SMAPVEX12 Database Report

Updated: December 18, 2012

Table of Contents

1. Study Area 5
1.1 Agriculture 6
1.2 Forestry 8
1.3 Permanent *in situ* soil moisture network 9
1.4 Temporary soil moisture network 12
2. Collection of Soil and Vegetation Data 14
2.1 Agriculture Cropland 15
2.1.1 Soil Moisture and Temperature 15
2.1.2 Surface Roughness 18
2.1.3 Cropland Vegetation 19
2.1.4 Vegetative Structure 22
2.2 Forested Sites 23
2.2.1 Soil Moisture 24
2.2.2 Surface Roughness 24
2.2.3 Forest Vegetation 25
3. Airborne Imagery 29
3.1 Passive Active L-band Sensor (PALS) Data Collection 30
3.2 UAVSAR on NASA G-III 32
4. Satellite Imagery 34
Appendix A. Calendar of all data collected during SMAPVEX12 38
Appendix B. SMAPVEX12 participants 39

Table of Figures

Figure 1. Location of the SMAPVEX12 study area (red) with major towns (green stars) and highways (black).....5
Figure 2. Soil texture map of the SMAPVEX12 study area.....6
Figure 3. Fifty-five agricultural fields (red), labelled 11 to 125, used during the SMAPVEX12 campaign 7
Figure 4. Sixteen sampling points (red) used in each of the 55 agricultural fields (orange), during the SMAPVEX12 campaign. 8
Figure 5. Spacing between soil moisture sampling points.....8
Figure 6. Forestry sampling sites (red) used during the SMAPVEX12 campaign 9
Figure 7. Location of Manitoba *in situ* soil moisture sensors within the Canadian portion of the Red River watershed 9
Figure 8. Location of the AAFC Manitoba *in situ* soil moisture network (red star) 10
Figure 9. Schematic of probe location within each soil pit for AAFC *in situ* monitoring sites 10
Figure 10. Site installation of AAFC *in situ* soil moisture sites 11
Figure 11. Spatial location of weather stations; MAFRI & MWS (red), Environment Canada (purple) and WeatherFarm (blue) 12
Figure 12. USDA soil moisture station in a soybean field 13
Figure 13. Configuration for a USDA CR206 datalogger with Hydra probe 14
Figure 14. Hand held Stevens Hydra probe with PDA 16
Figure 15. Location of replicate soil moisture measurements at each site 16
Figure 16. Soil core sample.....17
Figure 17. Temperature at 5 and 10 cm (left) and at the surface (right).....18
Figure 18. An example of the placement of the profilometer.....19
Figure 19. Measurement of surface roughness using the pin profiler 19
Figure 20. Biomass measurements (left) and drying trailer (right) 21
Figure 21. Fisheye photo for Field 34 (June 16, soybeans).....22
Figure 22. Location of the 14 points for crop scan measurements and LAI photos. 22
Figure 23. Canola field 124 on June 7 (left) and June 16 (right), 2012 23
Figure 24. Schematic representation of the forestry soil moisture transects 24
Figure 25. Measurement of surface roughness using the pin profiler over the forested sites F1 (left) and F2 (right) 25
Figure 26. Example of tree flagging 26
Figure 27. Measurement of fractional ground cover and understory height within a quadrat 27
Figure 28. Trunk height and diameter measurements on an aspen.....28
Figure 29. FieldFox with dielectric probe and drill bit hole to facilitate full probe contact 28
Figure 30. DHC-6 Twin Otter International (left) and NASA Gulfstream III (right) 29
Figure 31. Low altitude PALS flight lines (red) and high altitude lines (yellow).....32
Figure 32. The PALS radiometer data in H polarization for June 12 (left) and July 3 (right).....32
Figure 33. SMAPVEX12 UAVSAR Coverage Boxes.....33
Figure 34. A UAVSAR Imagery acquired near Carman (Manitoba) on July 17th, 2012.....34
Figure 35. Imagery acquisition coverage for RapidEye and SPOT-4/5 sensors.....35
Figure 36. Coverage for RADARSAT-2 imagery. 36
Figure 37. TerraSAR-X coverage in ascending (left) and descending (right) modes. 37

List of Tables

Table 1. Location of AAFC permanent and MAFRI temporary in situ stations 11
Table 2. Field and crop type for each USDA soil moisture temporary station 13
Table 3. Dates for soil moisture, vegetation and surface roughness data collection. 15
Table 4. Field number and crop type of vegetation structure sample fields. 23
Table 5. Imagery acquisition dates for the PALS and UAVSAR instruments during SMAPVEX12 30
Table 6. Description of PALS. 30
Table 7. Geometric features of PALS data acquisitions. 31
Table 8. Description of the UAVSAR. 33
Table 9. Imagery acquisition dates for RapidEye and SPOT-4/5 sensors 34
Table 10. Imagery acquisition dates for RADARSAT-2 imagery during SMAPVEX12 36
Table 11. Imagery acquisition dates for TerraSAR-X imagery. 37

1. Study Area

The study area for the SMAPVEX12 campaign is located in south central Manitoba, Canada centered on the town of Elm Creek (98^{o} 0’23”W, 49^{o} 40’ 48”N) (Figure 1). The site is 12.8 km wide by 70 km long and was selected for a variety of reasons. The soil texture varies greatly across the site with heavy clays in the east, which sharply transition to loamy fine sands in the west over a distance of a few kilometers (Figure 2). This abrupt change in soil texture provides a large range of soil moisture levels within a small spatial footprint. Agriculture and Agri-Food Canada (AAFC) has a permanent *in situ* soil moisture station network in the area, and the data from this network was available to SMAPVEX12 participants. AAFC has conducted numerous remote sensing research studies in this area and thus has developed a working relationship with many of the producers in this region. The selected area covers a range of annual and perennial crops typical of the region and of interest to the SMAPVEX12 team. In addition, the study area contains some wetland and forest land cover.

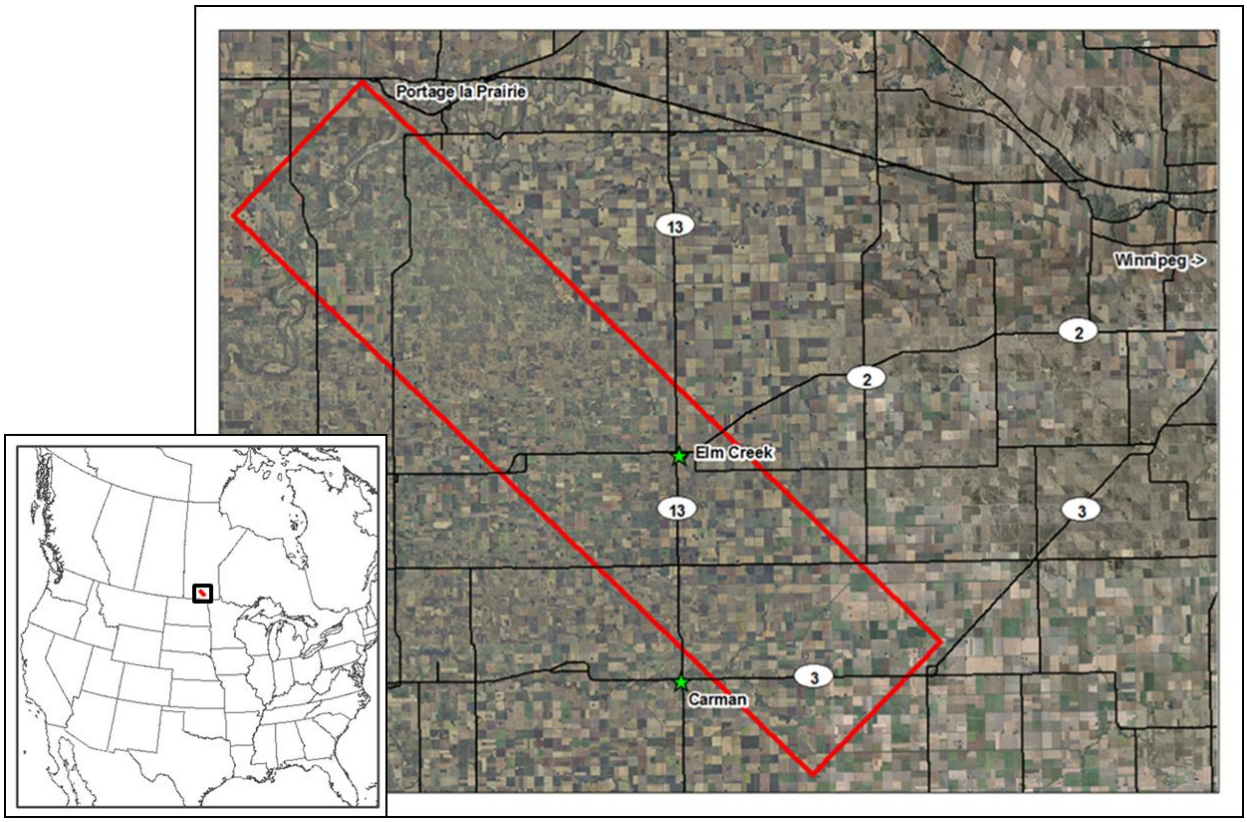


Figure 1. Location of the SMAPVEX12 study area (red) with major towns (green stars) and highways (black)

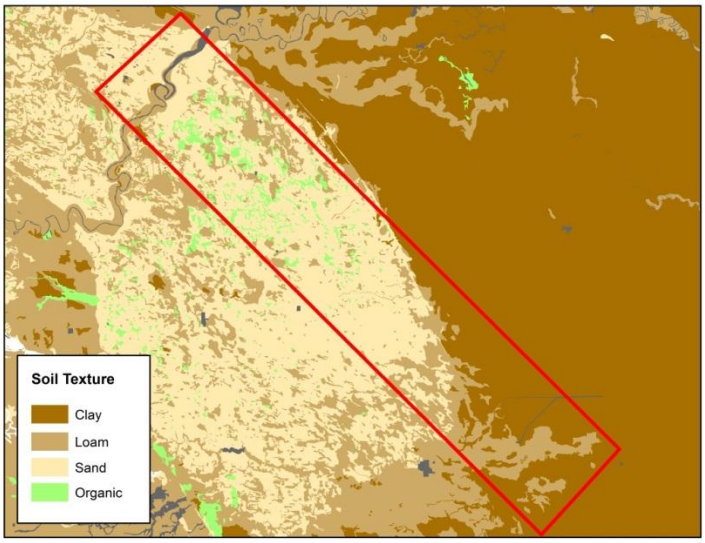


Figure 2. Soil texture map of the SMAPVEX12 study area

1.1 Agriculture

In 2011, the dominant annual crops in the area included cereals (32.2% of area), canola (13.2%), corn (7.0%) and soybeans (6.7%). Approximately 16.4% of the study area was occupied by perennial cover (grassland and pasture). For the purposes of SMAPVEX12, fifty-five agricultural fields were selected with the following crop type distribution: 15 soybean, 1 bean, 6 canola , 10 corn , 14 spring wheat, two winter wheat, 1 forage and 6 pasture (Figure 3). Due to market and environmental conditions early in the season, in 2012 greater acreages of beans were planted than typical of this region. Consequently a large number of soybean fields were selected for the SMAPVEX12 campaign.

