Anonymous Referee #1

GENERAL COMMENTS The manuscript and dataset are of value to those involved in soil moisture research. Aside from small errors the manuscript is of appropriate length and reasonably clear. The data set is well organized and consistently structured. The data is unique and very useful, especially as the dielectric value and soil temperature is provided, and its coverage of 11 years. The dataset is presented in a usable format (checked with R and Excel). Sufficient background is given on sensors and usage.

Before publication the manuscript requires numerous, but minor, improvements (see Specific Comments), and the data set requires further quality improvements.

The dataset presented is limited to May thru Sept although it appears that year-round data is available. Although the dielectric value of soils is strongly affected by freezing it can still be of value to researchers, especially if soil temperature of the probe is given. For example, see Kelleners and Norton, 2012 (Soil Science of America) and Roy et al 2017 (Remote Sensing of Environment). Both studies used Hydra probes. If available it is recommended that the entire year-round data set be made available, with appropriate caveats given about freezing conditions.

While other studies have included winter and shoulder season data in their analyses, data from these periods require significantly more QAQC, with care taken to identify when the sensors are in frozen, partially frozen, and thawed ground. The two major purposes of this dataset, remote sensing and hydrological model validation, are typically not yet capable of doing that interpretation themselves and require straightforward inputs. Progress is being made to create repeatable, automated processes that will allow careful identification of freezing and thawing periods to avoid biases and inaccurate identification of frozen or thawed ground, at which point a new version of the database will be released.

Dataset needs further quality control:

high moisture content values greater than 0.60 m3/m3 are present and in one known case greater than 1.0 m3/m3;

The data has been more carefully reviewed and this issue has been corrected.

moisture content fluctuations between 30 minute intervals for many probes (especially at 20 and 50 cm) are greater then acceptable (>0.02 m3/m3 and up to 0.10 m3/m3).

Fluctuations of this type have been more fully described in the paper. With an error tolerance on the Hydra Probes of +/- 0.03, some amount of fluctuation could be reasonable. Some errors of this type have been removed from the dataset, however some caution is required by data users.

Although the fluctuations are stated as being caused by possible salinity it was not made clear by the authors whether they were to be kept or removed from the data set. They should be kept and clarification (and caveat) statements need to be added.

Further clarification on the data fluctuations has been given and a statement added that data users will need to be aware of this issue in the dataset as not all periods of significant fluctuation have been removed.

Additionally, some data sets do not extend up to the years indicated in Table 1 (e.g. they only go as far as 2010, not to 2013).

Corrected.

There is confusion around the terms 'two spatial scales' and 10 km2 and 40 km2. Spatial scale implies different spacings or densities. The areas measure 10 km by 10 km and 40 km by 40 km thus are more 100 km2 by 1600 km2 in area. Perhaps referring to density of the stations per km2 or their average spacing would provide more information for the reader.

Corrected.

The authors refer to the manufacturers loam setting being used to calculate the moisture contents, however this 'loam' equation cannot be found in the provided references.

Equation has now been included and confirmed in the included reference: The equation [A2] is listed in Appendix C and the coefficients are noted in Section 5.2.3 - Soil Moisture Calibrations.

SPECIFIC COMMENTS/QUESTIONS

3:67-70, confusion with sensor locations; make it clear in the text and in Figs 2 and 3 which probes are set within the tilled field and which in the field edge.

An additional figure has been added and more detail has been given about sensor location at each type of site.

Lines 67 to 68 (5 cm, 20 cm, and 50 cm) do not state location, however Figures 2 and 3 indicate the 20 cm and 50 cm are within the tilled field. Also Figure 2 states "(3) location of vertical 0-5 cm sensor during off season". This implies the sensor is still active and recording or it is 'off'? Clearly indicate this in text.

An additional figure has been included to clarify the location of the probes at each type of site and text has been added to the Soil Moisture and Precipitation Site Details section.

4:85, give length of tines

Added.

4:102, why not publish the calibration equations in the paper or on the data web site? What is the degree of moisture difference between the calibrated probes and that given by the manufacturer?

Further details were provided in this section giving RMSE values found by a previous study and the continued issues in calibration method. These references go into much greater detail regarding the need for calibration equations beyond those given by the manufacturer.

5:118, some confusion about that of electrical conductivity (EC) measurements. Do Hydra probes measure EC? If so, was this measured by the installed probes? If it was measured, then it should be mentioned in the text and rational given as to why it is not published – as it appears it might be useful in discerning problem readings which are in the data set (e.g. site 2701023 50 cm probe).

Hydra Probes are capable of measuring electrical conductivity however not all sites collect this data and it has not been measured for the entire data record, which is why it is not included. Statements have been added to clarify that some periods of high fluctuation have been removed, but not all, and data users will need to review this themselves.

6: 149-150, and Table 3 gives a flag for soil moisture not being greater than 0.6 m3/m3, however many data sets have values greater then this at various depths (e.g., 2701023 at 50 cm). Were these to have been removed? If so then please check all data sets. If they are to stay in then clearly indicate so.

The flags given, which include the test of soil moisture greater than 0.6 m3/m3, are not meant to specifically indicate incorrect values, but data intervals that require extra attention. In certain conditions soil moisture greater than 0.6 m3/m3 have been recorded at the sites that even after investigation appear to be correct. While the porosity of loam soils is typically limited to 60%, the inclusion of organics during the growing season can increase this upper limit. A statement has been added to the Manual Review Details section clarifying the use of the flags and the data has been further reviewed removing missed issues or confirming previous decisions to include or remove data.

6:155, the manuscript does not indicate which set of sites were the 'dense set'.

Rephrased.

When were the soil moisture and precipitation sites established? This should be stated in the paper and not in the Summary.

Added in the network description section.

Are they still maintained and visited?

Sentence added in the network description section clarifying that as of publication a majority of the sites are still active.

How often were the sites visited? The document states 'regularly' however is this once a year or 5 times?

Sentence added giving clarification of the frequency of site visits.

Table 1 shows Data records up to 2017 – does this mean the data was not collected after 2017 or is this when the table was compiled?

As per other comments, details have been added in various parts of the paper indicating that the sites are (as of the time of publication) still in operation and additional data can be requested.

Figures 2 and 3; make it clear that only the ECCC sites (the dense network) have the vertical 5 cm sensor in the agricultural field.

Sentence added to each figure caption.

As indicated by the authors some of the data is more variable than expected (e.g. possible saline conditions at 20 and 50 cm depth, see lines 119-122). Although it is stated on lines 168 to 169 that erroneous data is removed from the final data set there are numerous instances of ‘unexplained drops and unusually high or low values’. If some of the values retained are due to possible saline conditions then it should be clarified that these values were kept but the user must be careful about their interpretation. See Technical Corrections for examples.

Additional data review has been completed. Sentences have been included to clarify that some periods of high variability remain in the dataset and users need to be cautious. Certain other drops and jumps are similar in that they have been left in the dataset and caution may be required.

TECHNICAL CORRECTIONS

1:21, insert ‘the’ before ‘hydrological cycle’. For clarification change the following: “While soil moisture constitutes a small portion of the global water cycle, it has a. . .”.

Fixed.

2:43, As this is an international journal add the following “..a typical prairie agricultural. . .” to help define ‘typical’.

Fixed.

2:46, ‘considered’.

Fixed.

2:46, remove ‘in general’.

Corrected to ‘typically’ as these non-contributing areas can, in certain circumstances, contribute to streamflow.

