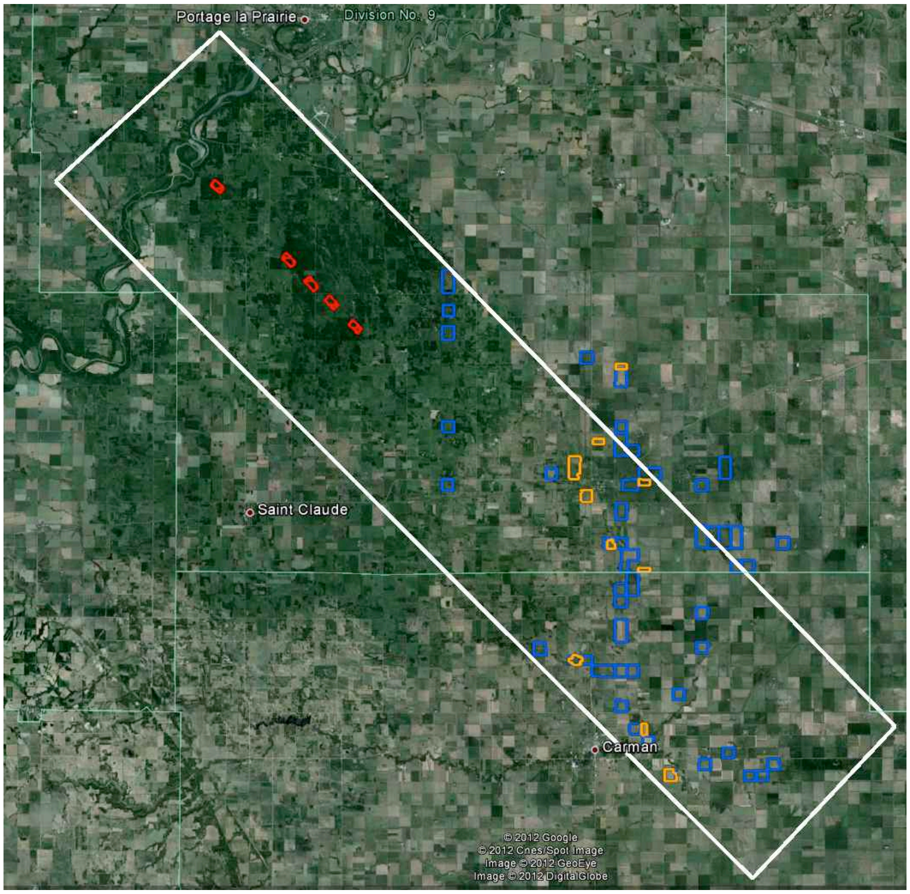



Figure 14 Location of cropland fields (blue) and forest sites (red) where access has been granted. The fields where the AAFC long term in situ stations are installed are identified in orange.

The forested sites have a mix of forest/grassland land cover (figure 15). Natural vegetation varies depending upon the dominant soil moisture regime for that site. Grasslands typically occur in the areas of rapid or very poor soil drainage. This would be the top of ridges or areas that are very sandy as well as in depressions where water collects. The remainder of the area is dominated by deciduous forest. Areas of willows are sometimes present which represent the transition between aspen forest and poorly drained areas dominated by grasses. Generally the landscape is dominated by aspen forest with varying levels of maturity with some sites dominated by younger aspen trees. Some wooded sites are also pastured. Grasses are grazed down with little undergrowth of shrubs and seedlings.

Figure 15. Photo of forest cover for site 5

# 3. Description of measurement instruments

## *3.1. Ground instruments specifications*

Ground measurements during the campaign will be made continuously through in situ network stations discussed above, 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 portable Stephen's Hydra probes identical to the ones used in the AAFC in situ network. 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 can me made using site specific texture information, custom calibration models calculated using a laboratory experiment or reference to gravimetric soil moisture samples collected periodically during the field campaign.

Soil roughness measurements can be made using a portable pin profilometer (figure 16) 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 perpendicular 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 16. 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.

Leaf area index (LAI) will 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 very 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 1 provides a listing of major equipment required for SMAPVEX. The table also indicates contributions to this equipment by the SMAPVEX team.

Table 1. List of ground instruments available for SMAPVEX

| Equipment | AAFC (Ottawa + Winnipeg) | Université Sherbrooke | University of Guelph | EC | Other |
|---|---|---|---|---|---|
| Hand held Hydra Probe | 4 Pogos | 1 Pogo | 4 Pogos | 6 with data loggers<br>6 Pogos | |
| Temporary in situ stations | 5 | | | | 40 (USDA)<br>4 (MAFRI) |
| Theta probes (as a backup) | 16 | | | | |
| Cropscan | 2 | | 1 | | |
| Metris TN400L Professional Grade Infrared Thermometer | 22 | | | | |
| Taylor® Switchable Digital Pocket Thermometer | 20 | | | | |
| GPS units | 15 | | | | |
| LAI camera + FishEye lense | 5 | | | | |
| LAI-2000/2200 | 2 | | | | |
| Cameras | 4 | | 2 | | 2 |
| Bulk density samplers | 30 | | | | |
| Roughness pin profiler with mounted camera | | 2 | | | |
| Balance - soils | 2 | | | | |
| Balance - biomass | 2 | | | | |
| Drying ovens for soils | 3 | | | | |
| Drying rooms for vegetation | at ROC | | | | |

### *3.2. Aircraft instruments*

#### *3.2.1 NASA G-II and UAVSAR*

The Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) is an aircraft based fully polarimetric L-band radar that is also capable of interferometry. It is currently implemented on a NASA Gulfstream-III aircraft (http://uavsar.jpl.nasa.gov/). Details on the UAVSAR are listed in table 2.

Table 2. Description of the UAVSAR

| Instrument | Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) |
|---|---|
| **Owner** | NASA/JPL/Dryden (USA) |
| **Platform** | Gulfstream III; operating altitude up to 13 km |
| **Frequencies** | L-band (1.26 GHz) |
| **Polarizations** | HH, HV, VH, VV |
| **Spatial Resolution** | 80 MHz Bandwidth, 1.66 m range x .8 m azimuth SLC<br>3 m multi-looked (6 looks) |
| **Scan Type** | SAR with Electronically scanned active array, range swath<br>~20 km looking left of track between 25 and 65 degrees. |
| **Antenna Type** | Phased Array |

For SMAPVEX, the nominal flight altitude is 13 km and the aircraft speed is 220 m/s. UAVSAR looks to the left of flight direction and collects data over a swath between 25 and 65 degrees, which is a nominal swath of 21 km. The most relevant portion of the data swath for SMAP, which has an incidence angle of 40 degrees, will be data collected between ~35 and 45 degrees, which is a narrower swath of ~3.8 km.

PALS is a combined polarimetric radiometer and NASA licensed radar sharing a rotating planar array antenna (http://airbornescience.jpl.nasa.gov/instruments/pals/). The PALS instrument includes a combined L-band radiometer and scatterometer, operating at 1.413 GHz and 1.26 GHz respectively. During SMAPVEX, PALS will be flown on a Twin Otter aircraft.

For the PALS acquisitions, eight high altitude lines (about 10,000 ft) and four low altitude lines (about 4,500 ft) are being planned for SMAPVEX. The location of the low altitude lines are provided in figure 17. Two low altitude lines will be positioned N-S over annual cropland, one N-S over pasture land cover and a fourth E-W line over the forested region of the site. To date, access to five quarter sections have been granted for the eastern cropland low altitude flight line, 12 sections for the western cropland low altitude flight line, six for the pasture low altitude flight line and five sites for the forested low altitude flight line.