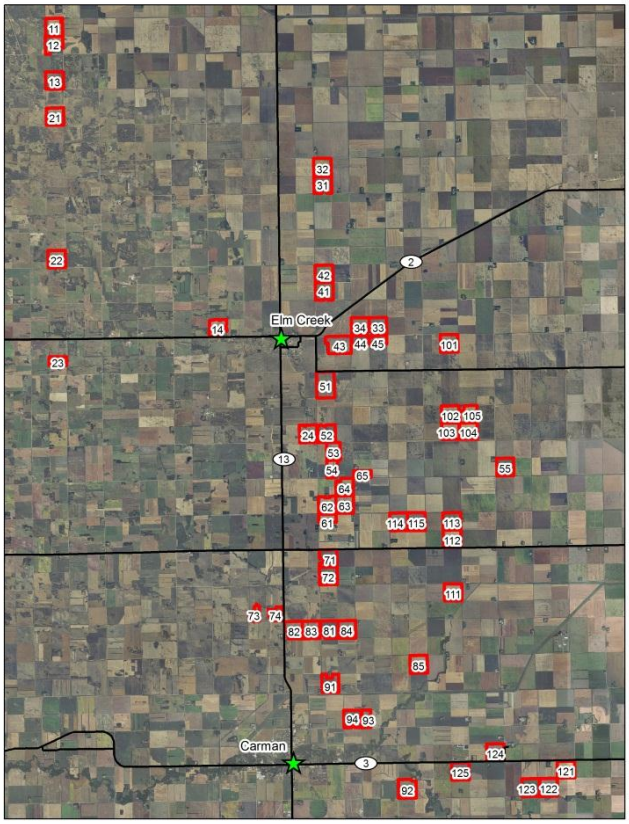


Figure 3. Fifty-five agricultural fields (red), labelled 11 to 125, used during the SMAPVEX12 campaign

Soil moisture varies significantly across the landscape. In order to capture soil moisture conditions representative of each of the SMAPVEX12 fields, multiple sampling was required. Thus for each field, soil moisture was measured at sixteen sampling points, with three replicate measurements at each of these sample points. For ease of access and navigation, these 16 sample points were arranged in two transects of 8 points running parallel to crop row direction (Figure 4). The location of each sample point was pre-loaded into handheld GPS devices so that crews could easily navigate to each point. For the most part, the positioning of the transects meant that moisture conditions were measured along the full extent of the field. Transects were also positioned to avoid edge effects were soil and vegetation conditions may not be typical of the field due to management practices (Figure 5).

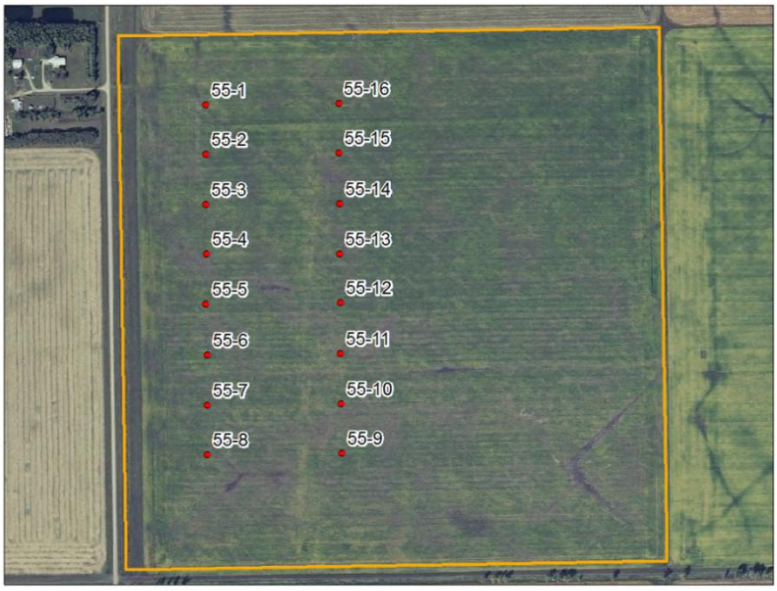


Figure 4. Sixteen sampling points (red) used in each of the 55 agricultural fields (orange), during the SMAPVEX12 campaign.

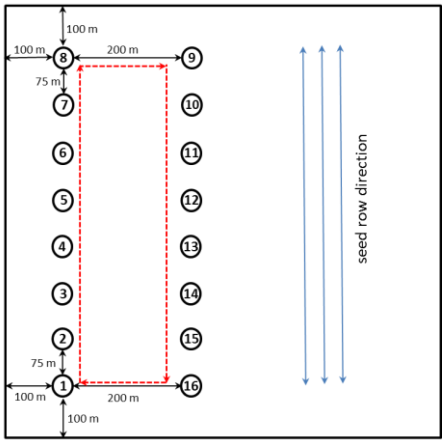


Figure 5. Spacing between soil moisture sampling points

1.2 Forestry

The forestry team utilized 4 sampling sites within the SMAPVEX12 study area, each with a varying degree of tree cover (Figure 6). Main tree species included Trempling Aspen (*Populus tremuloides*), Bur Oak (*Quercus macrocarpa*), and Balsam Poplar (*Populus balsamifera*) on soil textures ranging from clay to loamy fine sand. During SMAPVEX12 planning, five sites were selected. However after visiting site F4, the forest team decided to drop this sample site as the forest cover was too sparse and land cover too varied.

Figure 6. Forestry sampling sites (red) used during the SMAPVEX12 campaign

1.3 Permanent *in situ* soil moisture network

Diverse soil moisture networks are present in the agricultural regions of southern Manitoba, operated by the University of Manitoba, AAFC, 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 dispersed across a larger area (Figure 7).

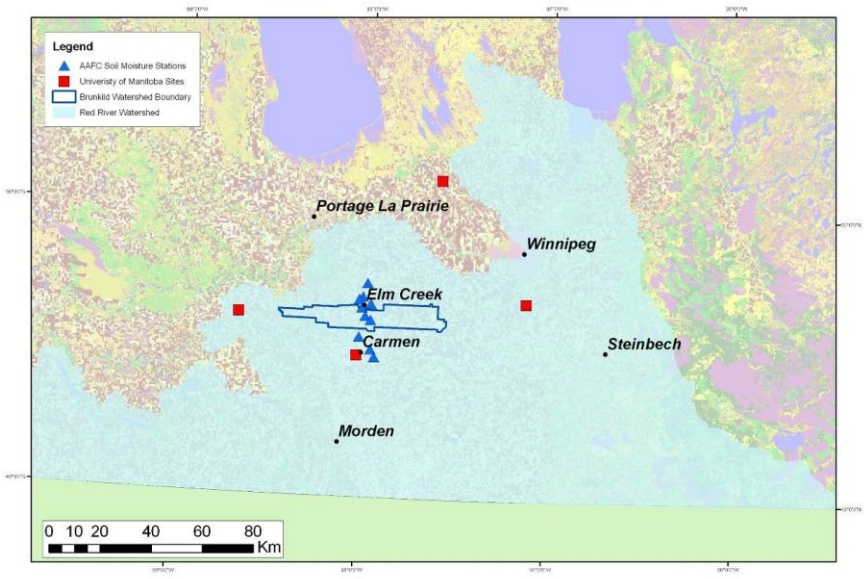


Figure 7. Location of Manitoba *in situ* soil moisture sensors within the Canadian portion of the Red River watershed

In 2011, AAFC installed 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 the calibration and validation of these products.

The network was designed based on geostatistical principles to capture the maximum soil variability within the Red River watershed. The soils and landscape particular for this region led to the location of the sensors along a gradient in soil texture classes (Figure 8). The network consists of nine monitoring stations, distributed to capture this variance in soil classes and thus soil moisture. At each station three Stevens Hydra probes have been placed at each of four depths – 5, 20, 50 and 100 cm. At the surface, three probes have been placed vertically to capture the 0-6 cm integrated soil moisture, in addition to the three probes buried horizontally at 5 cm. This yields in total, 15 soil moisture measurements per station. Each probe records soil moisture percentage (using Stephen's default dielectric conversion model), soil temperature in Celsius and real soil dielectric permittivity. Each station is also equipped with a tipping bucket rain gauge (Campbell Scientific 700). Data are 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.