2:47, incomplete sentence – suggest the following “Texture of the soils in the region is predominantly silt loam but ranges from sandy loam to clay.”.

Agreed, fixed.

2:49, remove ‘over the years’.

Fixed.

2:53-55, Do the references given in line 55 refer to the 2010 (CanEx-SM10) study? If not then perhaps create two sentences. Remove ‘previous’ as not necessary.

Corrections made with separate sentences as suggested.

3:57-58, clearly state that the AAFC stations are not included in this data set.

Clarification given in at the end of the section.

3:67, add an ‘s’; “Additionally, sites at . . .”.

Fixed.

3:68, insert ‘the’ before “site at the. . .”.

A repeat of the previous comment, fixed.

3:71, “..vertically placed probe,. . .” add the ‘d’ to place.

Fixed.

3:73-74, “the sum over the ‘30 minute’ interval for the TBRG.”.

Fixed.

3:76, ‘..within the Kenaston network, . . .”.

Fixed.

3:79, “and to check for “.

Fixed.

3:79, “Sites with a vertically. . .”.

Fixed.

4:84, there is no Stevens Water Monitoring Systems Inc 2009 or Burns 2016 in the Reference list. Why the double parenthesis – is Burns 2016 a reference within the other?

Corrected.

4: 99, Burns et al 2014 is missing in the reference list (or year not given).

Year added to existing reference.

4:102, always provide a space between the value and the units; e.g. “5 cm”. Check through the manuscript for this.

Fixed and all other instances checked.

4:117, what is a ‘timestamp’ ? Is this the 30 minute interval?

Clarified: "typical variation between successive measurement intervals (timestamps)"

4:137, replace 'currently' with a date or at least a year as the article can be in existence for much longer than the network.

Rephrased.

5:130, why 'regularly' completed? Were calibrations required every year or so or just once? What about the RG3's – did they require calibration?

Clarification of the calibration process was included.

5:137, reword removing 'at maximum' as this is too confusing when referring to dates.

Rephrased.

8:195, a year is needed for the first Burns et al reference.

Added.

Table 1, should indicate which site is ECCC and which is Guelph (using same terminology in Figure 1).

Table 1 has been updated to include these details.

Table 1, Note at end, "Onset RG3 and . . ." insert space.

Fixed.

Table 3, if Conductivity refers to soil Electrical Conductivity it should have units, e.g. dS/m

Fixed.

Dataset web pages:

'moisture' is repeatedly spelt wrong in the 'Readme' file.

Corrected.

Below are some of the issues found with the data sets. Not all data sets were investigated.

V2701000 for 2007; H5 cm probe varies by 0.02 up to 0.1 m3/m3 each time interval so it appears that there could be a choice of three possible sets of data to choose from each day. This type of fluctuation appears to be common for most probes with the range of fluctuation becoming greater at certain moisture contents and more so at 50 cm depth. Could be a function of both the Hydra probe and salinity?? 20 cm probe has values greater than 1.0, (July 2007) likely because the dielectric values are greater than 100. 50 cm probe has values vary by more than 0.1 m3/m3 within each day.

Multiple other comments are similar and statements have been given here as well as in the paper clarifying the potential for salinity issues and that while some have been removed, users should still be cautious. The other data issues noted here have been corrected.

V2701001 and V2701002 something with the dates that R did not like.

Corrected.

V2701003 had no data from 2011 on (Table 1 states data from 2007-2013).

Corrected in Table 1.

V2701004, 50 cm VWC varies too much and no data present from 2011 on.

Corrected in Table 1, and statement given about the possibility of fluctuations in the data.

V2701005 data appears reasonable in values and range. No data present from 2010 on.

Corrected in Table 1.

V2701006 data appears reasonable in values and range. No data present from 2011 on.

Corrected in Table 1.

V2701023, 50 cm probe has high range of daily fluctuations and values greater than 0.60 m3/m3.

Additional removals have been made.

V2701025, 50 cm depth has a strange fluctuation that when plotted over the season it appears to have three distinct sets of data. This is not seen for the other sensors of this site. Many dielectric values are high and some sensors show very little response to seasonal rains or drying events.

Further review of the site was completed and any further removals were completed.

V2701034 has values > 0.60 at the 20 cm depth. At 50 cm depth moisture readings indicate saturation (0.50 or higher).

Further review of the site was completed and additional removals have been made.

V2701035 has values > 0.60 at the 50 cm depth.

As stated in other comments, certain circumstances will result in soil moisture > 0.60. The ranges identified in Table 3 are only guidelines for the manual QAQC process.

Anonymous Referee #2

Specific Comments: This article is well written and well organized. These data are clearly described and well formatted (Excel). The article targets an important issue of calibration and validation of growing space-based observations and hydrological model outputs against ground-based measurements. It is crucial to evaluate the reliability of those products before routine use at a global scale. However, there are a few points in the article that can benefit from improvement:

- 75: It would be clearer if the loam calibration equation were included.

The loam equation is now included.

- It is not clear why the authors have chosen only 11 years and whether this dataset will be continued or the operations has stopped after 2017

Statement added in the Data Availability section for access to data beyond 2017.

- If the stations are actively reporting the measurements, will the dataset be publicly available later? In addition, how long does it take data to become publicly available after ingest?

Statement added in the Data Availability section for access to data beyond 2017. As stated in the Quality Control Process and Data section, automatic review can be completed in near real time, while secondary manual review is completed as needed or seasonally.

- Since the network was designed for validation purposes, a comparison between the quality controlled data and existing datasets like SMAP and SMOS could be beneficial.

Assessments of this type have been completed by other groups, such as Champagne et al. (2016) which assessed the SMOS and Aquarius products, and Chan et al. (2016) which gives initial results of the SMAP products. References to a selection of these works is now included in the introduction.

- 94: Include the equation and the reference in this section

Included and referenced.

- 99-101: Then what is the range of the uncertainty involved in these calculations?

Further details were provided in this section giving RMSE values found by a previous study and the continued issues in calibration method.

-102: Providing these equations in the text will make it easier for the readers to follow your method.

The general equation has been added and the sentence in question has been clarified.

- 104-112: The issue is explained very well, but the authors do not clarify whether they have removed such problematic measurements from the data or if they are just recorded as they are.

Sentence entered clarifying that these issues are removed from the dataset.

- The sources of errors in the dataset are explained, but the study will benefit from a calculated estimate of such errors.

Each station only has one probe at each location, so a quantitative estimation of errors cannot be completed.

Technical Corrections:

1. 12: Change ESA to European Space Agency.

Changed.

2. 14-15: According to Fig. 1's scale, the two domains are 10x10 (100km2) and 40x40 (1600 km2)

Corrected.

3. 14-15: Please clarify the wording, because it is not clear if this is describing two different domains or two different domains with different spatial resolution among the sensors. The wording is not clear but the figure clearly shows an outer domain and a higher-resolution inner domain.

The abstract has been reworded to clarify.

4. 35-36: The last sentence need more explanation: "The high resolution of the network sites allows for both intergrid and intragrid validation".

Rephrased.

5. 59-61: The author clearly states that AAFC stations are located within the pasture sections but it is not clear what type of landscape the ECCC and University of Guelph cover. Please clarify this in the text.

Details of the landscapes of the ECCC and UG sites have been noted in the Network Description section and Soil Moisture and Precipitation Site Details section.

6. 63: Please refer to comment #2

Corrected.