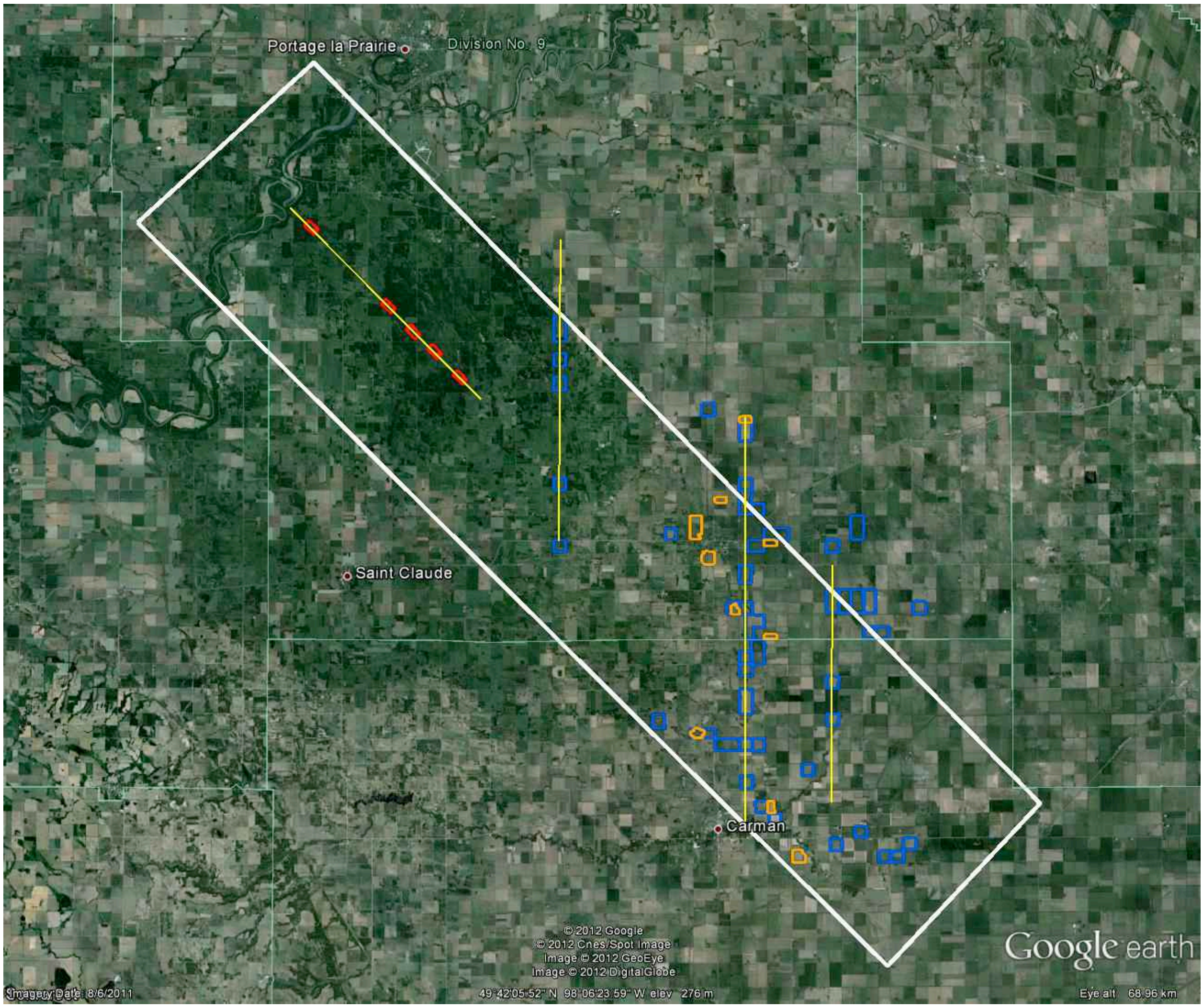



Figure 17. Location of low altitude PALS flight lines (in yellow)

### 3.2.2 Satellite sensors

The technical characteristics of satellites to be programmed for SMAPVEX are summarized in table 3. For detailed descriptions, the reader is referred to the individual sensor web sites.

Table 3. Technical characteristics of satellite instruments

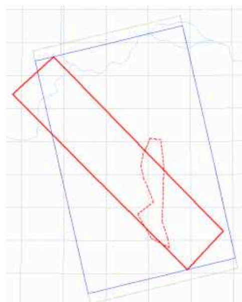
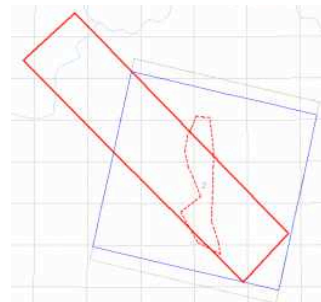
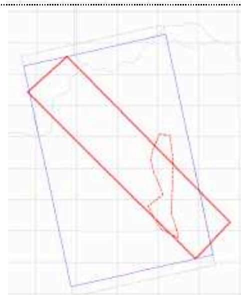
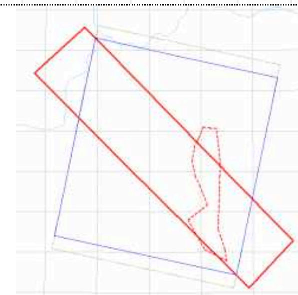
| Satellites | Frequency (GHz) | Polarization | Incidence angle ($^o$) | Resolution |
|---|---|---|---|---|
| SMOS | 1.4 | H and V | 0 -55 | 30 km |
| WindSAT | 6.8, 10.7, 18.7, 23.8, 37.0 | H and V | 54 | 10 to 55 km |
| RADARSAT-2 | 5.4 | Single: HH<br>Dual: HH, HV<br>Quad Pol: HH, HV, VH, HV (plus phase) | 20-49 | 3-100 m |
| TerraSAR-X | 3.1 | Single<br>Dual<br>Quad | 15 to 60 | 1 to 16 m |
| SPOT-4 | | | | 20 m |
| Landsat | | | | 30 m |
| RapidEye | | | | 6.5 m |

# 4. Data acquisition

### *4.1. Calendar of satellite acquisitions*

Twenty-two RADARSAT-2 Wide Quad-Polarimetric acquisitions have been programmed for the entire SMAPVEX campaign (table 4). Acquisitions were limited to steeper incidence angles, but both orbits (ascending and descending) were programmed. Ascending acquisitions occur at approximately 7:10 PM local time; descending acquisitions at approximately 7:50 AM local time. Even with its wider swath, the Wide-Quad mode will not cover the entire SMAPVEX site. Consequently nine Standard mode (S3) RADARSAT-2 acquisitions were also programmed (April 18, May 2, May 12, May 26, June 5, June 19, June 29, July 13, July 23). These acquisitions will be in the HH and HV polarizations and will cover the entire SMAPVEX site. To date, two S3 images have been lost due to conflicts or satellite anomalies.

Table 4. RADARSAT-2 Wide Fine Quad acquisitions programmed for SMAPVEX

| *Ascending Mode* | | | | *Descending Mode* | | | |
|---|---|---|---|---|---|---|---|
| **Mode** | **Month (local)** | **Day (local)** | **Coverage** | **Mode** | **Month (local)** | **Day (local)** | **Coverage** |
| **FQW 2** | April | 15 |  | **FQW 3** | April | 18 |  |
| | May | 9 | | | May | 12 | |
| | June | 2 | | | June | 5 | |
| | June | 26 | | | June | 29 | |
| | July | 20 | | | July | 23 | |
| **FQW 6** | May | 2 |  | **FQW 8** | April | 25 |  |
| | May | 26 | | | June | 12 | |
| | June | 19 | | | July | 6 | |
| | July | 13 | | | | | |
| **FQW 10** | April | 25 |  | | | | |
| | May | 19 | | | | | |
| | June | 12 | | | | | |
| | July | 6 | | | | | |
| | July | 30 | | | | | |

**Legend**

PALS coverage

In situ network coverage

Radarsat-2 image footprint

Both ascending (14 dates) and descending (14 dates) acquisitions of TerraSAR-X have been programmed. Lists of these acquisitions are provided in tables 5 and 6. The evening ascending polarizations (VV, VH) were selected to facilitate crop information extraction and to avoid early morning dew. The dual like-polarization (HH, VV) configuration was chosen for soil moisture modeling. The swath of the TerraSAR-X dual stripmap mode is only 15 km and consequently these acquisitions were limited to the south eastern SMAPVEX region in order to capture acquisitions over the AAFC permanent in situ sites, as well as the two low altitude PALS flight lines over the annual cropland (figures 18 and 19).

Table 5. TerraSAR-X: ascending mode imagery

| Local Start Date | Local Start Time | Sensor Mode | Polarization Mode | Polarization Channels | Beam | Minimum Incidence Angle | Maximum Incidence Angle | Pass Direction |
|---|---|---|---|---|---|---|---|---|
| 2012-05-06 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-05-17 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-05-28 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-06-08 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-06-19 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-30-01 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-07-11 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-07-22 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-08-02 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-08-13 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-08-24 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-09-04 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-09-15 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |
| 2012-09-26 | 7:11:20 PM | Stripmap | Dual | VV+VH | stripFar_006R | 28.66 | 30.08 | Ascending |

Table 6. TerraSAR-X: descending mode imagery

| Local Start Date | Local Start Time | Sensor Mode | Polarization Mode | Polarization Channels | Beam | Minimum Incidence Angle | Maximum Incidence Angle | Pass Direction |
|---|---|---|---|---|---|---|---|---|
| 2012-05-08 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-05-19 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-05-30 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-06-10 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-06-21 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-07-02 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-07-13 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-07-24 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-08-04 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-08-15 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-08-26 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-09-06 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-09-17 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |
| 2012-09-28 | 7:54:11 AM | Stripmap | Dual | HH+VV | stripNear_005R | 25.08 | 26.58 | Descending |