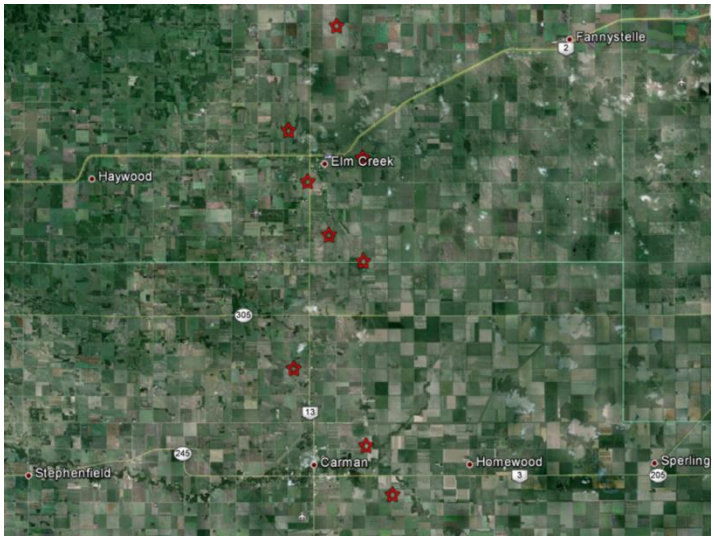


Figure 8. Location of the AAFC Manitoba *in situ* soil moisture network (red star)

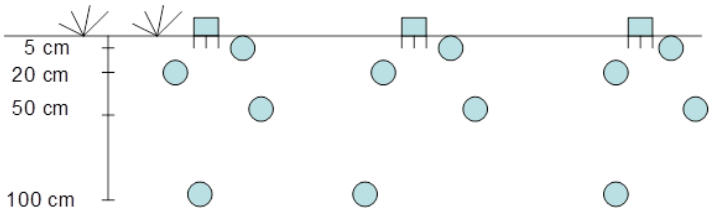


Figure 9. Schematic of probe location within each soil pit for AAFC *in situ* monitoring sites

Figure 10. Site installation of AAFC *in situ* soil moisture sites

All AAFC soil moisture stations are located within or on the edge of cultivated agricultural fields, with the station set up to capture data year round, without removal of equipment to accommodate land management activities. During installation, soil cores were collected at the location of each probe. Soil cores were preserved for soil moisture dry down calculations and soil texture and bulk density analysis. The location of these AAFC permanent stations, relative to the SMAPVEX12 fields, is provided in Table 1. For two of the nine AAFC stations, landowner permission was not granted for the SMAPVEX experiment. Thus only seven of the nine stations are situated within a SMAPVEX12 field, although data from all nine stations was collected during the campaign. In addition to these permanent stations, four MAFRI stations were installed for the duration of the field campaign. These temporary MAFRI stations had sensors installed at the same depths as the AAFC permanent station, but with only one probe installed per depth.

Table 1. Location of AAFC permanent and MAFRI temporary in situ stations

AAFC/MAFRI In-Situ Station	SMAPVEX12 Field
AAFC-1	92
AAFC-2	93
AAFC-3	73
AAFC-4	65
AAFC-5	24
AAFC-7	44
AAFC-9	32
MAFRI-1	11
MAFRI-2	22
MAFRI-3	85
MAFRI-4	F3

Also, 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 WeatherFarm, WeatherBug and Weather Innovations Inc. (Figure 11). Most stations record typical meteorological variables including air temperature, total precipitation, wind speed and relative humidity, with some providing additional data, such as 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.

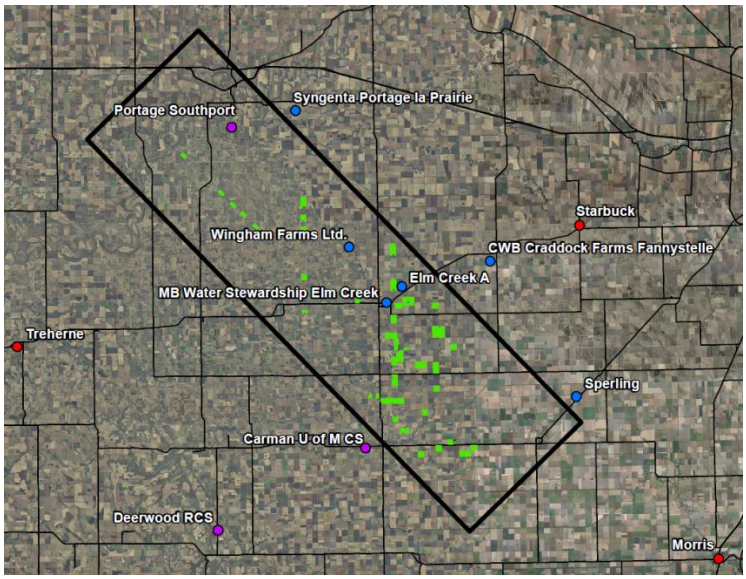


Figure 11. Spatial location of weather stations; MAFRI & MWS (red), Environment Canada (purple) and WeatherFarm (blue)

1.4 Temporary soil moisture network

The U.S. Department of Agriculture provided forty soil moisture sensors which were installed in SMAPVEX12 fields for the duration of the experiment (Table 2).

Table 2. Field and crop type for each USDA soil moisture temporary station

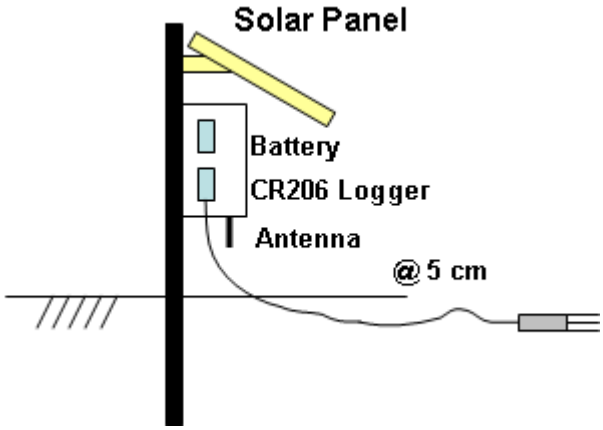
Field	Crop	USDA Station		Field	Crop	USDA Station
112	Soybeans	1		124	Canola	21
41	Winter Wheat	2		85	Wheat	22
34	Soybeans	3		101	Soybeans	23
53	Corn	4		51	Soybeans	24
94	Corn	5		63	Soybeans	25
14	Soybeans	6		61	Canola	26
33	Soybeans	7		64	Soybeans	27
43	Oats	8		74	Wheat	28
114	Soybeans	9		74	Soybeans	28
F2	Forested	10		125	Canola	29
104	Wheat	11		31	Wheat	30
72	Corn	12		54	Corn	31
62	Canola	13		52	Soybeans	32
62	Corn	13		82	Soybeans	33
83	Corn	14		45	Wheat	34
13	Pasture	15		21	Pasture	35
84	Canola	16		91	Wheat	36
113	Soybeans	17		122	Canola	37
F4	Forested	18		123	Soybeans	38
F1	Forested	19		55	Wheat	39
71	Corn	20		81	Wheat	40

These stations consisted of a Stevens Hydra soil moisture sensor, a data logger, and a solar panel for continued operation. Stations were removed from SMAPVEX fields prior to harvest in early August for winter wheat fields, late August for soybean, spring wheat, oats, canola forage and pasture fields and mid-September for corn fields. Data were downloaded from data loggers a day after removal from the field.

Source: Mike Cosh, 2012

Figure 12. USDA soil moisture station in a soybean field

The USDA temporary soil moisture stations were placed a quarter of the way along the row, facing upslope if a slope was present. The center of the probe was installed horizontally at a 5 cm depth. These parameters yield soil moisture readings at a depth of approximately 3 -7 cm. Placement ensured that there were no obstructions above the sensor, other than natural vegetation. Thus no antennas, solar panels or enclosures were within 1 meter of the surface (Figure 13).



Source: Michael Cosh, 2012

Figure 13. Configuration for a USDA CR206 datalogger with Hydra probe

The sensor recorded soil moisture and soil temperature measurements. Several factors potentially influence the accuracy of the readings, with the most significant factor being the installation itself. Soil disturbance associated with the installation can either increase or decrease soil infiltration, affecting the representativeness of the moisture reading; however, this degree of variation typically does not represent significant alteration to recorded data values. Battery voltage is a second factor which can affect the accuracy of the sensors, but this was not found to be an issue during the course of the SMAPVEX12 campaign. While one or two of the sites were periodically disturbed by cattle, usually only the post and datalogger were displaced, while the sensor was left undisturbed.

2. Collection of Soil and Vegetation Data

A critical pre-launch activity for the SMAP mission is to acquire and process surface validation data to calibrate, test, and improve models and algorithms for SMAP soil moisture retrieval. To assist with this objective, soil and vegetation variables known to influence microwave emissions and scattering were targeted for measurement. These variables included soil moisture, surface and sub-surface temperature, surface roughness, vegetation biomass and water content, and vegetation structure.

Soil and vegetation data were collected by field crews on the 55 cropland fields and 4 forest sites beginning on June 7th and ending on July 19th, 2012. Crews were provided two days of training prior to the commencement of the experiment. Sampling days were dedicated to either soil moisture or vegetation/surface roughness depending on whether aircraft flights took place (Table 3). During flight days, crews measured soil moisture and surface/sub-surface temperature on the cropland and forest sites. During non-flight days crews measured surface roughness and vegetation parameters such as biomass, reflectance and Leaf Area Index. The crop structure team operated independently, collecting data during flight and non-flight days. Down days were due to rain events or were used to give crews a

rest. On soil moisture days, crews were deployed to the field at approximately 6:30 AM to allow for collection of soil moisture measurements coincident with flight overpasses.

Table 3. Dates for soil moisture, vegetation and surface roughness data collection.

Soil Moisture	Vegetation	Roughness
June, 7	June, 11	June, 10
June, 12	June, 13	June, 11
June, 15	June, 16	June, 12
June, 17	June, 18	June, 13
June, 22	June, 21	June, 15
June, 23	June, 24	June, 16
June, 25	June, 28	June, 17
June, 27	June, 30	June, 18
June, 29	July, 7	June, 19
July, 3	July, 9	June, 21
July, 5	July, 16	June, 24
July, 8	July, 18	June, 30
July, 10		July, 7
July, 13		
July, 14		
July, 17		
July, 19		

The soil and vegetation sampling approaches deviated for the agriculture cropland and forest sites, due to the inherent differences in the characteristics of these landscapes, accepted measurement strategies for forests and crops, and the ease with which the sites could be accessed.

2.1 Agriculture Cropland

2.1.1 Soil Moisture and Temperature

During SMAPVEX12 soil measurements were collected in each of the 55 cropland fields, coincident in time to flight overpasses. A crew of two was tasked to measure soil moisture, surface and sub-surface soil temperature and surface vegetation temperature. Each crew was assigned four to five fields, typically arriving at their first field around 7:30 AM and finishing their last field around noon.

Crews were equipped with hand held soil moisture probes. Most crews were provided with Stevens Hydra probes connected to a PDA. 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 numerically solve Maxwell's equations, to calculate the impedance and the real and imaginary dielectric permittivities. The probes were inserted vertically into the soil, which provided dielectric and temperature measurements integrated over the top 6 cm of soil. Although readings were recorded digitally, crews were also asked to record soil moisture values on their field sheets. At the end of each day, data from the PDAs and data loggers were downloaded and quality checked. Field sheets were scanned.