7. 64: "45 x 55 km" should change to "45 x 55 km2 " and also x should be replaced my multiplication symbol

This was corrected to 45 km by 55 km.

8. 68: please refer to comment#2. Also there is a typo in km2-

Both corrected.

9. 74: "is" should be replaced by "are"

Corrected.

10. 79: “regularly” should be explained in detail. How often are the sites visited?

Sentence added to explain the normal interval of visits.

11. 80: “more frequently”. Please refer to comment# 10

Sentence added to explain the normal interval of visits.

12. 99: adding a comma after “manufacturer supplied” will make the sentence more clear

Rephrased.

13. 126: “10 km2” should be replaced by “10 km”

Corrected.

14. 137: keep the consistency between the used words: year-round (line 40)

Rephrased.

15. 138: “occur” should be replaced by “occurring”

Rephrased.

16. 140: How do the thunderstorms producing solid precipitation (e.g. hail-stones) in the growing season will add to the error of your measurements?

The sentence in question is in support of why winter and shoulder season data is being excluded from the dataset. Additional details on the impact of hail on the tipping bucket rain gauge data have been included in the Precipitation Instrumentation section.

17. 47-50: what is the source of these thresholds? Please add a reference.

References included.

18. 154: What about irrigation. The abstract mentioned that the site is an agricultural site with croplands but irrigation is not mentioned anywhere in the text.

Details about irrigation in the area added in the Network Description section.

19. 182-186: The external funding sources for these operations should be mentioned in the acknowledgement.

Funding sources for the University of Guelph have been added.

20. 226-231: The references are in alphabetical and chronological orders. Rowlandson et al. 2013 should precede Rowlandson et al. 2015

Corrected.

21. 258-260: please refer to comment # 2.

Corrected.

Anonymous Referee #3

Specific comments

Introduction: the introduction is rather short and some elements could be added to better insist on the need of detailed hydrometeorological dataset in this region of Canada. For example, at P2 L 28-30, it would be interesting to add a few sentences and references on the remote sensing of soil moisture and the associated challenges, including the need for calibration at reference sites.

The introduction was expanded to give further background on how the data has been used and many of those publications go into much greater depth on the challenges of both remote sensing of soil moisture and modelling.

The second paragraph could be also more accurate:

- What is the "unique combination of landscape and climatic conditions" mentioned at P 2 L 33-34?

The introduction was reworked and this phrase removed.

- What are the other few existing monitoring networks available in the Canadian Prairies?

Over the last few years, these networks have been used to evaluate land surface models applied for hydrological and weather forecasting in Canada (Garnaud et al., 2016,2017).

The other networks across the Canadian Prairies have been noted in the Introduction.

P 2 L 40-41: the authors mention the presence of an eddy-covariance tower (also mentioned in the abstract). No additional information are available in the rest of the text. Are the data of this tower available from one of the institutional partner involved in this community site? If not, can the author add this dataset to their paper and make this dataset available on the FRDR website? It would be extremely valuable for the evaluation of land surface and hydrological models.

Details have been added at end of the Network Description about the status of the eddy-covariance tower data.

P 3 L 56: how does the University of Saskatchewan contribute to the community site?

Detail added to end of section indicating U of S contributions.

P 3 L 57-58: the AAFC stations are of potential interest for any studies in this area. I recommend the author to mention in the text the number of AAFC stations located in the area and to show their location on Figure 1.

The figure has been modified to include the locations of the AAFC stations and the number of stations is now included in the Network Description section.

P 3 L 63: the spatial scales are not accurate when compared to Fig. 1. Are the authors mentioning an area of 10*10 km2 instead of 10 km2? And 40*40 km2 instead of 40 km2? The abstract should be modified accordingly.

Corrected.

P 3 L 63-65: it would be interesting for the readers to know the number of stations in the network and to refer to Table 1 to mention that the exact position of each stations is given in Table 1.

A specific number has not been given for the number of stations in the network as this total has varied over time. This has been clarified at the beginning of the section.

P 3 L 75-78: which institutional partner has collected the additional data? Can these data be obtained on request?

Various partners were involved in ancillary data collection and details of how to request this additional data are included in the paper.

P 3 L 79-81: what is the typical frequency of the visits at the sites in summer time?

Sentence added to explain the normal interval of visits.

P 4 L 100: the loam calibration equation should be given in the paper since it is a paper focusing on the data.

Equation has been included.

P 4 L 101-102: what is the impact of using in-situ calibration equations on the accuracy of the computation of soil moisture? How large is the decrease in accuracy when using the loam calibration equation? Even if the in-situ calibration equations are not available for each probe, this comparison would be very useful for the reader to better understand the accuracy of the dataset presented in this paper.

RMSE values from a calibration comparison project were provided in the text and further clarification was given regarding what calibration equation was used for the data of this publication.

P 4 L 103-109: which treatment is applied to the soil moisture data when measurements issues occur with the Hydra Probe? Based on Table 3, it seems that these issues are identified during the automatic QC but Section 4.2 does not detail the final treatment applied to the soil moisture data.

Additional clarification on how specific issues are dealt with in the dataset has been included

P 5 L 125-126: what is the impact of the replacement of the rain gauges at the ECCC sites on the quality and the consistency of the times series of precipitation?

The manufacturers listed accuracy for each type of TBRG has been listed to give a guideline on the uncertainty between gauges. Analysis of the aforementioned impact has not been completed.

P 6 L 149-150: it is not clear in Section 4.2 how the flags described in Table 3 are used during the manual review process. I recommend the authors to describe the specific treatment applied on the dataset for each flag.

Additional details describing the purpose of each flag has been included in Section 4.2, clarifying that the flags in Table 3 are not strict thresholds but guidelines to assist in QAQC.

P 7 L 172: mention the format of the data on the FRDR website,

Added statement in Data Availability section indicating that the data is available as a comma-separated-value format.

P 7 L 179-180: is the data acquisition still continuing at the ECCC stations and at the University of Guelph stations? If it is the case, will the data be made available in a near future? At which frequency and on which platform? The fact that the data acquisition is still continuing is really important and should be clearly mentioned in the conclusion and also in the introduction.

Multiple additions made to several sections clarifying that the future data can be requested from the corresponding author and that the network is still active.

P 13: do the stations equipped with 4 probes share the same configuration? In particular, are the probes at 20 cm and 50 cm always located in the ground below the agricultural field as shown on Fig. 3?

An additional figure has been included to clarify the location of the probes at each type of site and text has been added to the Soil Moisture and Precipitation Site Details section.

P 14: Table 1: it would be interesting to know in the table which stations belong to ECCC and which stations belong to the University of Guelph.

Table 1 has been updated to include these details.

Technical Comments

Abstract

L 9: mention that Saskatchewan is located in Canada.

Added.

P 4 L 84: the references are not correct.

Corrected.

Comments on the dataset

Metadata

the metadata on the FRDR website does not contain the location of each stations. These information are only given in Table 1 of the submitted paper. I recommend the authors to add an ascii file containing the locations of each station. This file could have the same content as Table 1 and could be used with Python or R by a person interested in this dataset.

A .csv version of Table 1 is now included with the metadata.

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An 11-yr (2007 – 2017) soil moisture and precipitation dataset from the Kenaston Network in the Brightwater Creek basin, Saskatchewan, Canada.