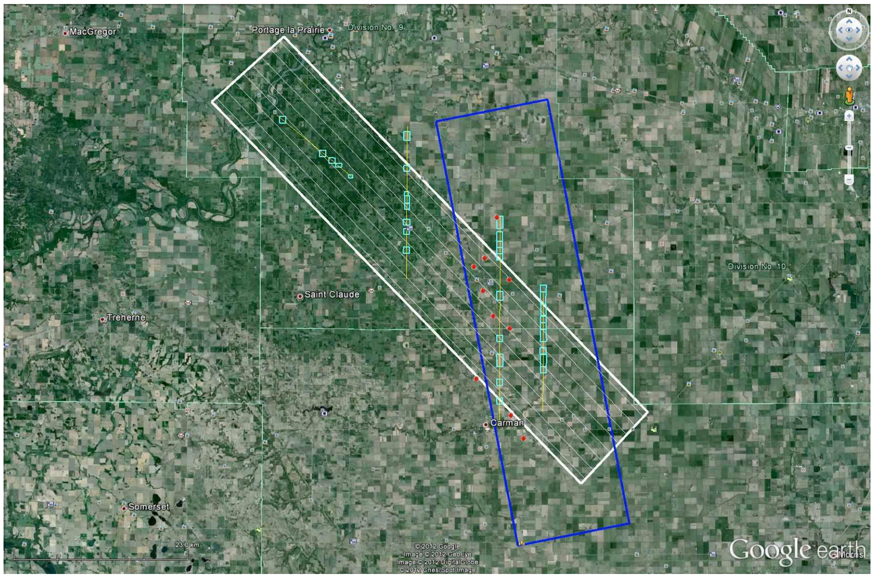



Figure 18.  Ascending pass over the SMAPVEX site which will be acquired around 6:00 PM (local time). Incidence angle is around 30°

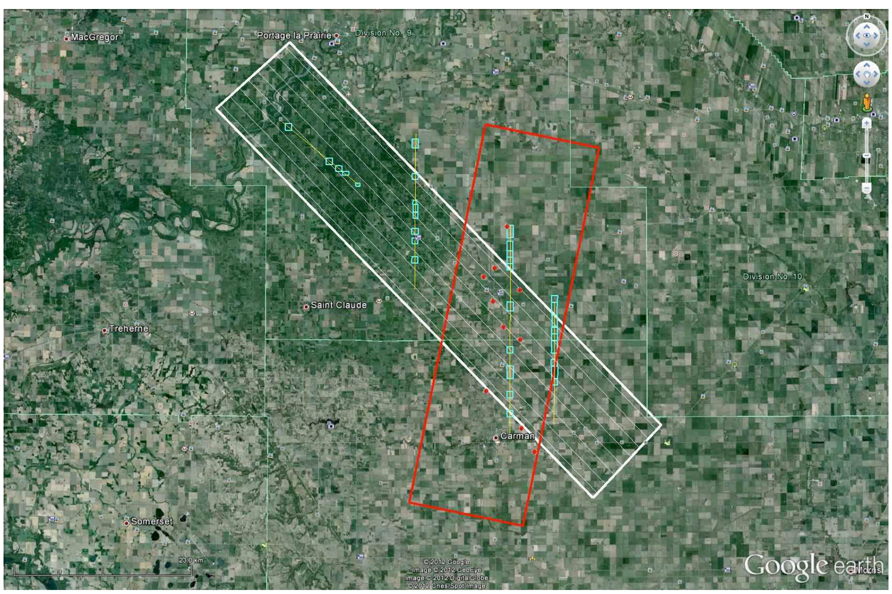



Figure 19.  Descending pass over the SMAPVEX site which will be acquired around 6:00 AM (local time). Incidence angle is around 25°

### *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 Temperature
SP3: Soil Bulk Density and Texture

**SP 1. 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.

**Measurement approach for agricultural fields:**
Surface soil moisture measurements will be acquired over selected agricultural fields coincident in time to flight overpasses. Field crews will use hand-held probes to measure moisture at near surface depths (5.7 cm) at 16 locations in each field.

Each crew will consist of 2 members, outfitted in a manner illustrated in figure 20. Soil moisture measurements will be recorded electronically and on hard copy. Each crew will be given 5 fields to sample in a prioritized order. The crew members will work together on each field following a prescribed pattern of sample locations and a specific sampling protocol at each sample point (figure 21).

Up to sixty fields will be sampled during SMAPVEX, along with 5 forest sites. With 12 cropland field crews, between 36 (assumes only 3 priority fields are sampled) and 60 (if all 5 assigned fields are sampled) will be visited. A separate field crew will be tasked with measuring soil moisture at the forest sites.

Figure 20. Illustration of a soil moisture sampler with a holder.
This setup will facilitate the capture of surface soil moisture with a hydraprobe and recording each reading electronically and hard copy.

In addition to the surface soil moisture collected by field crews, soil moisture at discrete depths down to rooting zones 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.

Forty-nine temporary soil moisture stations will also be installed. These stations are being provided by USDA, AAFC and MAFRI. One station will be installed at site 1 in priority cropland and pasture fields, as well as selected forest sites. One probe will be installed at each station to record surface soil moisture (5.7 cm) during the course of the field campaign. Soil moisture will be recorded on data loggers. The temporary stations will be installed by the end of May.

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. 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 21). The transects will be oriented parallel to the seed row direction to make it easier to walk between points. Seeding direction will be confirmed by the end of May. The end points of each transect will be 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.

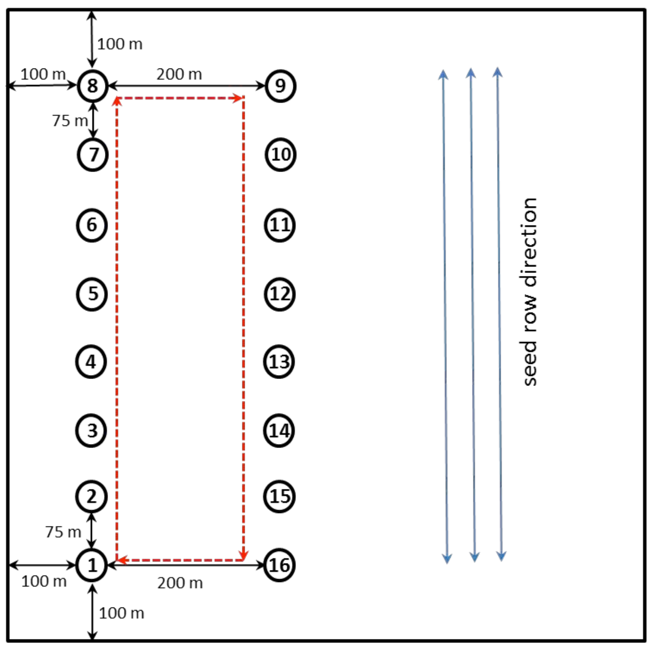



Figure 21. Soil moisture sampling strategy for SMAPVEX

All sample points will be pre-loaded into handheld GPSs to allow easy navigation to the sample sites using a go-to function. 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 #

Soil moisture measurements will be stored in the handheld probe data logger, and will also be written onto data sheets.

Agricultural 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 to wider spacings for the row-seeded crops such as corn or soybeans. The rows are normally along the top of a small ridge of soil created by the seeding equipment with the inter-rows at the bottom of the ridge. 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. In these fields, the rows can be more difficult to discern, especially when the crop has reached biomass and the canopy has closed.

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 a ridge (figure 22). If there are no discernible ridges, all the 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.

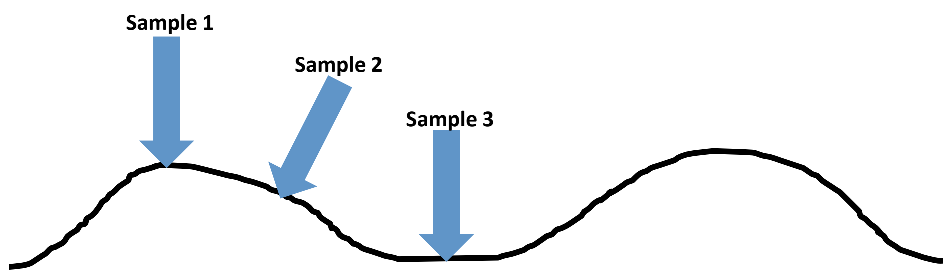



Figure 22. Location of replicate soil moisture measurements at each site

Each sample location will avoid large cracks or 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.

Each crew will be assigned 5 fields to sample and they should be sampled in order (from 1 to 5). The first four fields are "priority fields" (i.e. they must be sampled if accessible) with the 5$^{th}$ field as an option if there is time. The goal is to ensure a subset of fields have a complete time series of surface soil moisture samples throughout the SMAPVEX campaign. Currently, there are 24 samplers (twelve 2-person crews) and thus this strategy would ensure that at least 48 fields have a complete time series of surface soil moisture samples for each date of sampling.

**Measurement approach for forest sites:**
The sampling protocol for forested sites will involve three measurements sites at each sampling region (i.e. location where the vehicle is parked) with three replicates at each site (9 soil moisture measurements total).

Forest sampling will be conducted off of the road network and the site accessed by entering the forest canopy 25 metres perpendicular to the road. The next two sampling locations will be 10 metres away from the first site (again walking perpendicular to the road). The sampling protocol for each site will involve the measurement of volumetric soil water content, soil bulk density and collection of the leaf litter or organic soil layer.