Figure 14. Hand held Stevens Hydra probe with PDA

Each cropland field had 16 sample points as shown in Figure 5. At each sample point, crews were instructed to collect three replicate soil moisture measurements. Replication was important to capture spatial variability created by soil properties or management practices. Tillage and planting activities can create macro structures, affecting surface soil moisture. If crews observed obvious soil structure, they were instructed to distribute the three replicate measurements according to this structure 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 15). In each position, the probe was to be inserted vertical to the surface and flush to the soil. If crews did not observe discernible structure, measurements were to be taken diagonally across rows, with the first reading close to the crop row. Crews noted on sampling sheets whether structure was present. Over the course of SMAPVEX12, more than 44,000 hand held soil moisture measurements were recorded.

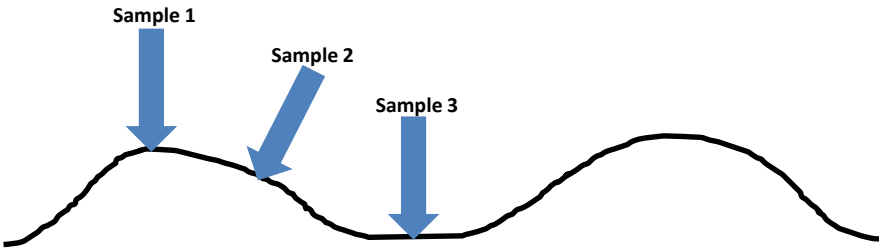


Figure 15. Location of replicate soil moisture measurements at each site

For the most part, field crews were successful in collecting data on all their assigned fields. However, on any given day some crews encountered circumstances preventing access to fields. This included poor road conditions, or aerial spraying of crops.

Site specific calibration of measurements from the hand held probes is necessary. To assist with this calibration, during flight days crews were instructed to collect one bulk density core per field. The

location of the one bulk density site was moved each flight day such that by the end of the campaign, one sample had been collected at each sample point within each field. This strategy yielded more than 850 cores during the course of SMAPVEX12.

The dimensions of the soil core were approximately 4.6 cm in height and 4.7 cm in diameter with a core volume of 80 cm^3. When the crew arrived at the designated bulk density site for that particular sampling day, they took their three standard probe readings. As well, the crew collected a soil core and three additional probe readings. These three additional readings were located in close proximity to the location of the soil core extraction, and were recorded separately on the field sheets. Crews were careful to collect an undisturbed soil sample. These samples (soil and core) were placed in a soil tin with a lid, with the tin then being placed in a re-sealable plastic bag to minimize moisture loss. Soil cores were transported back to Winnipeg for weighing and drying. The entire sample (soil, core, tin and bag) was weighed. The tin was then removed from the plastic bag and placed in a soil drying oven. The samples were oven dried for 24 hours at 105^oC. Following drying, the entire sample (soil, core, tin) was then re-weighed.

Figure 16. Soil core sample

Surface and sub-surface temperatures were also measured during flight days. Temperatures were recorded at four sites in each field (sites 1, 8, 9 and 16). Sub-surface soil temperatures were measured using a simple digital pocket thermometer (Figure 17). The digital thermometer was inserted to two depths, 5 cm and 10 cm. In addition, surface soil and vegetation temperatures were measured at these same four sites. In this case a thermal infrared thermometer was used (Figure 17). Crews recorded the temperature for sunlit vegetation and sunlit soil, as well as for shaded vegetation and shaded soil. During cloud cover it was not possible to acquire sunlit readings and thus not all sites have all four readings. All temperature measurements were recorded on the field sheets.

Figure 17. Temperature at 5 and 10 cm (left) and at the surface (right)

2.1.2 Surface Roughness

Macro and micro surface roughness are known to effect microwave emission and scattering. For agriculture fields, this roughness is primarily due to land management activities, modified over time by the effects of erosion by water and wind. Although the effects of land management on roughness can vary due to soil characteristics large roughness variations across a field are small. Consequently roughness was measured at only two sites in each field. In addition, the SMAPVEX12 campaign began after seeding and further effects due to management activity were not expected. As well, canopy closure reduced the influence of erosion forces. Thus roughness was measured only once. Roughness crews visited fields early in the campaign. For corn, bean and canola fields the presence of vegetation at the beginning of SMAPVEX12 was low, facilitating the collection of roughness photos. Roughness measurements were also collected over each forest site.

Information on surface roughness was gathered with a portable pin profilometer (Figure 21) that uses surface displacement and post-processing techniques to obtain root mean square roughness (rms) and roughness correlation length (ℓ). The pin boards are custom built, using metal pins with tips coated in red material, a wooden board, a set of legs to support the board and a mechanism to release pins for surface displacement. A metal bar is mounted on the board to hold a standard digital camera to take a picture of the roughness profile once it is in place. The board is one metre in length and the distance between the camera and the profiler is ~ 118 cm. Before taking the photo, if vegetation obstructed the view of the board the vegetation was flattened. As well, a bubble level on the pin profiler was used to level the board.

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

PALS flights) (Figure 21). The look direction is the direction perpendicular to the orbital track or flight line. For RADARSAT-2 this is perpendicular to the descending orbital track. For the UAVSAR and PALS this is perpendicular to the flight track.

For each site a total of 9 photos (3 adjacent photos x 3 look directions) were taken. This led to 18 photos (3 adjacent photos x 2 sites x 3 look directions) for each field.

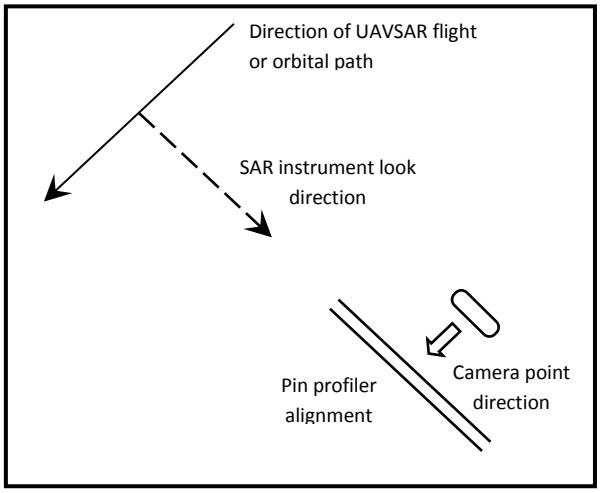


Figure 18. An example of the placement of the profilometer

Figure 19. Measurement of surface roughness using the pin profiler

2.1.3 Cropland Vegetation

Prior to the commencement of SMAPVEX12, fields were visited to determine planting density, row spacing and row direction. The density of plants was 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 was replicated for 10 rows. Row spacing was determined by measuring the distance

between rows, for the 10 rows used to determine plant density. Finally, the direction of planting was recorded using a compass.

During SMAPVEX12, non-flight days were dedicated to collecting vegetation data. The goal of the experimental plan was to measure vegetation conditions once per week for each field. This strategy was a compromise between capturing the changes in crop growth and available resources. By and large for the vast majority of fields this time table was achieved. However, field access due to impassible roads or aerial spraying did influence this schedule.

Vegetation measurements were collected at three of the 16 soil moisture sample points. Sites 2, 11 and 14 were selected as this distribution was expected to capture variance in vegetation conditions across each field, and also provided ease of navigation within the field. At each of these three sites, measurements of crop height and stem diameter were made. In addition biomass samples were collected and photos to measure Leaf Area Index (LAI) were taken. When clear sky conditions permitted, crop reflectance was measured at site 2. Restriction of reflectance measurements to one site was a result of the limitation in the memory capacity of the Crop Scan instrument. Due to different planting approaches of various crops, and the accumulation of crop biomass, the strategy to acquire vegetation measurements varied depending on crop type. For wheat, forage and pasture crops crews collected biomass, height and stem diameter measurements within a 0.5 m x 0.5 metre biomass square. All other crops have wide row and plant spacing and thus these measurements were taken along two adjacent plant rows.

Crop height and stem diameter can vary significantly along and between rows and thus multiple measurements are required. For all crops, 10 height and diameter measurements were taken using a tape measure (height) or caliper (stem diameters). For wheat, forage and pasture 10 plants were randomly selected within the biomass square for measurement. For corn, beans and canola five consecutive plants were measured in one row, with five more measured in the adjacent row. The height was measured to the top of the upper most part of the canopy, whether leaf or fruit. Leaves were left in their natural orientation, and not extended, for this measurement. The diameter was measured half way up the crop (at mid-level). Heights were recorded on field sheets.

Vegetation biomass and water content were determined via destructive sampling. One biomass sample was collected at each of the three measurement sites (2, 11 and 14). For wheat, forage and pasture fields a 0.5 m x 0.5 metre square was placed over the canopy. All above ground biomass was collected by cutting all vegetation at the soil level. For beans, corn and canola crops, five plants along two rows (10 plants in total) were collected. Knowledge of the density of the crop permits scaling of these measurements to a unit area (m^2). Dead plant matter (residue) was not included in the sampling. Following cutting, biomass samples were placed first in a paper bag, and then a plastic bag to minimize water loss prior to weighing the wet sample. Vegetation will degrade rapidly (within a few hours) and thus weighing of the wet sample must be completed quickly. During most vegetation sampling days, the lab crew set up a temporary weighing station located on site in Elm Creek. When convenient to do so, crews periodically brought their vegetation samples to this temporary station for weighing. More than 900 biomass samples were collected during SMAPVEX12.

Wet weights were taken with the paper and plastic bags (size of bags used and average bag weight was recorded). Following wet weighing, the plastic bags were removed and samples were placed in drying facilities at temperatures of approximately 30^{o}C. Initially a drying trailer was set up. However as the volume of biomass accumulated during the campaign, a larger capacity facility was required.

Consequently samples were then placed in the University of Manitoba Department of Soil Science drying room. Most samples were left in the drying room from several days to a week. As lab crew had to enter these drying facilities health and safety standards dictated a lower drying temperature. To determine whether all plant water content was removed during the drying process, selected sub-samples of air-dry vegetation, for each crop, were placed in a drying oven at 60^{o}C for 48 hours. This exercise determined that the air-dry to oven-dry conversion was remarkably consistent for wheat, beans, canola and forage. Almost all water (~95%) had been removed by air-drying. Based on oven-dry results a conversion factor of 94.57% was applied to dry biomass and vegetation water content calculations for these crops.