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Abstract. Soil moisture and precipitation have been monitored in a hydrometeorological network situated within the Brightwater Creek basin, east of Kenaston, Saskatchewan, Canada, since 2007. The majority of the prairie landscape is annually cropped with some sections in pasture. This agricultural region is ideal for remote sensing validation and calibration and, in conjunction with the flux tower situated within the network, hydrological model validation. Remote sensing validation collaborations have included ~~ESA's~~European Space Agency's Soil Moisture Ocean Salinity (SMOS) and NASA's Soil Moisture Active Passive (SMAP). The network was developed ~~to capture soil moisture variation~~ at two spatial scales, one high-resolution ~~network~~set of sites installed over a 10 ~~km^2~~km × 10 km region and a second installed over 40 ~~km^2~~km × 40 km. The ~~networks~~sites are all similar in design with three instrument depths for soil moisture and temperature, as well as precipitation measurement. The 2007 – 2017 dataset published in this paper has gone through a quality control review process, which involved both automated and manual processes. The dataset is limited to the summer months (May 1 – Sept 30) due to the uncertainties and complexities of measurement in frozen soils and the freeze/thaw period each year. Data ~~is~~discussed in this publication are available at https://dx.doi.org/10.20383/101.0116~~.~~, and data beyond 2017 can be requested from the corresponding author.

1 Introduction

Soil moisture and precipitation are important elements of the hydrological cycle. While ~~it~~soil moisture constitutes a small portion of the global water cycle, ~~soil moisture~~it has a significant influence on atmospheric and hydrologic processes. Soil moisture is highly variable across a landscape, being influenced by both atmospheric conditions (e.g. precipitation, evaporation), landscape variability (e.g. topography, soil characteristics), and vegetation. This creates difficulty when attempting to asses soil moisture at the typical scales of atmospheric circulation models

(Crow et al., 2012), however inclusion of soil moisture as a dynamic parameter within numerical modelling improves forecast skill for both hydrological and meteorological models (Koster et al., 2010; Koster et al., 2011; Drewitt et al., 2012; Wanders et al., 2014). The difficulty of measurement has prompted researchers to develop remote sensing techniques to try and quantify soil moisture conditions at various scales. Any remote sensing technique requires calibration and validation, in this case achieved with *in situ* monitoring stations. Relatively few monitoring network exist across the Canadian Prairies and the variation in landscape and climate present particular challenges. Other networks include the Agriculture and Agri-Food Canada (AAFC) network in Manitoba (Bhuiyan et al., 2018) and the stations established across the agricultural regions of Alberta (Walker and Howard, 2003), along with the Kenaston Network in Saskatchewan. The Kenaston Network was designed to fulfil both the needs of land-atmospheric modelling and remote sensing validation programs. Very few existing monitoring networks have the ability to validate remote sensing products and hydrometeorological models over the Canadian prairies due to the unique combination of landscape and climatic conditions. Specifically for remote sensing of soil moisture, the individual stations were distributed at two spatial scales to accommodate validation of remote sensing products at various scales. The high resolution of the network sites allows for both intergrid and intragrid validation. validation of remote sensing products or hydrological models at a range of spatial scales. To date, the network has been widely used for several purposes in remote sensing hydrology (e.g. Chan et al., 2016), data assimilation (Dumedah et al., 2011; Reichle et al., 2017) and to a lesser amount in hydrological modelling (Garnaud et al., 2016). With respect to soil moisture remote sensing, validation studies have been performed for soil moisture retrievals derived from the Advanced Microwave Scanning Radiometer –Earth Observing System (AMSR-E) (Champagne et al., 2010) and retrievals derived from the AMSR-2 (Bindlish et al., 2018). Further it has been used for validation of soil moisture retrievals from the Soil Moisture and Ocean Salinity mission (e.g. Champagne et al., 2016; Djamai et al., 2015) and the Soil Moisture Active Passive mission (e.g. Chan et al., 2016; Colliander et al., 2017) largely demonstrating statistically significant correlations to observed soil moisture anomalies. To continue the development of new applications and opportunities that make use of soil moisture data for this environment, the release and description of the collected soil moisture and precipitation data sets to the broader public is of importance, and the purpose of this paper.

2 Network Description

The Kenaston Network, also called the Brightwater Creek Monitoring Network is located on the Canadian Prairies in central Saskatchewan, approximately 80 km south of Saskatoon. Stations within the network were established in 2007 and consist of a series of soil moisture and precipitation sites, set at two spatial scales, and a year-round eddy-covariance tower with a full complement of meteorological instrumentation. The monitoring sites are situated within the basin of Brightwater Creek, which drains northward into the South Saskatchewan River. Brightwater Creek has been monitored by a Water Survey of Canada flow gauge since 1965. The landscape is a typical prairie agricultural region with annually cropped fields, mainly of cereals, oilseeds, and pulse crops, and pasture lands. There are no irrigated sections in the study area, the nearest being the South Saskatchewan River District to the west surrounding Outlook, Sk. The area is flat with slopes of less than 2% (Burns et al., 2016) which affects runoff in the region. Significant portions of the area are ~~considering~~considered non-contributing, where ~~in general~~typically water does not drain to streams or rivers but instead ponds in small wetlands and sloughs (Shook et al., 2013). ~~Predominantly~~Texture of the soils in the region is predominantly silt loam~~, the area~~ but ranges from sandy loam to clay ~~in texture.~~(Ellis et al., 1970, Magagi et al., 2013). Data from the network have been used for several projects~~ over the years~~ including the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission, the National Aeronautics and Space Administration's (NASA) Soil Moisture Active Passive (SMAP) mission, the Drought Research Initiative (DRI), and the Changing Cold Regions Network (CCRN). A field campaign for the SMAP satellite was conducted in 2010 (CanEx-SM10), ~~and previous~~primarily described in Magagi et al. (2013). Additional publications that describe ~~this~~the spatial scaling of the network include ~~Magagi et al. (2013) , Champagne et al. (2010; 2016),~~ Rowlandson et al. (2015), and Burns et al. (2016).

The Kenaston Network is a community site, with involvement from Environment and Climate Change Canada (ECCC), the University of Guelph, the University of Saskatchewan, and ~~Agriculture and Agri-Food Canada (~~AAFC~~),~~, each of which is responsible for portions of the overall network. ~~The~~There are four AAFC stations, which are located within pasture sections and measure soil moisture down to 150 cm, along with standard meteorological sensors: data and site details can be found at [http://agriculture.canada.ca/SoilMonitoringStations/index-en.html]. This paper presents data only from the soil moisture and precipitation stations managed by Environment and Climate Change Canada and the University of Guelph~~.~~ and does not include data from the AAFC sites or the eddy-covariance tower managed by ECCC and the University of Saskatchewan. As mentioned above AAFC data is available through their website, and the eddy covariance tower data is in progress to be published. As of this publication a majority of the stations within the network are still operational and additional data can be requested from the corresponding author.