To collect the organic layer, a rectangular grid (in this case a picture frame) measuring 21.59cm by 27.95cm will be laid over the ground. Measurements of the organic layer depth will be recorded from each corner of the picture frame. The organic layer (leaf litter and organic soil if present) will be scraped from the mineral soil layer and placed in a labeled zip-locked bag (site and sample number) for subsequent oven drying and calculation of the volumetric water content.

Within the scraped region, three measurements of the soil volumetric water content will be performed using the Hydra probe instrument. Finally a single bulk density sample will be taken from the now exposed mineral soil. The bulk density sample will be placed in a labeled zip-locked bag for weighing and oven drying for calculation of volumetric water content.

**SP 2. Soil and Vegetation Temperature**

**Measurement approach:**
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 6). These will be sites 1, 8, 9, and 16 as per figure 21. 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. 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 7. Summary of temperature and bulk density sampling strategies

| Property | Number of sites per field | Depth | Instrument | Description of approach |
|---|---|---|---|---|
| **Soil Temperature** | 4<br>Sites 1,8,9,16 | 5 and 10 cm | Digital pocket thermometer | insert to 5 cm, take reading then push to 10 cm, take reading |
| **Soil and Vegetation Temperature** | 4<br>Sites 1,8,9,16 | Surface | Thermal infrared thermometer | measure sunlit soil, sunlit vegetation, shaded soil, shaded vegetation |
| **Bulk Density** | 1 | 5 cm | Soil core | 1 core and 1 probe reading within 15 cm of each other; replicated 3 times |
| **Site Photos** | | | Digital camera | one taken parallel to row direction; also take photo of field ID, date, time and direction |

**SP3: Soil Bulk Density and Texture**

**Objective:** To provide data to calibrate the soil moisture measured by the hand-held moisture probes over a range of soil moisture conditions and for all fields.

Field measurements of soil moisture will be made using portable Stephen's Hydra probes. Each soil moisture team will be assigned a specific hydra probe and data reader for measuring their specific fields on each soil measurement date. It is essential that each probe be calibrated in the field to provide an assessment of their absolute accuracy with regards to volumetric soil moisture content. This will be done by collecting actual volumetric soil samples for moisture content at sites from which hydra probe readings have been gathered during the moisture sampling campaign.

**Measurement Strategy:**

On each soil moisture sampling day, each team will collect three volumetric core samples on one field. A hydra probe reading will be taken in close proximity (within 15 cm) of the core. This will be replicated three times. The field sampled, as well as the site within each field sampled, will be rotated as per table 8.

Table 8. Sampling strategy for soil core collection

| Soil sample day | Which field do I sample? | At which site do I sample? |
|---|---|---|
| 1 | 1 | 1 |
| 2 | 2 | 1 |
| 3 | 3 | 1 |
| 4 | 4 | 1 |
| 5 | 5 | 1 |
| 6 | 1 | 2 |
| 7 | 2 | 2 |
| 8 | 3 | 2 |
| 9 | 4 | 2 |
| 10 | 5 | 2 |
| 11 | 1 | 3 |
| 12 | 2 | 3 |
| etc. | etc. | etc. |

Samples will be collected using bulk density cores (figure 23). The soil cores will be placed in sample containers for transport to the lab. Field crews will place the containers in individual plastic zip lock bags to minimize any moisture loss. Each bag should be labeled with a permanent marker, with the field, field-site number and the date. The probe readings will be recorded on data sheets.

Figure 23. Aluminum sampling rings ready to be inserted alongside a hydra probe reading location. Sample containers are for transporting each sample to the lab for weighing.

At the laboratory, the lab crew will remove the sample from the zip lock bag for immediate weighing. The wet weight is recorded and the sample (container, core and soil) is placed in the drying oven. The sample is then oven dried for 24 hrs at 105°C and re-weighed.

Once the dry weight of the sample has been recorded, one sample per field will be kept for lab textural analysis.

### *4.2.2. Soil roughness*

**Introduction:** Over the agricultural site, the CanEX-SM10 campaign was conducted during a shorter period (2 weeks from 1st to 14th June, 2010) and at an earlier stage of the agricultural growing season than occur for SMAPVEX. Soil roughness during SMAPVEX-2012 will probably be modified by flattening due to rain events and by field operations. Due to the presence of vegetation, the sampling of soil roughness will take more time and will cause more damage to crops than in CanEX-SM10. As a result, and in order to obtain representative values of soil roughness at each field and to optimise the number of sampling fields, the following soil roughness measurements protocol will be considered : 2 sites per field, 1 replicate per site in the look direction of each SAR sensor, and 2 field visits.

**Objective:** To measure both the standard height (s) and the correlation length (ℓ) of surface roughness to assist with modeling of soil moisture from SAR signals (RADARSAT-2, UAVSAR, and PALS), at the SMAP scale, and from PALS passive microwave airborne measurements.

**Measurement approach:**

*CanEX-SM10*

Data collected by Sherbrooke University in July 2008 has been used to assess the within and between field variability associated with surface roughness. This analysis determined that at this stage of the growing season (after planting and during crop growth) field to field variability in roughness was small. Within field variability was assumed to be even less than field to field variability. Tillage is the most significant driver of roughness and the same tillage implement is applied to an entire field. Small differences across a field can occur during tillage and erosion events due to variations in topography and soil properties. Based on these data, it was determined that roughness for the entire field could be characterized by measurements taken at a single site. However, replicates are still required to counter measurement errors and instrument precision. Consequently, 3 replicates were taken, in the look direction of each SAR sensor, at one site per field.

*SMAPVEX*

Since there are no archived roughness measurements over the fields that will be sampled during SMAPVEX, an assumption can not be done regarding the within field variability of soil roughness. Therefore roughness will be measured at 2 sites per field, with only one replicate per site, in the look direction of each SAR sensor (RADARSAT-2 descending mode, UAVSAR, and PALS), in order to reduce the damage to crops. Surface roughness is expected to be quite stable through the campaign. Since it is not a highly variable parameter in time (following seeding), it will be measured only twice on each field – at the beginning of the field campaign, and near the end of the campaign. Any changes in roughness due to field operations, including harvesting, as well as eroding of the soil will be captured with the second measurement.

The surface roughness is measured using a 1-m long pin profilometer and digital camera. 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 is repeated a second time to achieve a 3-metre profile comprised of three 1-metre profiles. The photographs of the three separate profiles are joined into a single profile using a matlab application, post data collection, to provide the two roughness parameters per site. This end-to-end approach is conducted at two different sites per field (table 9) in order to provide two 3-metre profiles for the determination of field mean roughness value.

The profilometer is a camera based method of capturing the roughness profile. Vegetation will interfere with the collection of these photos. Thus vegetation in front of the profile will be removed (or flattened by using a long piece of cardboard).

It is important to characterize roughness in the same direction as the look direction of the SAR instruments, particularly if any macrostructure is present. Consequently the roughness profiles need to be taken parallel to the look directions of both the UAVSAR and PALS flights, as well as the look direction of RADARSAT-2 (figure 24).

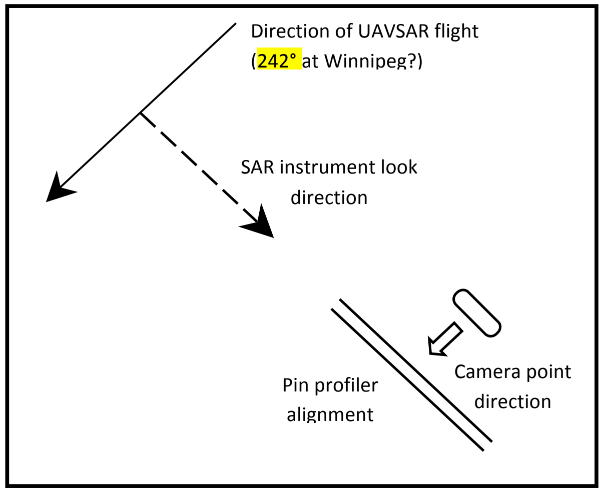



Figure 24. An example of the placement of the profilometer for a UAVSAR flight path at 242º.

A summary of the approach to measuring roughness is provided in table 9.

- 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 look direction of UAVSAR and PALS flights, and RADARSAT2 (descending mode),
- 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,
- Roughness measurements will be collected a second time, toward the end of the field campaign, at the same sites as the beginning of the campaign.

Table 9. Summary of surface roughness measurement strategy

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

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 3 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. For the second sampling, the same number of fields can be sampled during the last week of the campaign.

### *4.2.3. Vegetation properties for cropland*

**Objective:** To measure biomass and canopy water content, and characteristics of the vegetation structure, 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 SMAPVEX. 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 spring wheat, canola, oats, barley, corn and soybeans. Some fields of perennial land cover, including grassland and tame hay (alfalfa and grass) will also be selected.