The results of the air-dry to oven-dry analysis were not consistent for corn. Thus the University of Manitoba undertook an experiment to grow a number of corn plants and oven dry these samples to determine percent vegetation water content. For this experiment, corn seeds were planted in 30 pots in a growing chamber on September 14, 2012. Three seeds were sown in each pot and of those 90 seeds, 76 germinated. Beginning October 3rd, plants were harvested, weighed and then oven dried at 60^{o}C for 48 hours. Results of this experiment are pending.

The SMAPVEX experimental plan called for the determination of vegetation water content as a function of plant organ. Thus for the sample collected from site 2, the lab crew segmented this sample by plant organs (heads, leaves, stalks, seeds/pods, tassels) prior to weighing the wet sample. Due to level of effort, the wheat samples were only segmented into heads and leaves/stems. The proportion of biomass in the wheat stalk is considered small relative to that of the leaves and heads.

For each of the three biomass samples, the lab crew also determined and recorded plant phenology. Phenology was determined using the BBCH scale.

Figure 20. Biomass measurements (left) and drying trailer (right)

Leaf Area Index (LAI) was captured using hemispherical digital photos (Figure 19). In each field, seven photos were taken along two transects (14 photos in total) at each of the three sites (2, 11, 14). Along

each transect, each photo was taken approximately five metres apart (Figure 20). For row crops (corn, canola and beans), photos were taken in the middle of the row.

The fisheye camera lens was positioned at nadir, at a minimum of 50 cm above the highest point of the canopy (when photos were taken downward) or 50 cm below the lowest leaf of the canopy (when photos were taken upward). A bubble level positioned on the extension arm was used to ensure that the camera was level prior to taking the downward facing photos. In the case of upward photos, the camera was placed on the ground, pointed upward. Near the end of the SMAPVEX12 campaign crews were unable to position the camera above the canopy of some canola fields and yet lower leaves obstructed the camera view. For these fields no photos were taken. Photos were taken with the crew facing the sun to avoid shadows in the photos. These photos are post-processed to estimates of LAI. Over 12,000 photos (0.5 TB) were taken during the 6 week campaign.

Figure 21. Fisheye photo for Field 34 (June 16, soybeans)

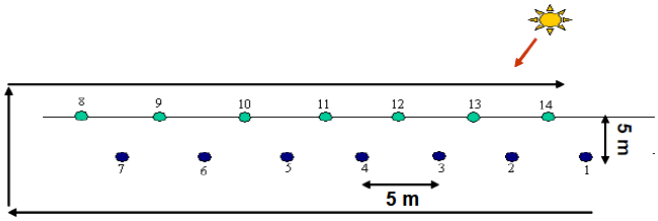


Figure 22. Location of the 14 points for crop scan measurements and LAI photos.

Above canopy crop reflectance was recorded using the Crop Scan instrument. The Crop Scan is a multispectral radiometer operating in 22 channels, ranging from 440 nm to 1700 nm. The radiometer has both upward and downward sensors to capture incoming solar radiation to the sensor and energy reflected from the canopy. Crop Scan data were collected at the same location of each LAI photo; seven measurements in two transects (Figure 20).

2.1.4 Vegetative Structure

Measurements of the crop structure characteristics and attributes during the vegetation growth phases were an important part of the data collection, in particular to support forward modeling of radar scatter.

Seventeen of the 55 fields were strategically selected for vegetation structure measurement. The crop type breakdown was as follows: one forage, one winter-wheat, three corn, three bean, three pasture, three spring-wheat, and three canola fields. Crop attributes measured included plant height, stem width, stalk height, stalk angle, number of leaves, leaf length, leaf width, leaf thickness, leaf angle, number of plants per square meter, row orientation and row width. These vegetation attributes were measured on the bottom, middle and top of one plant at two sampling locations in 17 fields (Table 4) and revisited 5-6 times over the 6 week campaign. Figure 23 shows the structural change/growth of canola plants (Field 124) within a span of 9 days.

Table 4. Field number and crop type of vegetation structure sample fields.

Field	Crop		Field	Crop
13	Pasture		81	Wheat
22	Pasture		83	Corn
23	Pasture		93	Corn
24	Corn		121	Forage
34	Soybeans		122	Canola
41	Winter Wheat		123	Soybeans
43	Oats		124	Canola
64	Soybeans		125	Canola
65	Wheat			

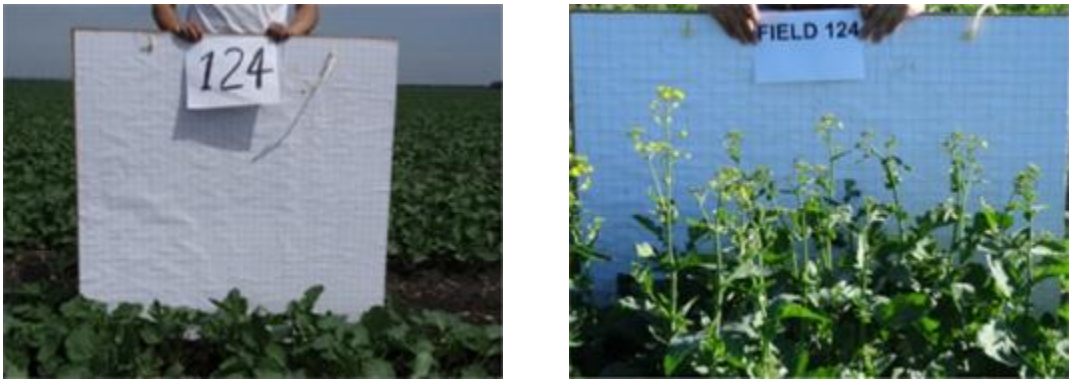


Figure 23. Canola field 124 on June 7 (left) and June 16 (right), 2012

2.2 Forested Sites

Data collected over the four SMAPVEX12 forest sites will be used primarily to enhance and develop radar forest scattering models and to test the current radar-based soil moisture retrieval algorithm, both of which are essential to successful SMAP post-launch validation. This work and the experience gained during SMAPVEX12 are expected to provide synergies between SMAP and the AirMOSS EV-1 mission.

2.2.1 Soil Moisture

A spatial and temporal soil moisture sampling strategy was designed, specific for the forest sites. Each of the four sites was diverse in terms of landscape and land cover. At the beginning of the campaign each site was visited and its heterogeneity investigated. The observation area for both soil moisture and vegetation sampling within each site consisted of two orthogonal transects within a circle of 100 m radius (Figure 24).

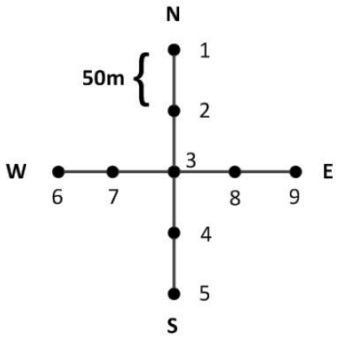


Figure 24. Schematic representation of the forestry soil moisture transects

This observation area was carefully selected to represent the heterogeneity of each site. At three sites, F1, F2 and F4, a temporary soil moisture sensor profile had previously been installed. However due to heterogeneity in the land cover of F4, this forest site was not sampled during the six week SMAPVEX12 campaign. After determining the center point, transects were laid in north/south and east/west directions. There were nine soil moisture sampling points within each observation area, including the center point and two points at 50 m and 100 m in each cardinal direction (Figure 24). The location of some of the sampling points was adjusted if they fell into areas of standing water or marsh. For example, in F3, the southern transect had to be modified to avoid marshlands. To allow for frequent revisiting of the soil moisture sampling points, the nine soil moisture sampling points per site were clearly flagged at the beginning of the campaign and their respective locations were confirmed with visualization in Google Earth and GPS coordinates were recorded.

The parameters of interest related to soil and soil moisture included:

1. Soil moisture and dielectric constant (using Steven's Hydra probes)
2. Soil organic depth
3. Soil temperature at 0 cm, 5 cm and 10 cm depths.
4. Soil bulk density samples to characterize soil composition (i.e. % sand, clay, and silt)

2.2.2 Surface Roughness

During SMAPVEX12, surface roughness was measured over the forested sites F1, F2, F3, and F5 located along the flight line LL4. The measurements were made at two locations over sites F1, F2, F3 and at one location over site F5 in the look directions of RADARSAT-2 (descending mode), UAVSAR, and PALS.

Information on surface roughness was gathered with the same portable pin profilometer that was used over the agricultural fields (Figure 25). Picture collection and post-processing techniques to obtain root mean square roughness (rms) and roughness correlation length (ℓ) were also silmilar to what was described in section 2.1.2 for the agricultural fields.

Due to shadow, poor quality pictures were collected over some sites. Despite a second revisit, these conditions led to no data over these sites in some directions, and for the second site of F5.

Figure 25. Measurement of surface roughness using the pin profiler over the forested sites F1 (left) and F2 (right)

2.2.3 Forest Vegetation

SMAPVEX12 forest vegetation sampling was divided into three parts: (1) spatial sampling, (2) destructive sampling and (3) dielectric constant measurements. The spatial sampling took place June 7 to June 28 and the destructive sampling and dielectric measurements occurred June 29 to July 17.

Spatial sampling involved recording and flagging every tree with a diameter at breast height (DBH) of more than 1 inch (2.54 cm) within +/- 1 meter of the transect line. This was done for both transects within an observation area, as shown in Figure 24. For each tree, the following parameters were measured:

a) DBH in inches;
b) Height in meters; and
c) Species

The DBH was measured with a DBH tape at breast height. The height was recorded with a hypsometer. While standing more than 10 meters away from the tree, two measurements were taken with the hypsometer: distance to base of tree and distance to top of tree. The hypsometer then displays the total height. This is a standard technique to measure tree heights, but posed a challenge in denser forests such as F2, F3 and F5 since there was a dense understory preventing line of sight measurements. The tree species was recorded by consulting a standard tree field guide, in this case “Trees in Canada” by John L. Farrar. An example of flagged trees in F3 can be seen in Figure 26.

Figure 26. Example of tree flagging
Each tree within +/- 1m of the transect was marked and recorded with its number, DBH value, height and species.

The spatial sampling measurements allowed better understanding of the denser forest sites covered in this campaign. Measurements such as forest density, tree height, DBH, tree species, as well as detailed information about branches and understory, are essential to successfully parameterize radar backscattering models.

At every 10 meters along the transect, the GPS coordinates and more detailed parameters were recorded:

a) Trunk height in meters;
b) Number of primary branches;
c) Angle of primary branches;
d) Fractional ground cover in percent; and
e) Understory height in meters.