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3 Soil ~~moisture~~Moisture and ~~precipitation site details~~Precipitation Site Details

The soil moisture and precipitation sites are distributed at two spatial scales: 10 ~~km^2~~km × 10 km and 40 ~~km^2~~km × 40 km (~~Figure 1).~~Figure 1). The larger scale network has been modified over time and began in a 45 ~~x~~km × 55 km area, and correspondingly the number of sites has changed. Each site consists of a datalogger, power system, tipping bucket rain gauge (TBRG), and 3-4 Hydra Probes. These sites are usually set outside of the actively managed area of the cropped field, in fence line strips, under powerlines, or at the very edge of the field. ~~Figure 2~~There are two types of sites, 3-probe at the 40 km × 40 km scale, and 4-probe at the 10 km × 10 km scale. Figure 2 shows a typical setup for either type, with Figure 4 and Figure 3 clarifying the differences between the 3-probe and 4-probe sites, respectively. All sites have at least three probes, inserted horizontally at depths of 5, 20, and 50 cm below the surface that remain in place throughout the year. ~~Additionally, site~~The 3-probe sites have all probes located at the ~~10 km^2 scale also~~edge of the field, outside of the actively managed field area. The 4-probe sites have a 5 cm probe at the edge of the field, with the 20 and 50 cm probes installed in the field, and a vertically placed probe, generally indicated as 0-5 cm, which ~~moves~~is moved into and out of the field during the cropping season. The vertical probe is moved into the field after seeding and ~~is~~ removed shortly before harvest~~. Figure 3 illustrates the general setup of the stations that include a vertically place probe, indicating the location of the four probes. Stations with only three probes have a similar setup, with all three probes inserted near the datalogger box~~ and reinserted at the edge of the field for the off season. This movement of the vertical probe creates separate data streams, which have been separated in the data files to avoid confusion.

Data is collected at 30 minute intervals, a single point measurement from each Hydra Probe and the sum over the 30 minute interval for the TBRG. Provided from each probe for this dataset ~~is~~are real dielectric constant (real dielectric permittivity, ε_r), temperature, and soil moisture using the manufacturer's loam calibration equation. Additional data has been collected at some sites within the Kenaston network, including soil conductivity, 2.5 cm soil temperature, crop types, heights, and photos, air temperature and relative humidity, point measurement snow depth, and snow surveys, which is not included in this dataset but can be requested through the corresponding author.

Sites are visited regularly throughout the field season to ensure TBRG cleanliness and to check for site issues. ~~Site~~Depending on the site these visits can be every two weeks or at minimum one a month, during the summer months. Sites with a vertically placed probe are visited more frequently than others due to the greater risk for disturbance and placement issues~~.~~, with visits generally completed every two weeks.

3.1 Soil Instrumentation

The instrument used throughout the network to measure soil parameters is the Stevens Hydra Probe II (Stevens Water Monitoring Systems (Inc, 2009: Burns 2016)).2018a). These are radiometric coaxial impedance dielectric reflectometer sensors, with four 5.7 cm tines extending from a 3.4.2 cm diameter head, along which a radio frequency is applied and the reflected frequency measured (Stevens Water Monitoring Systems, Inc., 2018b). This reflected signal is related to the real dielectric constant (ε_r) of the soil which in turn is correlated to soil water content (e.g. Topp et al., 1980; Campbell, 1990; Seyfried et al., 2005). General ranges for ε_r are roughly 80 in water, 1 in air, and 2-5 in dry soil. A more detailed description of the instrument and the measurement principles can be found in publications from Stevens Water Monitoring Systems, Inc. (2018a, 2018b). These sensors are widely used in university and government research networks, including NOAA's Climate Reference Network (Bell et al., 2013), the USDA's Soil and Climate Analysis Network (Schaefer et al., 2007), and Agriculture and Agri-Food Canada'sAAFC's national monitoring networks (Adams et al., 2014).

Real dielectric constant (ε_r) is related to soil moisture through a calibration equation. (1) (Seyfried et al., 2005). The equationsstandard loam equation supplied fromby the manufacturer, with coefficients A = 0.109 and B = -0.179, report a sensor accuracy of ±0.03 m^3m^{-3} (Stevens Water Monitoring Systems, Inc., 2018a or b), andhowever a site specific calibration is recommended (e.g. Huang et al., 2004; Seyfried and Murdock, 2004; Rowlandson et al., 2013). The uncertainty in calibration method and ongoing work in this area presents a difficulty that has not been satisfactorily resolved, particularly for the measurements at deeper depths, as described in Burns et al. (2014). To ensure consistency for all of the data the manufacturer supplied loam calibration equation (Stevens Water Monitoring Systems, Inc., 2018b) is used to calculate soil moisture, with the understanding that this decreases the overall accuracy of the network. Burns et al. (2014) reported loam calibration root mean squared errors (RMSE) ranging from 0.038 to 0.144 m^3m^{-3}, with improvements in RMSE when developing site specific calibrations. There have been difficulties, however, in the repeatability of these site specific calibration methods and further work is required before applying site specific equations wholesale (e.g. Rowlandson et al., 2018). *In situ* calibration equations have been established for the majority of the near surface probes (5cm) and5 cm) and while not used on the data for this paper these equations are available upon request.

$$\theta = A\sqrt{\varepsilon_r} + B \qquad (1)$$

Occasional measurement issues with the Hydra Probe were encountered, some of which may be specific to the Kenaston network. For example, during hot summer days when the surface soil becomes very dry, ε_r from the near surface probes (vertically placed 0-5 cm and horizontally placed 5 cm) will drop below ~2.6968, which produces a negative soil moisture value using the loam equation. These low ε_r values are possibly due to soil cracking, poor sensor contact with the soil, or are simply valid responses from the probe. During these dry periods repositioning the probe, which is the typical response to these types of issues in near-surface probes, is not typically possible simply due to the difficulty in inserting a probe into dry, hard-packed, fine grained soils. New cracks often form as the probe is taken out and re-inserted, resulting in the same issues. These probes are closely monitored and after the next sufficiently significant rain event, soil moisture typically increases and the probe begins responding as expected. Negative soil moisture values are automatically removed from the data set and periods of prolonged data intermittence are also manually removed. Additionally, a diurnal oscillation of measured ε_r is observed, with greater amplitude during hot, dry conditions. This suggests a temperature effect on ε_r but is not investigated further here (Seyfried and Grant, 2007). Periods with significant diurnal oscillation and unrealistic soil moisture values are removed from the dataset.

The Kenaston region is similar to other parts of Saskatchewan in the occurrence of saline soils, the results of which cause some issues with the deeper probes (horizontally placed probes at 20 and 50 cm) (Seyfried and Murdock, 2004). While a typical variation between successive measurement intervals (timestamps) outside periods of rainfall could be on the order of ±0.01 m^3m^{-3}, those probes measuring in saline conditions can vary as much as at ±0.10-0.20 m^3m^{-3}. This is corroborated by measurement of soil conductivity: increasing variability between consecutive timestamps coincides with an increase in conductivity, generally greater than 0.2 S m^{-1};, which is less than the threshold given by the manufacturer of 1 S m^{-1} (Stevens Water Monitoring Systems, Inc., 2018a). In some cases this only occurs for a season, while other sites show a consistent record of high conductivity and therefore large measurement variation in soil moisture. This type of issue can in certain cases be resolved by averaging the 30-minute data over a longer period, which is a common step used by modelling and remote sensing validation projects. Due to this, some periods of significant variation have been removed from the data set, however not all have been removed and should be reviewed by data users.