The following static and dynamic vegetation properties will be measured.

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

Dynamic Properties
VG4: Leaf Area Index (LAI)
VG5: Biomass and Canopy Water Content
VG6: Height
VG7: Stem Diameter
VG8: Phenology
VG9: Crop Structure and Architecture
VG10: Canopy Reflectance

The sampling strategy will consist of collecting vegetation data at three sites per field, once per week. The change in vegetation structure, biomass and water content is significant during this period of peak growth and senescence, and thus weekly measurements are warranted. Three of the 16 soil moisture sites will be selected for vegetation sampling (preferably one site on transect #1 and two sites on transect #2, to minimize edge effects). However, 2011 RapidEye satellite data will be used to validate that these 3 sites are representative of conditions for the entire field. Adjustments to the site locations may occur prior to the commencement of the campaign, but once these sites are established the locations will remain constant through the entire campaign.

The number of replicates required for each vegetation parameter will vary. These are detailed in table 10.

**VG1: Plant Density**
The density of plants will be determined by counting the number of emergent plants in a row, along a fixed distance (10 metres or 1 metre, depending on the crop type and planting density). This will be replicated for 10 rows. Counts will be recorded on data sheets. Row spacing measurements will also be required to calculate the density.

**VG2: Row Spacing**
Row spacing will be determined by measuring the distance between rows, for the 10 rows used to determine plant density. Row spacing should be measured at the soil level, with the distance measured being the distance between the centre of the plant from row one to the centre of the plant from row two. Row spacing will be recorded on data sheets.

**VG3: Row Direction**
The direction of planting will be recorded using a compass.

**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 three sites per field. These photos will be post-processed to estimates of LAI.

**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 biomass sampling will be determined by the crop (planting approach and overall biomass). For crops with low to moderate biomass (field peas, for example) 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 (wheat, for example). For large biomass crops and those that have a row spacing wider than 0.5 m (corn and soybeans, for example), a different sampling approach will be taken. For these crops, 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 ($m^2$).

*Biomass collected via 0.5 m x 0.5 metre square:* wheat, oats, barley, grassland and tame hay (alfalfa and grass)
*Biomass collected via 5 plants along 2 rows:* canola, corn and soybeans

Samples will be placed first in a paper bag, and then a plastic bag. The paper bag can be placed directly in the drying trailer, while the plastic bag minimizes water loss prior to weighing the wet sample. The paper bag must be labeled with the field and site number, as well as the date. 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 after each field is sampled.

Wet weights are taken with the paper and plastic bags (size of bags used and average bag weight must be recorded). Following wet weighing, plastic bags are removed and samples are placed in drying facilities one week at 30°C. The weight of the dry sample is then taken. To facilitate standardization and reduce errors, one team of two will be assigned to weigh all samples.

When weeds are present within the sample site, the weeds will be placed into separate bags for weighing. The paper bag should be labeled with the field and site number, and also with the word “weeds”.

For the sample from the first site in each field, the lab crew will segmented the sample by plant organs. Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. The level of segmentation will depend on the crop.

*Wheat, oats, barley* – heads cut off to provide 2 samples (a) heads and (b) leaves+stems
*Grassland and tame hay* – no segmentation
*Corn, canola and soybeans* – leaves, seeds/pods/cobs and stems separated to provide 3 samples (a) leaves, (b) seeds/pods/cobs and (c) stems

**VG6: Height**
Crop height can vary significantly and increasing the number of measurements will help to improve the accuracy of the average crop height. In total 10 heights will be measured, 5 in each of two rows. 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 will be recorded on data sheets.

**VG7: Stem Diameter**
The diameter of the plant stem will be measured for the 10 plants used for height measurements. A simple caliper can be used. The diameter will be measured half way up the crop (at mid level). Stem diameters will be recorded on data sheets.

**VG8: 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 crop sample. This

determination can take place during the weighing process and recorded on data sheets. The BBCH scale will be used.

**VG9: Vegetation Structure and Architecture**
The structure of the plant will be captured photographically. One photo will be taken in each field. A large piece of marker board, superimposed with a measurement grid, will be placed behind one crop row. A digital photo will be taken to record the overall plant structure.

In addition to this photograph, the geometry of the plant will be measured. These measurements will be taken with a caliper, ruler and protractor.

Table 10. Summary of vegetation sampling strategies

| Property | Number of sites per field | Replicates per site | Instrument | Temporal frequency | Description of approach | Assigned Team |
|---|---|---|---|---|---|---|
| **Static Vegetation Parameters** | | | | | | |
| **Plant Density** | 1 | 1 | | once | Count number of plants along 10 or 1 metre(s); replicate for 10 rows | AAFC students prior to campaign |
| **Row Spacing** | 1 | 1 | Meter stick/tape measure | once | | AAFC students prior to campaign |
| **Row Direction** | 1 | 1 | Compass | once | | AAFC students prior to campaign |
| **Dynamic Vegetation Parameters** | | | | | | |
| **Leaf Area Index** | 3 | 1 | Camera and fish eye lense | once per week | 7 photos taken along 2 transects (14 in total) | Biomass |
| **Biomass and Canopy Water Content** | 3 | 1 | 0.5 x 0.5 m square | once per week | For wheat, oats, barley, grassland, tame hay collect all biomass within square; For canola, corn, soybeans collect five plants along each of 2 rows (10 in total) | Biomass |
| **Height** | 3 | 10 plants | Meter stick/tape measure | once per week | | Biomass |
| **Stem Diameter** | 3 | 10 plants | calliper | once per week | | Biomass |
| **Phenology** | 1 | 1 | | once per week | | Lab Tech |
| **Canopy structure** | 3 | 1 | Digital camera and gridded board | once per week | Gridded marker board is placed behind one row and photo taken. | Structure |
| **Canopy architecture** | 3 | 1 | caliper, ruler, protractor | once per week | | Structure |
| **Canopy reflectance** | 3 | 1 | CropScan | once per week | One crop scan measurement at each of 14 LAI sites. | Biomass |

**VG10: 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 be collected at each location where an LAI hemispherical photo was taken. This will yield 14 crop scan measurements (7 in each of two rows) for each of the 3 vegetation sites in each field.

### *4.2.4. Forest vegetation sampling requirements and protocols*

**Objective:** The principal objective of sampling vegetation in forested areas during SMAPVEX is to provide the needed input parameters to radar scattering models as well as to radiometer brightness temperature (or equivalently, emission) models. These parameters will also be used to calculate the vegetation water content (VWC) and relate VWC to the fundamental electromagnetic properties that directly impact scattering and emission models. Once models are parameterized, they can be used to generate the so-called radar data cubes, from which the SMAP project is planning to retrieve soil moisture from its radar data.

**Summary of vegetation input parameters for radar scattering models:** The radar scattering models are set up to use detailed information about vegetation canopies and soils (moisture, texture, roughness) to predict the value of the radar backscattering cross sections. These models are planned for use in retrieval of soil moisture from radar data, possibly as well as in joint radar and radiometer retrievals.

The very top-level information needed to set up the radar models are:

- Fraction of vegetation cover
- Landcover type, including any understory

For each landcover/species type, the following specific parameters are needed:
- Stems per unit area
- Height from ground to canopy bottom (trunk layer)
- Height of crown layer
- Stem diameter
- Total tree height
- Branch, leaves/needles diameter
- Branch, leaves/needles length
- Branch, leaves/needles density
- Branch orientation angle
- Dielectric properties for trunk, branches, leaves/needles (equivalent to water content)

Not all of the above parameters will be measured for all trees within the sampling domain. Specifics are given later in this section. The list above is meant to show what parameters go into the radar scattering models. Table 11 gives more detail on the above parameters, their measurement method and equipment needed to make the measurements. Information about soils (surface roughness, texture, and moisture) are also needed, but will not be discussed here.