These measurements were generally taken on the tree at the 10 m point closest to the transect line. Trunk height was recorded with the hypsometer or a yard stick. The number and angle of primary branches were recorded based on visual inspection. The fractional ground cover and understory height were measured by laying down a quadrat in a representative area close to the 10m point and recording the values based on visual inspection or by using a yard stick for the height. A range of encountered fractional ground covers and understory heights can be seen in Figure 27.

Figure 27. Measurement of fractional ground cover and understory height within a quadrat

Destructive sampling involves harvesting an “average” tree for intensive destructive measurements. One “average” tree per field was felled using a chainsaw and the following parameters were measured:

a) Trunk diameter at each 30 cm interval;
b) Wafer of approximately 3 cm thickness for gravimetric measurements at each 30 cm interval;
c) Primary branch angles;
d) Number of branches (primary, secondary) and leaf count;
e) All branch lengths, diameters, and when possible, dielectric constant;
f) 3-4 samples of branches for gravimetric measurements; and
g) Note on leaf clumping

At the time of destructive sampling, the spatial information was not processed. The “average” tree was selected based on visual inspection of diameter and height compared to other trees in the forest. Along with the spatial sampling information, these parameters are essential in the electromagnetic modeling of forests. Trunks and branches are modeled as cylinders with the same properties (diameters, length, dielectric, branch angle, etc.) as the average tree in the site. The measurements above provide the distributions needed to do such modeling. Figure 28 shows a felled aspen’s trunk height and diameter being measure starting from the DBH location.

Figure 28. Trunk height and diameter measurements on an aspen.

Dielectric measurement of tree trunks, branches and leaves were taken using an Agilent field portable network analyzer (FieldFox N9923A). The FieldFox uses a custom made semi-rigid open-ended coaxial line to measure the reflection coefficient of the sample under test. Further analysis is then required to determine the sample's dielectric constant from the measured reflection coefficients.

In Figure 29 the FieldFox with the coaxial probe attached can be seen. A laptop is used to control and automate the measurement process. The measured dielectric constant values can be directly used as input parameters in the electromagnetic forward scattering models. To probe deeper into the tree, a ¾" drill bit was used to drill into the tree. The coaxial probe was then placed in full contact with the trunk. The measurement frequency ranges from 400 MHz to 2 GHz, which covers both P-band and L-band and is applicable to both the SMAP and AirMOSS missions.

Figure 29. FieldFox with dielectric probe and drill bit hole to facilitate full probe contact

3. Airborne Imagery

Several times per week NASA flew the DHC-6 Twin Otter International (TOI) and a NASA Gulfstream III (G-III) carrying instruments similar to the SMAP satellite. The Twin Otter (Figure 30) carried the Passive Active L-band Sensor (PALS) sensor. The G-III (Figure 30) transported the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR).

The goal was to attempt to fly these aircraft two to three times per week, through the six week campaign. Go and no-go flight decisions were based primarily on readiness of the aircraft, weather conditions and surface conditions. If the aircraft were ready and weather conditions favourable, flights were a go if soil moisture conditions on the ground provided sufficiently different conditions relative to recent conditions. Thus the intent was to capture a wide range of soil conditions, in particular those that follow rain events and subsequent dry down.

Figure 30. DHC-6 Twin Otter International (left) and NASA Gulfstream III (right)

Table 5 lists the dates the PALS and UAVSAR successfully acquired data. Every effort was made to coordinate the flight dates of both instruments in order to provide complementary passive and active data.

Table 5. Imagery acquisition dates for the PALS and UAVSAR instruments during SMAPVEX12

PALS Acquisition	UAVSAR Acquisition
June, 7	June, 17
June, 12	June, 19
June, 15	June, 22
June, 17	June, 23
June, 22	June, 25
June, 23	June, 27
June, 25	June, 29
June, 27	July, 3
June, 29	July, 5
July, 3	July, 8
July, 5	July, 10
July, 8	July, 13
July, 10	July, 14
July, 13	July, 17
July, 14	
July, 17	
July, 19	

3.1 Passive Active L-band Sensor (PALS) Data Collection

The Passive/Active L-band Sensor (PALS) provides radiometer products, vertically and horizontally polarized brightness temperatures, and radar products, normalized radar backscatter cross-section for V- transmit/V-receive, V-transmit/H-receive, H-transmit/H-receive, and H-transmit/V-receive. In addition, it can also provide the polarimetric third Stokes parameter measurement for the radiometer and the complex correlation between any two of the polarized radar echoes (VV, HH, HV and VH). Table 6 provides the key characteristics of PALS.

Table 6. Description of PALS.

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

The planar antenna consists of 16 stacked-patch microstrip elements arranged in a four by- four array configurations. Each stacked-patch element uses a honeycomb structure with extremely low dielectric loss at L-band to support the ground plane and radiating patches. The measured antenna pattern shows better than 33 dB polarization isolation, far exceeding the need for the polarimetric measurement capability.

PALS was mounted at a 40 degree incidence angle looking to the rear of the aircraft. The 3dB spatial resolution of the instrument was ~ 0.35*altitude above ground cross-track. PALS acquired data at two elevations during SMAPVEX12 (Low and High). The lowest elevation that PALS can operate at is determined by the minimum distance for radar data acquisition, which is 1067 m (3500 feet) above the ground surface. Based on a nominal elevation in this region of 305 m (1000 feet), this translates to a flight altitude of 1372 m (4500 feet). The highest flight altitude for SMAPVEX12 was determined by the maximum altitude for not requiring oxygen use by the flight crew; 2896 m (9500 feet). The spatial resolutions at these two flight altitudes are summarized in Table 7.

Table 7. Geometric features of PALS data acquisitions.

Target Altitude (m)	Nominal Ground Elevation (m)	MSL (m)	Cross Track Resolution (m)	Along Track Resolution (m)	Footprint Offset Along Track (m)
1067	305	1372	376	655	895
2591	305	2896	914	1592	2174

The PALS/TOI flight lines were designed to satisfy the major objectives of SMAPVEX12. Low altitude lines provided high spatial resolution data for fields/sites with homogeneous vegetation conditions. Many sampling sites were located directly on these lines. Since the nominal field size in the region is 800 m by 800 m, flying these at the lowest possible altitude should provide the data necessary for algorithm development and validation. Four lines were flown at low altitude, two covering annual cropland, one pasture land and a forth over the forest sites (red lines in Figure 31).

High altitude lines mapped the larger region and provide data for simulating SMAP combined algorithms (yellow lines in Figure 31). A total of eight lines were required to cover the entire SMAPVEX12 site (~12.8 by 70 km). Lines were spaced ~ 1.6 km apart.

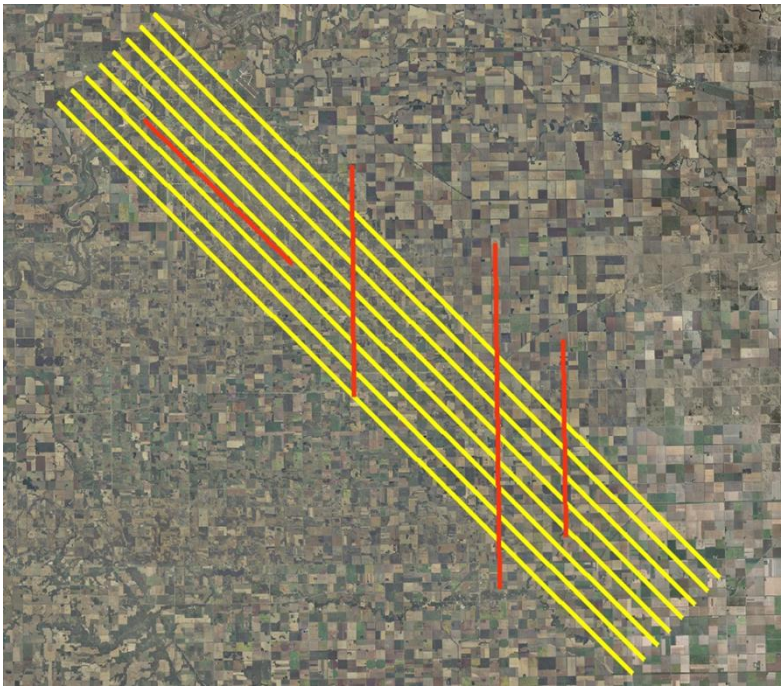


Figure 31. Low altitude PALS flight lines (red) and high altitude lines (yellow)

Preliminary data generated by the PALS radiometer are provided below. In these two examples, the PALS sensor detects very wet soil conditions (green-blue) on June 12th, 2012 over the study site. The average moisture according to field data was approximately 35%. On July 3rd, 21 days later and after 12 continuous days without rain high temperatures, data from PALS captures extremely dry soil conditions (orange-red).

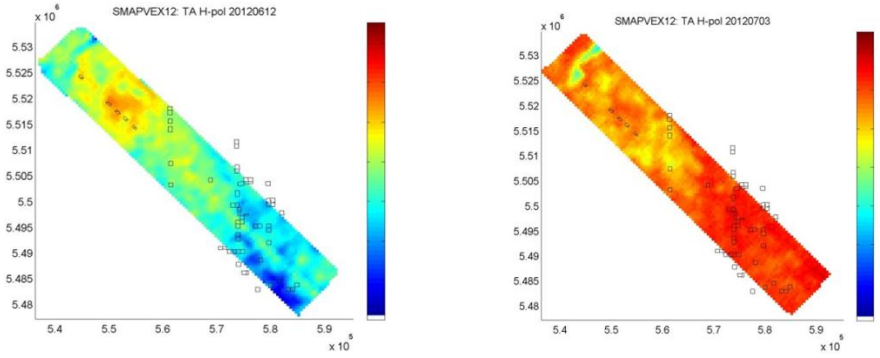


Figure 32. The PALS radiometer data in H polarization for June 12 (left) and July 3 (right).

3.2 UAVSAR on NASA G-III

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 8.

Table 8. 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 3 m multi-looked (6 looks)
Scan Type	SAR with Electronically scanned active array, range swath ~20 km looking left of track between 25 and 65 degrees.
Antenna Type	Phased Array

For SMAPVEX12, the nominal flight altitude was 13 km and the aircraft speed was 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. In order to provide coverage of the study domain, four flight lines were needed (Figure 33). In addition to these lines, two additional lines were flown to complement the low altitude PALS coverage. The coverages were oriented to provide data with the same azimuth angle as PALS.