3.2 Precipitation Instrumentation

All sites within the network are equipped with a tipping bucket rain gauge (TBRG) to capture precipitation. One of two varieties are used currently: the Onset RG3-M or the Hydrological Services (HyQuest Solutions Pty Ltd, 2014) TB3. All sites began with either an Onset TBRG or a Texas Electronics TR-525M (R2/R1) but over the years they have been replaced within the 10 km^2 scalekm × 10 km network to the configuration documented in Table 1. Currently all sites use a TBRG with a 0.2 mm scale but some earlier TBRG had a 0.1 mm scale. The accuracy for the TB3 is +/- 2% for flow rates of 0-250 mm/hour, and +/- 3% for rates of 250-500 mm/hour (HyQuest Solutions Pty Ltd, 2014); the accuracy of the Onset RG3-M is +/-1% for rates up to 20 mm/hour (Onset Computer Corporation); and the accuracy of the TR-525M-R1 is +/- 1% for rates up to 50 mm/hour (Texas

Electronics). Only the TB3 is equipped with a siphon unit which controls the flow of rainfall into the buckets, improving its performance against other TBRG (Devine and Mekis, 2008). Additionally, the filter design of the TB3 is superior in avoiding blockage of the funnel by debris.

Common issues with the TBRG overall include blockage due to debris, mount damage from farm equipment, ~~and~~ the occurrence of single tips not related to network-wide rainfall events, and inaccuracy related to hail events. Bird guards were installed on the TB3s where regular debris issues were common. Field calibrations of the ~~TB3s have been regularly completed since installation.~~TBRG have been completed every two to three years to confirm that the rain gauges were still functioning accurately. If the calibration target was not reached, the TBRG was replaced. A known issue with TBRG-style precipitation gauges is the possibility of single tips due to the retention of water in the bucket or siphon (the latter only in the case of the TB3). Single tips within the dataset that are not temporally correlated to a rainfall event may not be indicative of rainfall within the 30 minute measurement period. These records have not been removed from the dataset due to the uncertainty in consistently determining validity without removing significant credible data. Another source of error is inaccurate collection of precipitation during hail events, which would then melt and be recorded by the logger.

4 Quality Control Process and Data

~~While~~At the time of publication the network is ~~currently~~being run year round, ~~at maximum~~however only May 1 – September 30 is included for each year where shoulder season data ~~year~~exists. The main challenges are difficulties in measurement and calibration ~~occur during~~of data recorded within the winter and shoulder seasons when the ground is transitioning between a frozen and thawed state (e.g. Williamson et al~~.~~., 2018). Additionally, TBRGs are not designed for solid precipitation measurement. Two phases of quality control/quality assurance (QAQC) are performed to warm season data: an automated check and then manual review. The automated phase checks for logger errors and common sensor errors, with the secondary manual review process including a review of field notes and checks of all sensors for known instrument errors and gaps in the automated process. The automatic review begins with the raw measurements and can be completed in near real time, while the secondary manual review is completed on an as needed basis, or seasonally.

4.1 Automated Review Details

The automated review process checks for the limits documented in Table 2 and removes data outside of these thresholds. These checks mainly screen for obvious sensor errors and provide consistency for the next phase of

QAQC. Also applied during this process are flags that are using during the manual process to check for common errors (Table 3).

4.2 Manual Review Details

After the automated process, a manual review of the resultant data is conducted to do a final review of the data from each instrument and each site. Hydra Probes are typically reviewed against the site's TBRG, to ensure that jumps in soil moisture correlate with precipitation events. The TBRG are reviewed collectively, as at least for the ~~dense set of~~ sites within the 10 km × 10 km grid precipitation events will be collected by all instruments. This repetition of equipment allows for a relatively high level of confidence in rainfall events and provides useful information to diagnose TBRG collection or measurement errors. Review of field notes and comparison of TBRG between nearby sites confirms TBRG cleanliness~~,~~ (debris can delay or block rainfall passing into the buckets of the TBRG) and general agreement between sites. When disagreement between a single site and the majority is observed and confirmed by field visits, the data is removed.

Site visits can potentially cause erroneous data and the data from the day of each site visit is reviewed and edited for (1) extra TBRG tips due to cleaning; (2) erroneous data from the vertically placed 0-5 cm probe when it is moved into and out of the field; (3) other sensor issues that could result in incorrect data (physical damage, disturbance by field equipment or animals); (4) erroneous values from troubleshooting or maintenance checks. These checks are done in conjunction with review of field notes. Data from each sensor is also visually plotted and reviewed for general operation as sensor malfunction can often be caught in careful review of the sensor parameters~~.~~; the flags in Table 3 are used at the stage to assist in identifying issues. In this QAQC stage, the focus is on unexplained jumps or drops, gaps, and unusually high or low values that have not yet already been removed during the automated review. Any data diagnosed during this process as erroneous is removed from the final data set~~.~~, however as previously mentioned some periods of data that are suspect have been kept in the dataset. The ranges given in Table 3 are only guidelines to assist with manual review: specifically for soil moisture and real dielectric constant, values outside the ranges given may be kept in the data set if the extremes were justified by either the other sensors at the site or the site's TBRG data. The temperature flag is a simple check for frozen ground, as certain years had evidence of frozen ground in May or at the end of September that were removed. Undoubtedly, certain data issues have been overlooked and new versions of the data will be made as additional QAQC process are developed and implemented.

5 Data Availability

The data described here are available at the Federated Research Data Repository (FRDR) (https://dx.doi.org/10.20383/101.0116).), as comma-separated-value files. The corresponding author can be contacted for access to data beyond 2017 as well as any ancillary data.

6 Summary

Data from 2007 – 2017, May 1 – Sept 30, from the Kenaston Network in the Brightwater Creek basin in central Saskatchewan, Canada, has been quality controlled and compiled in a standard format. The network consists of two scales of sites, each with 3 – 4 Hydra Probes and a tipping bucket rain gauge. Included in this dataset from each Hydra Probe is soil moisture, temperature, and real-dielectric constant (ε_r). Some issues with the Hydra Probe have been identified and documented, and the overall network coverage is good. It is anticipated that this dataset and the data from the network beyond 2017 will continue to provide useful information for remote sensing validation and calibration as well as hydrometeorological modelling efforts.

Acknowledgements

The authors would like to thank all of the researchers and summer students who have contributed over the years to the network. This project would not have been possible without the collaboration and good will of these colleagues. Significant among those are Bruce Johnson, Warren Helgason, Dell Bayne, Craig Smith, Anthony Liu, Amber Peterson, Travis Burns, Justin Adams, Matthew Williamson, Sarah Impera, William Woodley, Jon Belanger and Mark Cliffe-Phillips. Funding for the University of Guelph has been provided from the Canadian Space Agency and grants from the Natural Science and Engineering Research Council of Canada.