Table 11. Measurement types and equipment needed for vegetation

| Measurement | Units | Measurement Method, Equipment Required | Equipment Needed (Required Minus Owned) | Expected measurement error |
|---|---|---|---|---|
| Needle/leaf | | Telescoping scissors, pruning shears | NEED | |
| Length | m | Measuring tape | Have 1 | 10% |
| Dry mass | kg | Oven dried, balance weighed | AAFC | 7% |
| Shape | descrip | Visual identification | (http://en.wikipedia.org/wiki/Leaf_shape) | 5% |
| Wet mass | kg | Field balance | AAFC | 8% |
| Needle/leaves density | # m-3 | Count/visual estimate | n/a | |
| Branch | | Ladder; tree climber; scaffold; saw | NEED | |
| Branch diameter | m | Measuring tape (steel) | Have 1 | 15% |
| Branch length | m | Measuring tape (steel) | Have 1 | 8% |
| Dry mass | kg | Oven dried, balance weighed | AAFC | 7% |
| Mean angle (orientation) | Deg | Compass; inclinometer/altimeter | Have 1 | 15% |
| Primary branch density | # m-3 | Count | n/a | 10% |
| Secondary branch density | # m-3 | Count/visual estimate | n/a | 20% |
| Wet mass | kg | Clippers, field balance | NEED | 8% |
| Tree | | | | |
| Ground to canopy height (trunk height) | m | Laser altimeter, hypsometer* | Have 1 | 7% |
| Tree height | m | Laser altimeter, hypsometer* | Have 1 | 10% |
| Upper stem diameter (?) | m | Ruler | Have 1 | 10% |
| Diameter at breast height (1.3 m, DBH) | m | DBH tape; tree caliper; Biltmore stick (?) | Have 1 | 4% |
| Dielectric constant (trunk, branches, leaves/needles) | kg m-2 | Dielectric constant probe | Have 1 (under development) | ? |
| Species identification | Name | Visual identification (field guide) | "Trees of the Northern United States and Canada" by John Laird Farrar | 2% |
| Stem dry wood density | kg m-3 | Stem corer (Bark gauge?); Increment borer; oven dried, | Have | 5% |

| | | | | |
|---|---|---|---|---|
| | | balance weighed | | |
| Understory (shrubs, herbs, mosses, lichens) | | | | |
| Dry mass (non-partitioned) | kg | Clippers; pruning shears; oven dried, balance weighed | NEED clippers | 15% |
| Wet mass (non-partitioned) | kg | Clippers, field balance | NEED clippers, field balance (AAFC) | 7% |
| Fractional understory vegetation cover | m2 m-2 (percent age?) | Quadrat; count/visual estimate | NEED | 10% |
| Species identification | Name | Visual identification | | 5% |
| Litter depth | m | Spade, measuring tape (steel); measuring pole | Have | |
| Forest | | | | |
| Fractional vegetation cover | m2 m-2 (percent age?) | Quadrat, balance, scope, visual ID, densionmeter* | NEED | 8% |
| Leaf area index (LAI) | m2 m-2 | LAI-2000 | AAFC (2) | 12% |
| Fractional Necromass cover | m2 m-2 (percent age?) | Quadrat, densiometer* | NEED | 10% |
| Stem density | # m-2 | Count | | 7% |

Additional equipment required:

- GPS units
- Walkie-talkies
- Calculator
- Camera
- Gloves

---

### *4.3. Aircraft campaigns (flight lines)*

(Tom to complete)

# Appendix – Ground measurement protocols

### *A.1. Overview of daily activities*

**Schedule 1 – Soil moisture sampling days**

| | |
|---|---|
| **Weather Briefing, by phone**<br>**Inform team of Go-No/Go** | 5:30 a.m. |
| **Departure from base to field if "Go"**<br>**No/Go days – vegetation/roughness**<br>**Rain days – down days for crew** | 6:45 a.m. |
| **Arrival at site and start sampling**<br>• **5 fields per team, sampled in order of priority** | 8:00 a.m. |
| **Overpass time** | 8:00 a.m. |
| **End of sampling and start to base** | 1:30 p.m. |
| **End of day time and activities** | 2:30 p.m.<br>o Truck cleanup and organization for next day (crew)<br>o Download photos (crew)<br>o Data sheets photocopied and filed (Rotimi)<br>o Data downloaded from Hydra Probes (Rotimi)<br>o Wet soil weighed (lab technicians)<br>o Dry soil and vegetation samples weighed (lab technicians)<br>o Check in with Grant (all) |
| **Weather Briefing, lead personnel only** | 5:00 p.m. |

**Schedule 2 – Biomass and roughness sampling days**

| | |
|---|---|
| **Departure from base to field** | 8:00 a.m. |
| **Arrival at site and start sampling** | 9:00 a.m. |
| **End of sampling and start to base** | 2:00 p.m. |
| **End of day time and activities** | 3:00 p.m.<br>o Truck cleanup and organization for next day (crew)<br>o Download photos (crew)<br>o Data sheets photocopied and filed (Rotimi)<br>o Download crop scan (Rotimi)<br>o Wet samples weighed on site; phenology recorded (lab technicians)<br>o Check in with Grant (all) |

| | |
|---|---|
| **Team debriefing meeting** | 4:00 p.m. |
| **Weather Briefing, in person (lead personnel only)** | 5:00 p.m. |

### *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 reader or PDA to the loam setting.

2. Using your pre-supplied GPS coordinate, walk to the first point in the field (paint marker). Use the field diagram to indicate the relative position of the datalogger (if available), the road, a north arrow, start and end points (1 and 16) and other identifying or significant features on the field diagram.

3. At each point (1, 2 …8) in each transect, take three measurements. Ensure that you step squarely on the foot rest of the probe holder and 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.

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

7. At one site (in one field per sample day), take 3 bulk density soil cores along side 3 hydra probe readings. Each core should be taken within 15 cm of the hydra probe reading. On sample day 2, take the bulk density cores at your second field, on day 3 the third field and so on until all 5 fields have been sampled (table 8). You will then start back at field 1. Each time you sample any particular field, you will take the core samples at a different site.

    a. Push the aluminum rings pushed vertically into the soil until fully inserted (figure 25).


Figure 25. Aluminum sampling rings fully inserted alongside a hydraprobe reading location

b. The aluminum rings are then gently removed by inserting a trowel underneath to loosen the soil (figure 26). Once removed, the soil sample is trimmed on both ends to ensure an exact volume of soil has been removed (figure 27). 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 26. Loosening a sample ring to remove the sample from the soil

Figure 27. 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 Hyda Probe and data download*

GUIDE TO THE POGO

A) BEFORE YOU START:

- Do not store it inserted in the soil or standing on its tines on a hard surface.
- First, take a "Sample" reading in air using the HydraMon to see if the temperature reading is the approximate air reading before starting. Then leave the sensor in the soil for approximately 1 minute to provide the most accurate soil temperature measurement.
- The Hydra Probe prongs, (including the base) of the Hydra Probe must be in full contact with the soil in order to acquire good readings.
- For turf applications, you may need a cup cutter in order to expose the soil for making the actual measurements.

B) USING HYDRAMON:
Under "Start" menu, find "Stevens HydraMon" and select it.

C) CONNECTING AND COM-PORT SELECTION:

1. When the HydraMon screen appears, click on the "Probe" menu at the bottom and select "Connect."

2. Connect the RS232 adapter cable to the PDA. The first time you use the software you will be prompted for a COM port number. Select COM Port 1.
3. Open “FILE” on the main screen, and make sure the RS485 DIRECT is not checked. If it is, then you need to un-check it.
4. Switch battery pack to the on position
5. Next, select “PROBE”, and click CONNECT

D) SAMPLING WITHOUT LOGGING:
Sampling without logging permits you to take soil measurements but will not record the measurements for later uploading. This is for one-time spot checking where trend data is not required.

1. When you open the HydraMon program, “connect” to your POGO, Click on the “Logging menu” and de-select Logging Enabled.

NOTE: The option cannot be de-selected without the PocketPC being connected to the POGO.

2. On the main HydraMon screen, open the “Probe” menu and select “Soil” and then a soil type: “Sand,” “Silt” “Clay”, “Loam” and Custom.

E) PUTTING THE PROBE IN THE SOIL:
If this is the first time that you have used the POGO after bringing it out from storage, wait for 1 minute for the temperature of the tines to achieve an equilibrium with the soil temperature.

1. Gently push the unit down so the tines slide into the soil. Push the prongs in as far as they will go so that the base where the prongs are attached is firmly against the soil.
2. To display the data collected by the POGO for the site where you are, click on the large “Sample” button on the main HydraMon screen to take a reading.

F) LOGGING SET-UP:
If you wish to log data, click on the “Logging” menu at the bottom of the screen and select “Logging Enabled” so that a check mark appears next to it.

- To enter customized locations, select “Location manager”. If a Location File is not listed, you can create one by going to the far left bottom of the screen and click “New”.
- To add a new location, click on the “Add” button, place your cursor in the “Location name” field and then use the keyboard to enter a new name.
  Press “Save” when you have completed your new entry. It should appear in the list of locations on the location manager screen.
- Use the “Edit” and “Delete” buttons on the location manager screen to modify the names of locations or delete them.

G) LOGGING DATA:
Logging of data occurs AFTER sampled data is displayed.

1. In “logging enabled mode” press the Sample button, HydraMon will ask “Store these readings?” To log the data select a location from the drop-down list of location names and press the “Store” button.

NOTE: The data for each location cannot be redisplayed on the PocketPC. However, it will upload normally to a laptop or PC.

WHEN FINISHED, select “Probe” then “Disconnect.” Exit HydraMon program and turn off Pogo power using the switch located at the end of the box.
* If clumps of soil remain attached to the tines, wipe them off and clean the unit with a cloth.

H) DOWNLOAD LOGGED DATA TO PERSONAL COMPUTER (PC):
Must use MicroSoft (MS) Active Sync:

1. Open Microsoft Active Sync under the “Start” menu of your PC (this can be done with or without you Pocket PC in synchronized to the PC.
2. Click on the “Explore” button. There you will see the file names that you saved the logged data to when using the HydraMon. It is likely in a .csv file. Click on this file and it should open in MS Excel which presents your logged data in a tabular format for review and analysis.