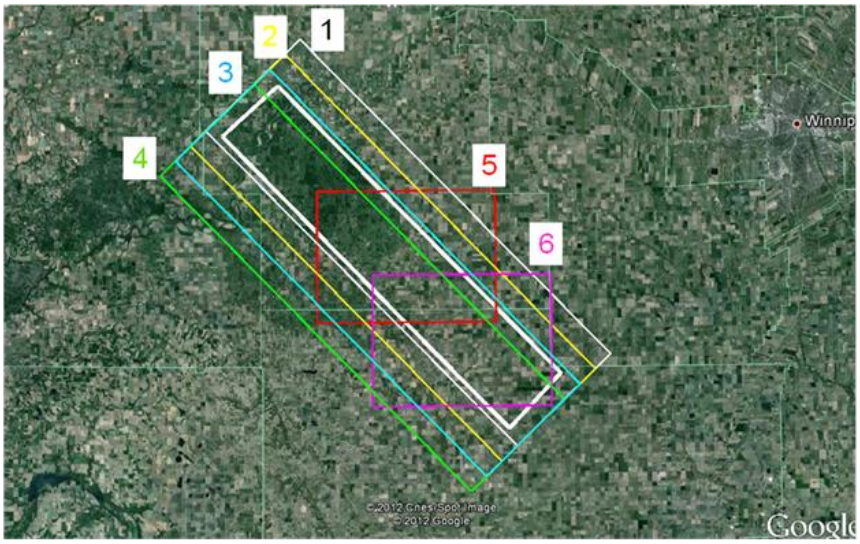


Figure 33. SMAPVEX12 UAVSAR Coverage Boxes

The UAVSAR instrument acquired imagery 14 times on the dates during SMAPVEX12. An image from early in the campaign is provided in Figure 34.

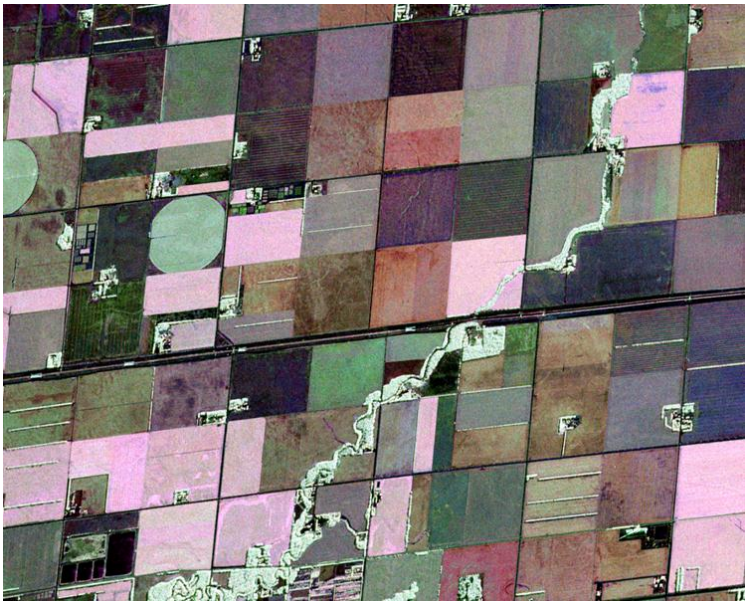


Figure 34. A UAVSAR Imagery acquired near Carman (Manitoba) on July 17th, 2012
Derived from Pauli composite
(R: double bounce (Shh-Svv); G: volume scattering (2*Shv); B: single bounce (Shh+Svv)

4. Satellite Imagery

In addition to airborne acquisitions, optical and SAR satellites were also programmed for the duration of SMAPVEX12. These included acquisitions of RapidEye and SPOT-4/5 (Tables 9 and Figure 35).

Table 9. Imagery acquisition dates for RapidEye and SPOT-4/5 sensors

RapidEye		SPOT-4/5
May, 14	July, 21	June, 23
May, 20	July, 27	June, 28
June, 4	August, 5	July, 5
June, 12	August, 19	July, 14
June, 23	August, 24	
June, 26	August, 29	
June, 28	September, 9	
July, 5	September, 14	
July, 14	September, 23	
July, 20	September, 26	

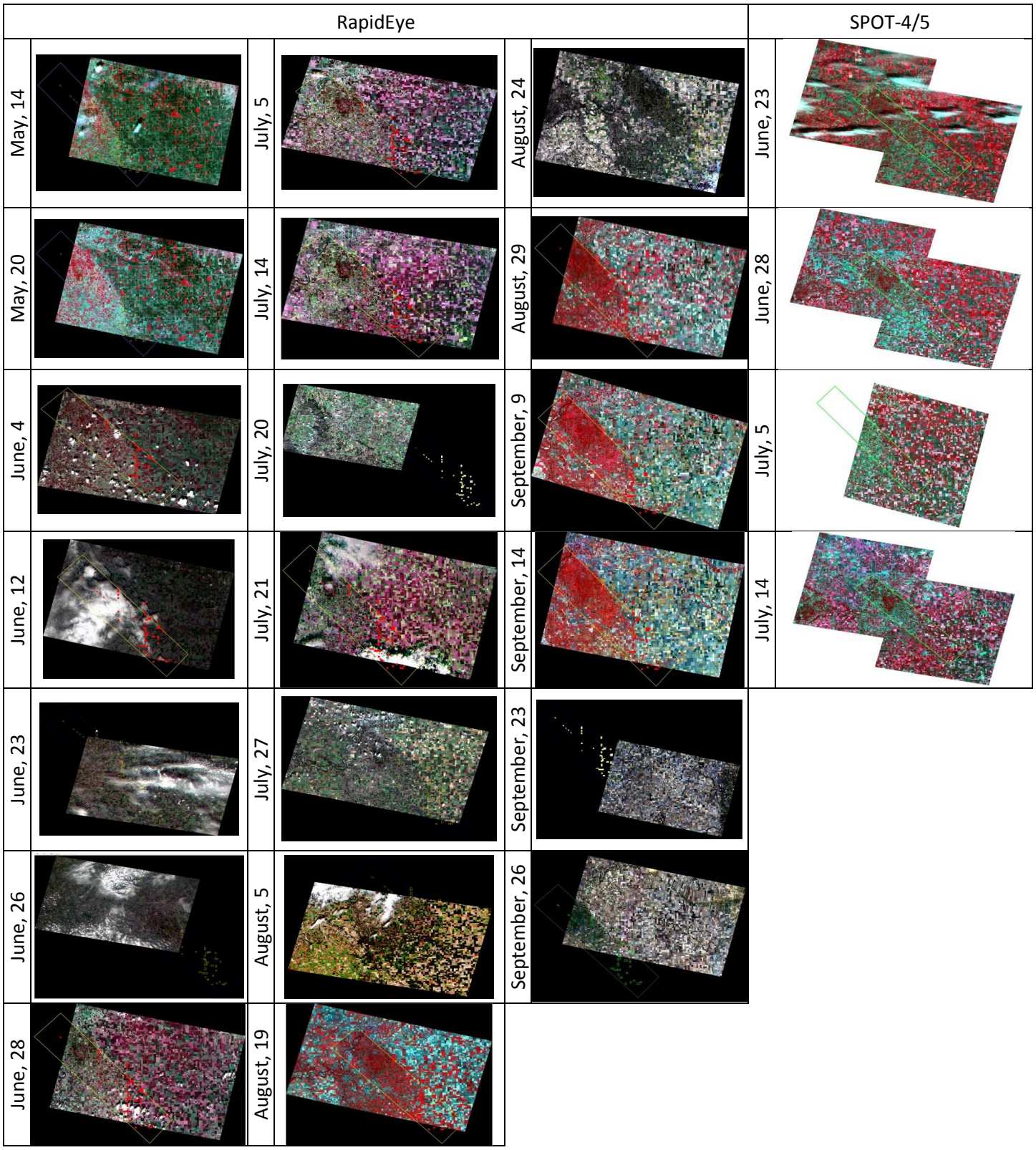


Figure 35. Imagery acquisition coverage for RapidEye and SPOT-4/5 sensors

A total of 29 RADARSAT-2 images were acquired under the Government of Canada RADARSAT-2 data allocation. This included 22 Fine Quad-Polarization and 7 Standard images with HH, HV polarization (Table 10 and Figure 36). The QP mode provided data of the full scattering matrix, but with its limited 50 km swath, only the south eastern annual cropland was covered. The Dual-polarization Standard mode, however, covers the entire SMAPVEX12 site.

Table 10. Imagery acquisition dates for RADARSAT-2 imagery during SMAPVEX12

RADARSAT-2 Imagery Acquisition			
April, 16	Fine-Quad Pol. Wide-2	June, 13	Fine-Quad Pol. Wide-10
April, 18	Fine-Quad Pol. Wide-3	June, 19	Standard Beam-3
April, 25	Fine-Quad Pol. Wide-8	June, 20	Fine-Quad Pol. Wide-6
April, 26	Fine-Quad Pol. Wide-10	June, 27	Fine-Quad Pol. Wide-2
May, 03	Fine-Quad Pol. Wide-6	June, 29	Fine-Quad Pol. Wide-3
May, 10	Fine-Quad Pol. Wide-2	June, 30	Standard Beam-3
May, 12	Fine-Quad Pol. Wide-3	July, 06	Fine-Quad Pol. Wide-8
May, 13	Standard Beam-3	July, 07	Fine-Quad Pol. Wide-10
May, 20	Fine-Quad Pol. Wide-10	July, 13	Standard Beam-3
May, 26	Standard Beam-3	July, 14	Fine-Quad Pol. Wide-6
May, 27	Fine-Quad Pol. Wide-6	July, 21	Fine-Quad Pol. Wide-2
June, 03	Fine-Quad Pol. Wide-2	July, 23	Fine-Quad Pol. Wide-3
June, 05	Fine-Quad Pol. Wide-3	July, 24	Standard Beam-3
June, 06	Standard Beam-3	July, 31	Fine-Quad Pol. Wide-10
June, 12	Fine-Quad Pol. Wide-8		