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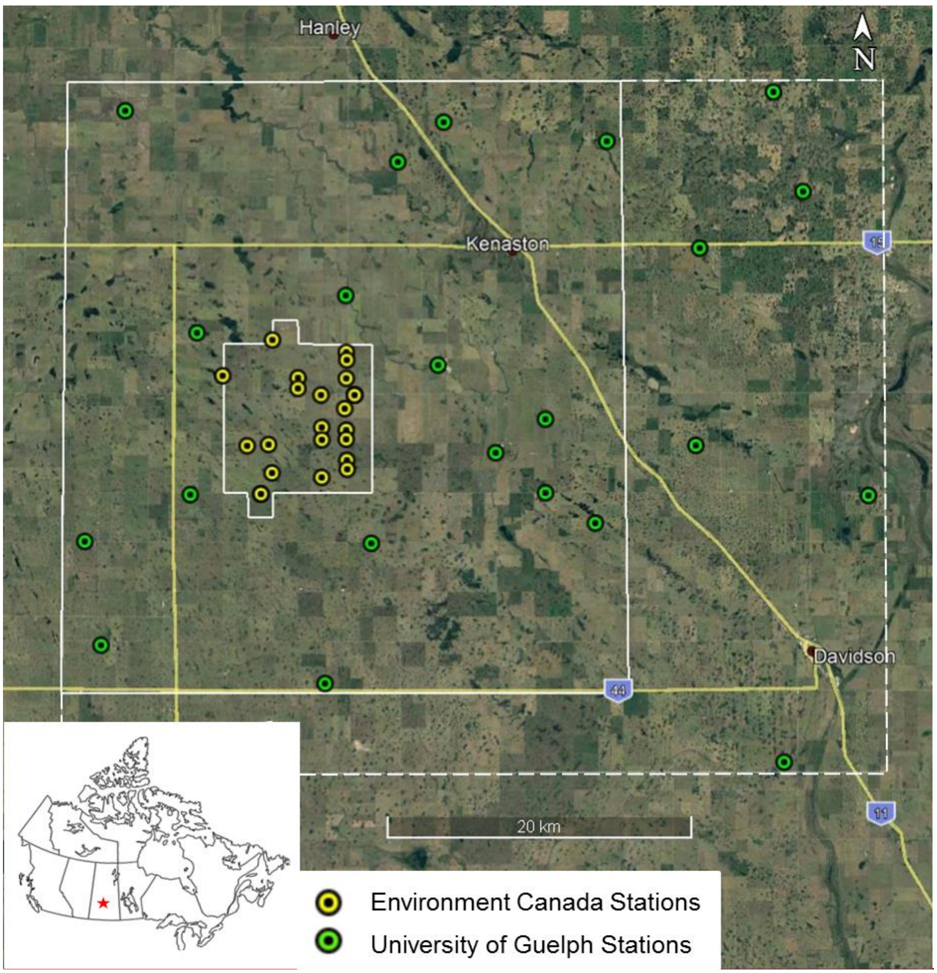

Hanley
N
Kenaston
15
Davidson
44
11
20 km
Environment Canada Stations
University of Guelph Stations

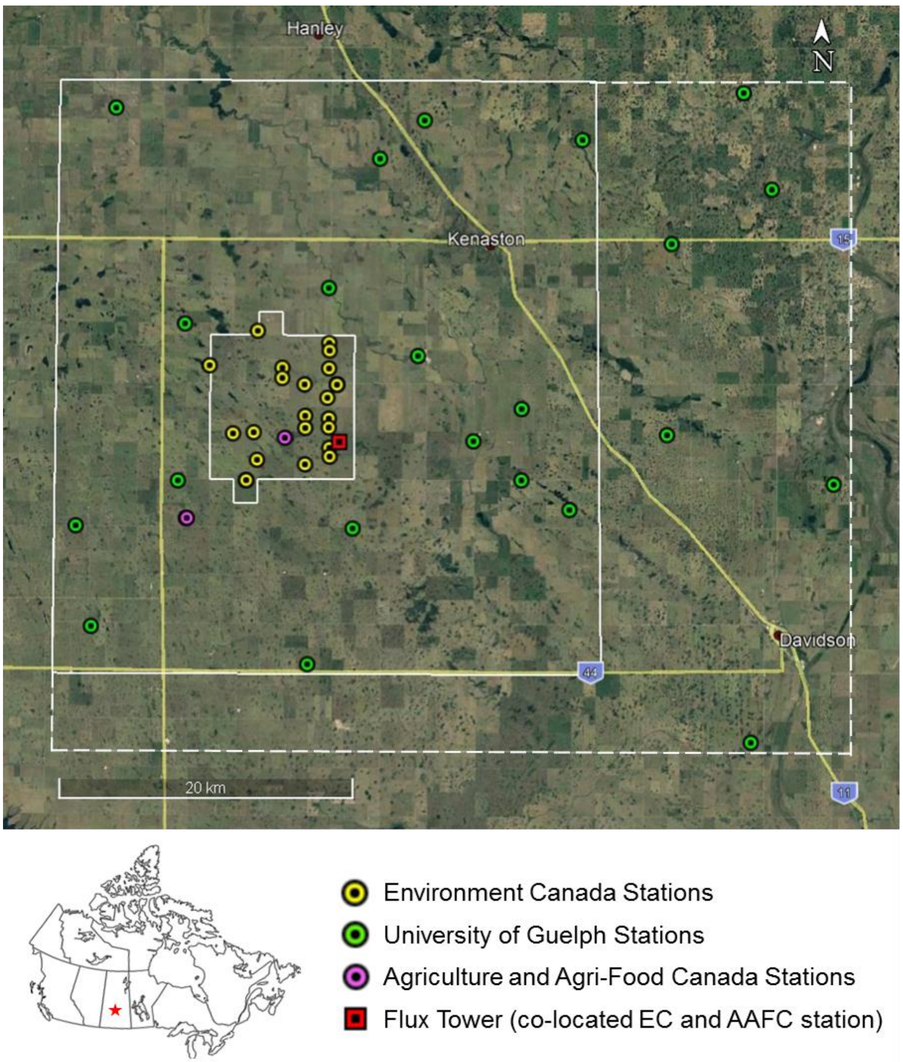

Figure 1. Map of site locations, the white frames indicating the two scales of the sites. ECCC sites are within a 10 ~~km^2~~km × 10 km area and University of Guelph sites are within the current 40 ~~km^2~~km × 40 km area. The dashed line indicates the original larger scale~~;~~: 45 ~~x~~km by 55 km.

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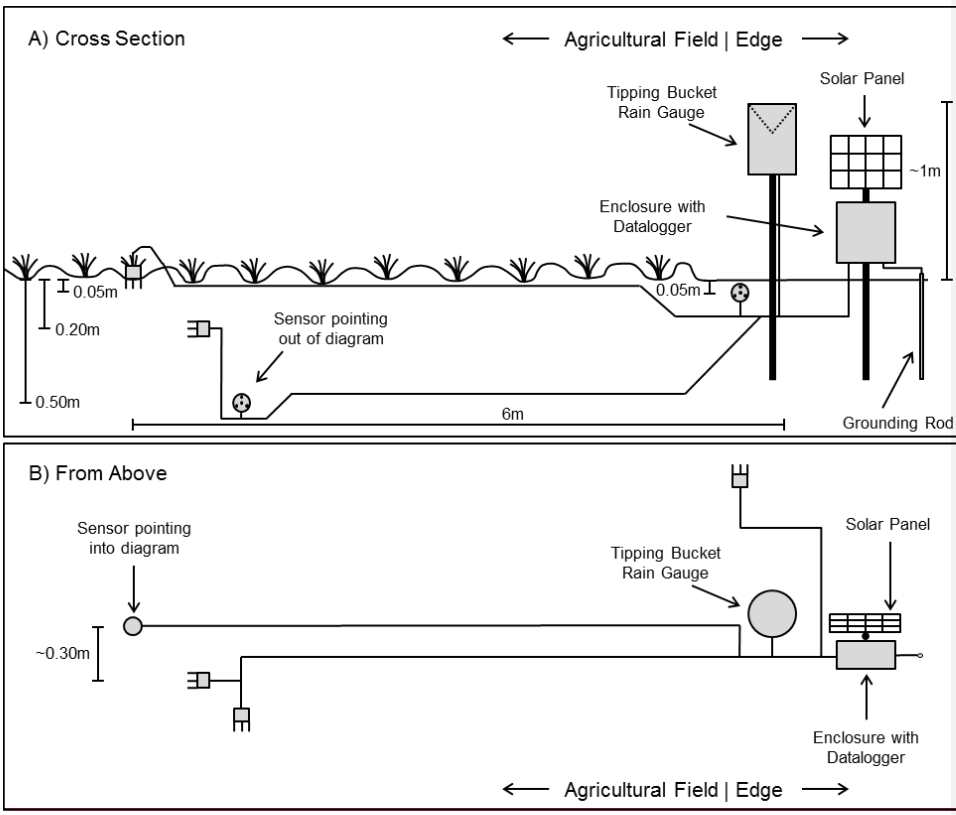
Figure 2. Typical site installation. ~~(1) Horizontal~~<u>The 4-probe sites include at (1) horizontal</u> 5 cm sensor; (2) horizontal 20 and 50 cm sensors and location of vertical 0-5 cm sensor during field season; (3) location of vertical 0-5 cm sensor during off season; (4) tipping bucket rain gauge; (5) loggerbox with datalogger; (6) solar panel.<u> Only ECCC sites have a vertically placed probe. The 3-probe sites are similar, with all probes located at the edge of field at (1).</u>