### *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:

RADARSAT2, descending mode
UAVSAR
PALS

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

RADARSAT 2 perpendicular to descending orbital track:
UAVSAR perpendicular to flight track:
PALS perpendicular to flight track:

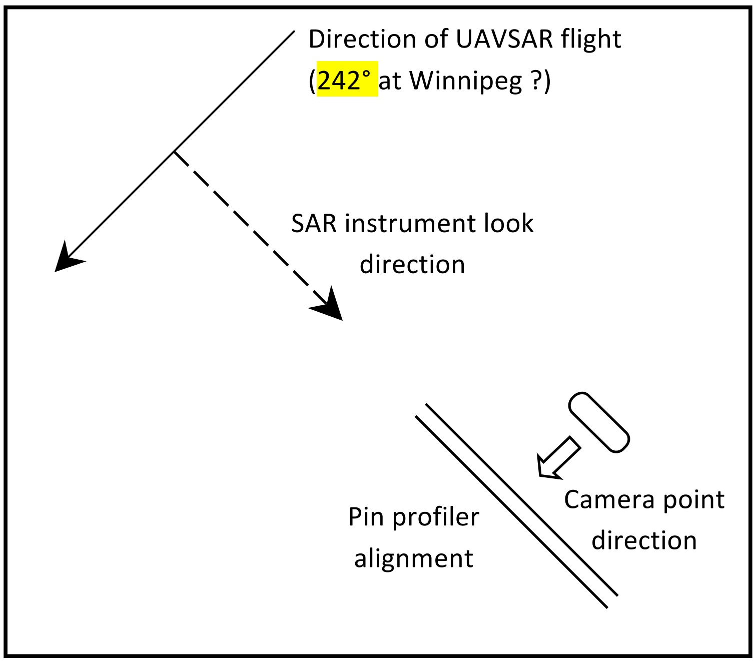
For each field, roughness measurements will be collected at two sites. For each site, a set of measurements consists of three, 3 m replicates in the look directions of RADARSAT2 (descending), UAVSAR and PALS flights. One replicate is represented as a surface roughness measurement of 3-m length. The 3-m 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 9 photos (3 adjacent photos x 3 look directions) will be taken in the look directions of the SAR sensors (RADARSAT2 (descending mode), and UAVSAR and PALS). This leads to 18 photos (3 adjacent photos x 2 sites x 3 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 satellite and of the UAVSAR and 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 each of the SAR sensors; RADARSAT2 (descending mode) and the UAVSAR 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,
- Roughness measurements will be collected at a second time toward the end of the field campaign, at the same sites as the beginning of the campaign.

**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 Spacing**

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

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

- Use a tape measure and flag a distance of 10 metres along one row (tie flagging tape to first and last plant, or use field flags to delineate first and last plant)
- For each of 10 consecutive rows, count the number of plants along the 10 m distance.
- Record each value on the data sheet.

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

- Use a tape measure to flag a distance of 1 metre along one row (tie flagging tape to first and last plant, or use field flags to delineate first and last plant)
- For each of 10 consecutive rows, count the number of plants along the 1 metre distance.
- Record each value on the data sheet.

**Timing: Plant spacing should be completed prior to commencement of field campaign. This task will be easier when crops are just past emergence, particularly for narrow-spaced crops.

**VG2: Row Spacing**

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

- Use a tape measure to record the row spacing for each of the 10 rows used to determine the plant density.
- Measurements are to be taken at the soil level, as the distance between the centre of the plant in row one to the centre of the plant in row two.
- The first measurement will be taken between the first row to the second row
- The last measurement will be taken between the 10th row to the 11th row (a row in which the plants are not counted) for a total of 10 row widths.
- Record each row spacing value on the data sheet.

Plant density (PD) will be calculated as follows:

$$\text{Rrcpv Fgpukv\{ *RF+} = \frac{\text{Uwo qh Rrcpvu kp 32 Tqyu z 32o Ctgc}}{(\text{Cxgtcig Tqy Ykfvj qxgt 32 Tqyu}) \times 32o} = \frac{\text{Cxgtcig \%Rrcpvu}}{o^4}$$

**VG4: Leaf Area Index (LAI)**

Seven hemispherical photos will be taken every 5 metres, along two parallel transects. Thus for each site, a total of 14 photos are taken.

- The camera lens should be a minimum of 50 cm above the highest point of the canopy (when photos are taken downward) or 50 cm below the lowest leaf of the canopy (when photos are taken upward)
- Based on crop height and this minimum required distance, decide if photos will be taken downward or upward. As a rule of thumb, when crops are over 80 cm, upward facing photos should be taken. Record this orientation (downward or upward) on the data sheet.
- In the case of row crops, photos will be taken in the middle of the crop row.
- In the case of downward photos, hold camera pointed downward, out at chest height and level. In the case of upward photos, place camera on ground and pointed upward.
- Take the first photo. Take photos 2-7 at 5 metre increments along first transect.
- Cross over to second row, and take photos 8-14 at 5 metre increments along this second transect.
- When walking back on this second transect, be sure to offset the location of photos as shown in Figure 28.
- 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)

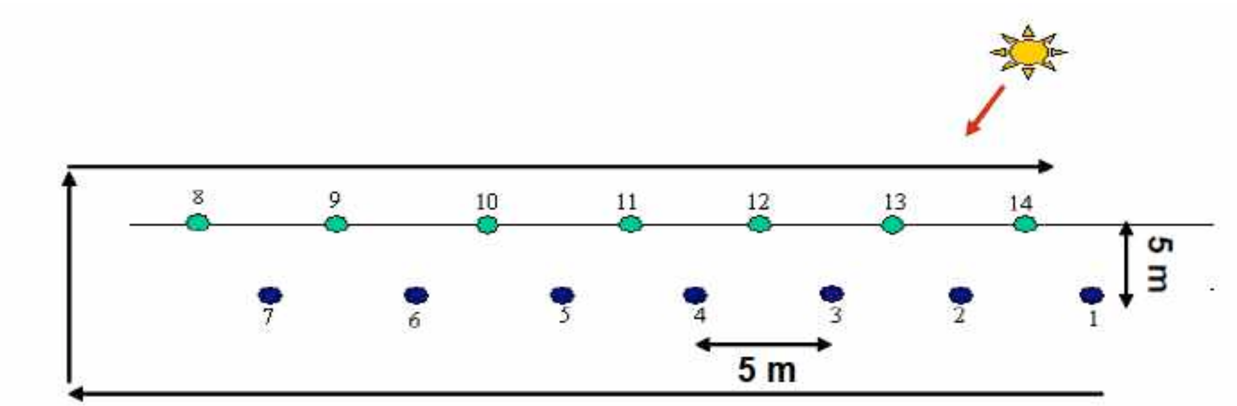



Figure 28. Sampling transect for hemispherical photos to measure LAI

**VG5: Biomass and Canopy Water Content**

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

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 labeled plastic bag. Secure the plastic bag with a firm knot.
- The paper bag should be labeled as follows:

Field # - Site #
Date

- 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 2 of 3)

- If the plants are wet with dew, gently shake the vegetation prior to bagging.

- If weeds are present, cut weeds at ground level and place in a separate paper bag. Then place the paper bag inside a labeled plastic bag. Secure the plastic bag with a firm knot. Label the paper bag as follows:

Field # - Site # - Weeds
Date

<u>At the lab</u>

Lab personnel should:

- For the sample gathered from site 1 of each field, the crop sample will be segmented. The level of segmentation will depend on the crop.

*Wheat, oats, barley* – heads cut off to provide 2 samples (a) heads and (b) leaves+stems
*Grassland and tame hay* – no segmentation
*Corn, canola and soybeans* – leaves, seeds/pods/cobs and stems separated to provide 3 samples (a) leaves, (b) seeds/pods/cobs and (c) stems

- Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. For example,

Field # - Site 1 - leaves
Date

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

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 site, 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 labeled plastic bag. Secure the plastic bag with a firm knot.
- The paper bag should be labeled as follows:

Field # - Site #
Date

- If the plants are wet with dew, gently shake the vegetation prior to bagging.

- If weeds are present, cut weeds at ground level and place in a separate paper bag. Then place the paper bag inside a labeled plastic bag. Secure the plastic bag with a firm knot. Label the paper bag as follows:

Field # - Site # - Weeds
Date

<u>At the lab</u>

Lab personnel should:

- For the sample from site 1 of each field, the crop sample will be segmented. The level of segmentation will depend on the crop.