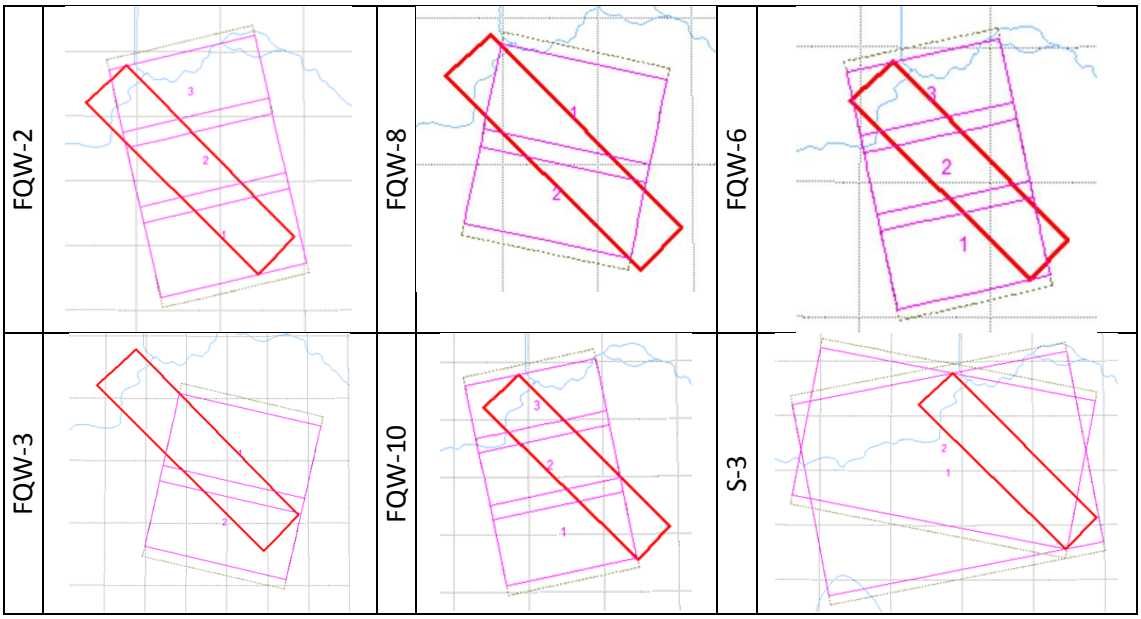


Figure 36. Coverage for RADARSAT-2 imagery.

The SMAPVEX12 team programmed 21 TerraSAR-X images for the 2012 growing season (May to September) through a proposal to the German Space Agency (DLR) (Table 11 and Figure 37).

Table 11. Imagery acquisition dates for TerraSAR-X imagery.

TerraSAR-X Imagery Aacuisitions			
Ascending Pass Cycle		Descending Pass Cycle	
May, 07	Stripmap/StripFar-006R	May, 08	Stripmap/ StripNear-005R
May, 18	Stripmap/StripFar-006R	May, 19	Stripmap/ StripNear-005R
May, 29	Stripmap/StripFar-006R	May, 30	Stripmap/ StripNear-005R
June, 09	Stripmap/StripFar-006R	June, 10	Stripmap/ StripNear-005R
June, 20	Stripmap/StripFar-006R	June, 21	Stripmap/ StripNear-005R
July, 23	Stripmap/StripFar-006R	July, 02	Stripmap/ StripNear-005R
August, 03	Stripmap/StripFar-006R	July, 13	Stripmap/ StripNear-005R
September, 27	Stripmap/StripFar-006R	July, 24	Stripmap/ StripNear-005R
		August, 04	Stripmap/ StripNear-005R
		August, 15	Stripmap/ StripNear-005R
		August, 26	Stripmap/ StripNear-005R
		September, 06	Stripmap/ StripNear-005R
		September, 17	Stripmap/ StripNear-005R

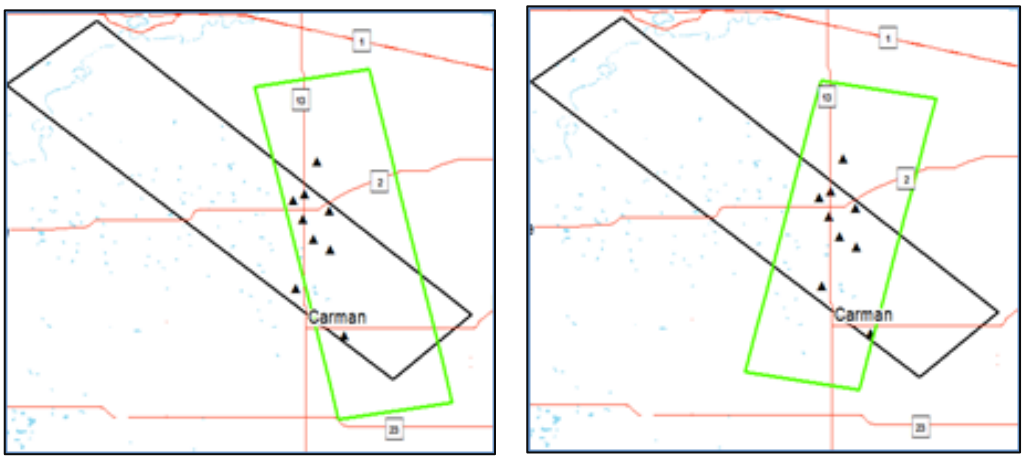


Figure 37. TerraSAR-X coverage in ascending (left) and descending (right) modes.

Appendix A. Calendar of all data collected during SMAPVEX12

Date	PALS	UAVSAR	RADARSAT-2	TerraSAR-X	RapidEye	SPOT	Soil Moisture	Surface Roughness	Vegetation
June									
7	X						X		
8									
9				X					
10				X				X	
11								X	X
12	X		X		X		X	X	
13			X					X	X
14									
15	X						X	X	
16								X	X
17	X	X					X	X	
18								X	X
19		X	X					X	
20			X	X					
21				X				X	X
22	X	X					X		
23	X	X			X	X	X		
24								X	X
25	X	X					X		
26					X				
27	X	X	X				X		
28					X	X			X
29	X	X	X				X		
30			X					X	X
July									
1									
2				X					
3	X	X					X		
4									
5	X	X			X	X	X		
6			X						
7			X					X	X
8	X	X					X		
9									X
10	X	X					X		
11									
12									
13	X	X	X	X			X		
14	X	X	X		X	X	X		
15									
16									X
17	X	X					X		
18									X
19	X						X		

Appendix B. SMAPVEX12 participants

- **Aaron Berg**, University of Guelph
- **Alan Rich**, University of Manitoba
- **Alicia Joseph**, NASA GSFC
- **Alexandra Konings**, MIT
- **Amine Merzouki**, Agriculture and Agri-Food Canada
- **Andreas Colliander**, JPL
- **Anne Walker**, Environment Canada
- **Bin Fang**, U.S. Carolina
- **Brandon Wyryha**, Agriculture and Agri-Food Canada
- **Brenda Toth**, Environment Canada/MSC/HAL
- **Brian Miller**, University of Manitoba
- **Catherine Champagne**, Agriculture and Agri-Food Canada
- **Craig Smith**, Environment Canada
- **Christina Neva Rivera**, Agriculture and Agri-Food Canada
- **Dara Entekhabi**, MIT
- **Dominik Schneider**, University of Colorado
- **Eni Njoku**, JPL
- **Erika Podest**, JPL
- **Erle Einarsson**, Agriculture and Agri-Food Canada
- **Evan Rodgers**, Agriculture and Agri-Food Canada
- **Grant Wiseman**, Agriculture and Agri-Food Canada
- **Greg Gibbons,** Agriculture and Agri-Food Canada
- **Heather McNairn**, Agriculture and Agri-Food Canada
- **Hida Manns**, University of Guelph
- **Hoda Jafarian**, University of Sherbrooke
- **Jacqueline Freeman**, Agriculture and Agri-Food Canada
- **Jarrett Powers**, Agriculture and Agri-Food Canada
- **Jeff Ouellette**, Ohio State
- **Jennifer Watts**, University of Montana
- **Jiali Shang**, Agriculture and Agri-Food Canada
- **John Fitzmaurice**, Agriculture and Agri-Food Canada
- **John Kimball**, University of Montana
- **Jon Belanger**, University of Guelph
- **Justin Adams**, University of Guelph
- **Kalifa Goïta**, University of Sherbrooke
- **Karel Janik**, University of Sherbrooke
- **Kaighin McColl**, MIT
- **Kurt Gottfried**, Agriculture and Agri-Food Canada
- **Luis Perez**, FIU – Florida International University
- **Mahta Moghaddam**, University of Southern California
- **Marco Carrera**, Environment Canada, Meteorological Research Division
- **Maria Abrahamowicz**, Environment Canada
- **Mariko Burgin**, University of Southern California

- **Maheshwari Neelman**, Texas A&M
- **Matt Jones**, University of Montana
- **Mehdi Hosseini**, University of Sherbrooke
- **Mike Cosh**, USDA, ARS Hydrology and Remote Sensing Laboratory
- **Mustafa Aksoy**, Ohio State
- **Najib Djamai**, University of Sherbrooke
- **Nandita Gaur**, Texas A&M
- **Narendra Das**, JPL
- **Parag Narvekar**, MIT
- **Parinaz Rahimzadeh**, University of Guelph
- **Patrick Rollin**, Agriculture and Agri-Food Canada
- **Paul Bullock,** University of Manitoba
- **Peggy O'Neill**, NASA GSFC
- **Rachel Molloy**, Agriculture and Agri-Food Canada
- **Rebecca Warren**, University of Guelph
- **Rebecca Scriver**, University of Guelph
- **Ramata Magagi**, University of Sherbrooke
- **Robert Terwilleger**, University of Florida
- **Rotimi Ojo**, University of Manitoba
- **Ruzbeh Akbar**, University of Southern California
- **Sab Kim**, JPL
- **Sarah Banks**, Agriculture and Agri-Food Canada
- **Sarah Dyck**, Environment Canada
- **Saeid Homayouni**, Agriculture and Agri-Food Canada
- **Shawna McKnight**, Georgia Institute of Technology
- **Sonia Becenko**, Agriculture and Agri-Food Canada
- **Stacie Westervelt**, University of Manitoba
- **Stéphane Bélair**, Environment Canada - NWP and Data Assimilation
- **Steven Chan**, JPL
- **Syed Anwar**, Agriculture and Agri-Food Canada
- **Tien-Hoa Liao**, University of Washington
- **Tom Jackson**, USDA, ARS Hydrology and Remote Sensing Laboratory
- **Tracy Rowlandson**, University of Guelph
- **Vanessa Escobar**, NASA GSFC