*Wheat, oats, barley* – heads cut off to provide 2 samples (a) heads and (b) leaves+stems
*Grassland and tame hay* – no segmentation
*Corn, canola and soybeans* – leaves, seeds/pods/cobs and stems separated to provide 3 samples (a) leaves, (b) seeds/pods/cobs and (c) stems

- Paper bags should include an additional descriptive: heads, leaves, stems, seeds/pods/cobs as appropriate. For example,

Field # - Site 1 - leaves
Date

- 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 2 of 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 Regional office 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 or a cooler 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 plastic bag used and weigh 10 plastic bags. Record the weight of these 10 bags.

- Remove plastic bag. Back at the Regional office place paper bag in the drying trailer.
- Dry at about 30°C for 1 week.
- Before re-weighing crop samples, verify that sample has been completely dried. If uncertain, place crop sample back in oven 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:

$$PlantWaterContent(PWC)(g) = \left[WetWeight(g) - plasticbag\ weight(g)\right] - DryWeight(g)$$

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

$$Area\ PWC\ (g\ m^{-2}) = \frac{(PWC)(g)}{Number\ of\ plants\ collected} \times PD\ (plants\ per\ m^2)$$

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.

- 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 all 10 measurements on the data sheet.

**VG7: Stem Diameter**

Stem diameter will be measured for the same 10 plants used for crop height.

- Use a caliper to measure the diameter of the stem, half way between the top of the crop and the soil.
- Record all 10 measurements on the data sheet.

**VG8: Plant Phenology**

Plant phenology will be determined by the lab technician charged with weighing the samples.

- After weighing the sample for site 1, 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 and place organs in separate bags
- Place samples in drying trailer

**VG9: Vegetation Structure and Architecture**

The structure of the plant will be captured photographically.

- Place the gridded marker board behind a row of crops.
- It will be necessary to either gently flatten the plants in front of the row to be photographed, or to take the picture where the biomass has been removed.
- Write the Field # - Site # and date on the gridded marker board.
- Take the photo. Check that photo is good (illumination, focus etc.).

### *A.4.2 Forest vegetation sampling protocols*

The design of the forest vegetation sampling strategy is highly dependent on the available personnel. The following strategy is expected to take 2 days per site (1/4 section).

**Sampling Strategy**

The following material outlines the sampling plan for each plot, which is assumed to be approximately ½ mile by ½ mile (1/4 section), or roughly 800m by 800m. Note that due to the irregular boundary shape of forested sites, it will not necessarily be true that the sampling plots are exactly of the above dimensions. Minor modifications will be made as needed for each specific site once the sites are finalized.

**Sampling geometry**

Please refer to figure 29. The geometry proposed here is meant to provide sufficient representation of the vegetation within each ¼ section field, but is not a unique design. The geometry can be modified as needed to meet resource requirements, as long as the representativeness of the measurements is preserved.

For each ¼ section field, three random circular sub-plots of 200m diameter will be selected. Within each circular area, the 4 transects in cardinal directions (N, S, E, W) will be measured. This could be accomplished by either starting from the center of the circle and walking 4 lines in the cardinal directions, or starting, for example, at the southern most point and walking all the way to the northern most point, then repeating for the E-W line.

**Measurements**

For each transect, the following measurements will be taken:

1. height of each tree within +/- 1 m (or full arm span) of the transect line
2. DBH of each tree within +/- 1 m (or full arm span) of the transect line

3. species of each tree within +/- 1 m (or full arm span) of the transect line
4. at every 10m interval: DBH, diameter, # of primary branches, height from ground to base of live crown, and an estimate of the primary branch angle for the two trees closest to the transect line
5. at every 10m interval: fractional ground cover and understory height within a 2m by 2m area (or larger)

The above plan results in 2 (trees) *3 (circles) *4 (directions) *100 m/10m = 120 "point" measurements of trees and many more measurements of height and DBH.

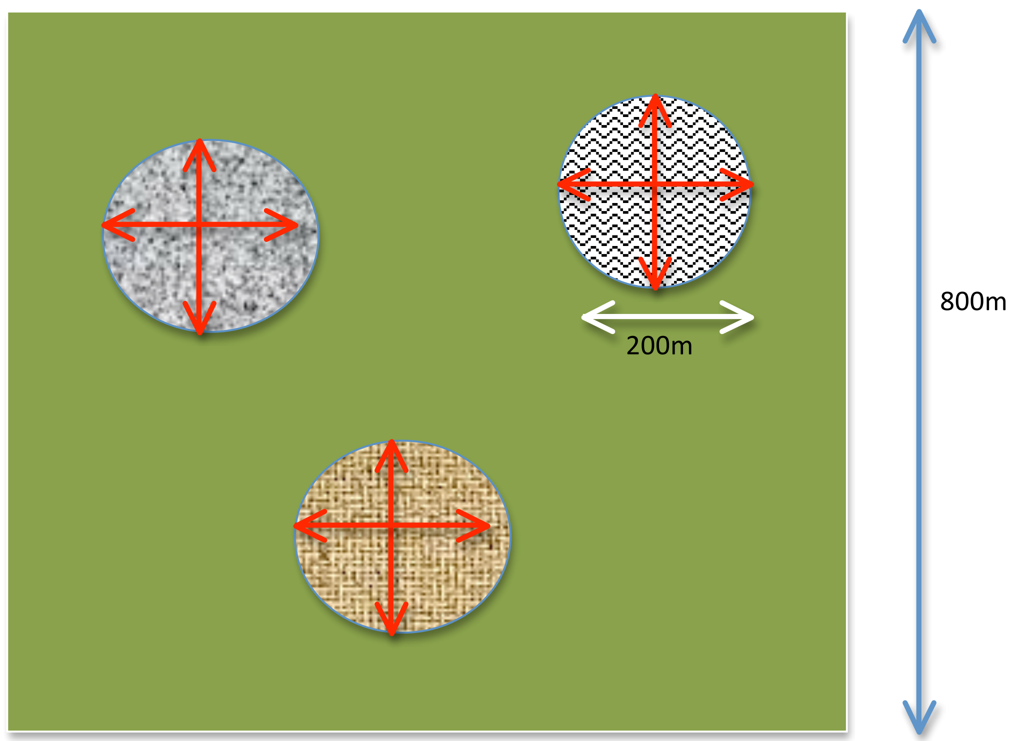



Figure 29. Design of the sampling geometry for SMAPVEX forested regions.
Total length of each two-sided red arrow is 200m

**Destructive samples**

Ideally, one tree per circular subplot (or 3 per ¼ field) will be harvested for intensive destructive measurements. This number can be reduced to a total of 2 per ¼ field if needed. The trees to be harvested will be chosen based on the results of transect measurements, such that an "average" tree per transect can be defined and cut.

Specific measurements for destructive samples will be as follows:
1. diameter at each 30cm interval
2. dielectric constant at each 30cm interval
3. wafer of approximately 3cm for gravimetric measurements at each 30cm interval
4. primary branch angles
5. number of branches (primary, secondary)

6. all branch lengths, diameters, and if possible, dielectric constant
7. 3-4 samples of branches for gravimetric measurements
8. number of leaves for each branch
9. note on leaf clumping

**Other considerations**

At the center of each circular sub-plot, a photo of each cardinal direction will be taken.
Photos will be taken of all harvested trees, before and after cutting
Photos of understory will be taken

An “application” is under development in Moghaddam’s group for handheld devices (iphone, android phone, ipad, and android tablet) that allows the data collection process and geolocation to be streamlined. This App has spreadsheets with pre-designated measurement types, and can be used to enter GPS way points. Once fully tested, the App can be made available to the entire SMAPVEX team.

### *A.4.3 Vegetation sampling teams*

The number of personnel assigned to the vegetation teams, as well as the frequency and timing of data collection, is provided in table 13.

Table 12. Summary of vegetation sampling teams

| | Number of people required | Source of Personnel | Frequency | Timing | Notes |
|---|---|---|---|---|---|
| Plant Density | 2 | Students hired in MB | once | Before field campaign commences | Should be completed just after emergence so that ID of individual plants is easier |
| Row Spacing | 2 | Students hired in MB | once | Before field campaign commences | Should be completed just after emergence so row measurement is easier |
| Row Direction | 2 | Students hired in MB | once | Before field campaign commences | |
| Crop Structure and Architecture | 2 (1 team of 2) | | Each field visited once per week | | Led by Dr. Sab Kim |
| Crop Biomass, Height, Stem Diameter, LAI, Crop Scan | Teams of 4<br>*1 - LAI*<br>*1 - biomass*<br>*1 - cropscan*<br>*1 - notes and photos* | | Each field visited once per week | | Each team visits 4 fields per day; assume 4 work days/week (16 fields per week per team). Other days are rain days, down days or helping with soil moisture) |
| Phenology | 2 | Lab Tech | | | Done at time of biomass weighing |
| Forest Vegetation | Teams of 2 or 4 | | once | | |
| Sample weighing | 2 | Lab Tech | | | |

### *A.4.4. Crop scan measurement instructions*

Reflectance data will be collected for each vegetation sampling location. One reflectance measurement will be taken at the location of each of the 14 LAI measurements (see figure 28).

- 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 of 3 vegetation sites in each field.