A) Cross Section
Agricultural Field | Edge
Tipping Bucket Rain Gauge
Solar Panel
~1m
Enclosure with Datalogger
0.05m
0.20m
0.50m
0.05m
Sensor pointing out of diagram
6m
Grounding Rod
B) From Above
Sensor pointing into diagram
Tipping Bucket Rain Gauge
Solar Panel
~0.30m
Enclosure with Datalogger
Agricultural Field | Edge

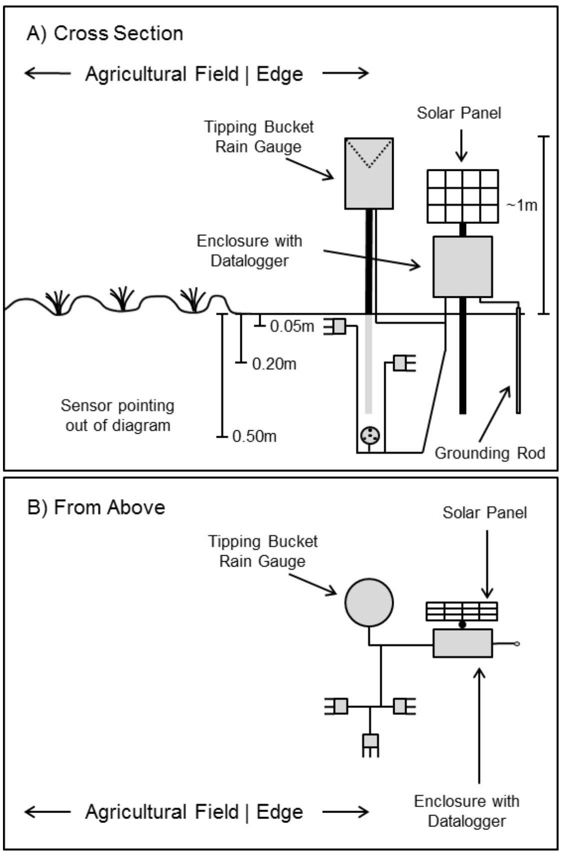


Figure 3. General configuration of ~~each~~3-probe soil moisture station.

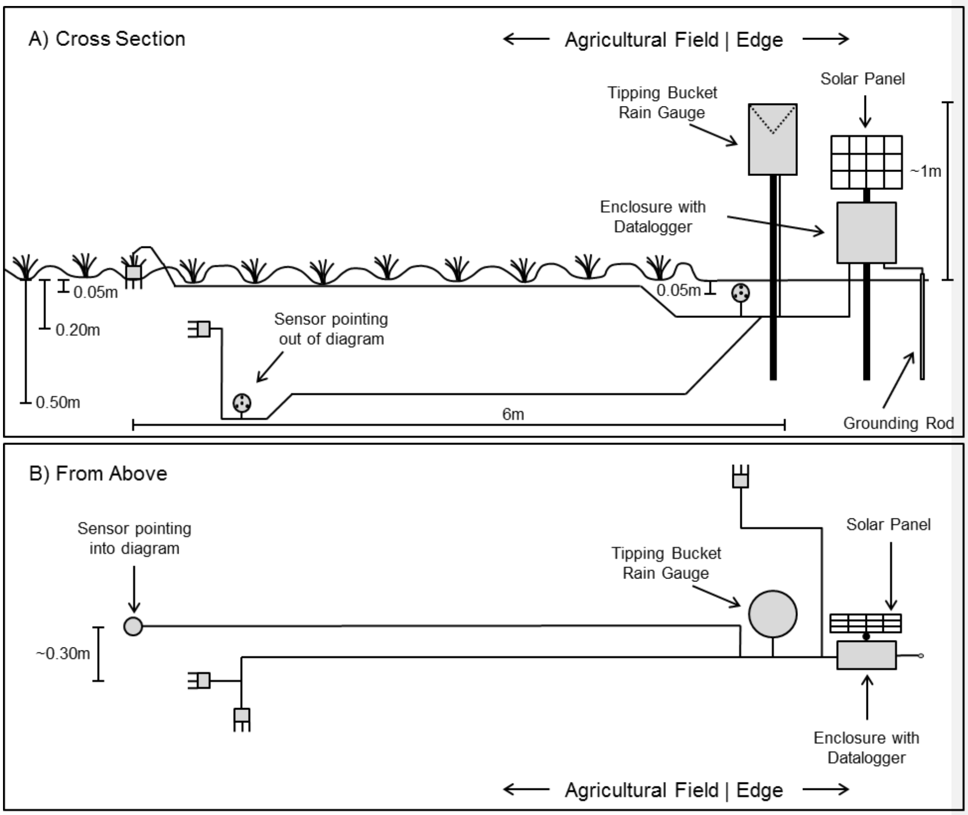


Figure 4. General configuration of 4-probe soil moisture station.

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Table 1. Site metadata details including soil texture information.

Site ID	Partner	Coordinates		Instrumentation		Soil Texture			Data Record
		Latitude	Longitude	Hydra Probes	TBRG Type	Sand (%)	Silt (%)	Clay (%)	
2701000	Guelph	51.2001	-106.0156	3	RG3	47.1	50.3	2.6	2007- 201320
2701001	Guelph	51.5836	-106.6364	3	RG3	33.4	63.7	2.9	2007-20
2701002	Guelph	51.5767	-106.3342	3	RG3	60.0	38.8	1.2	2007-20
2701003	Guelph	51.5651	-106.1799	3	RG3	54.7	43.0	2.3	2007- 201320
2701004	Guelph	51.5914	-106.0146	3	RG3	54.7	42.9	2.2	2007- 201320
2701005	Guelph	51.4529	-106.5672	3	RG3	35.7	60.8	3.5	2007-20
2701006	Guelph	51.5534	-106.3776	3	RG3	58.4	40.3	1.3	2007-20
2701007	Guelph	51.5021	-106.0927	3	RG3	61.7	37.0	1.3	2007- 201320
2701008	Guelph	51.5351	-105.9950	3	RG3	-	-	-	2007- 201320
2701009	Guelph	51.3300	-106.6724	3	RG3	31.0	52.0	17.0	2007-20
2701010	Guelph	51.4374	-106.2222	3	RG3	47.1	50.3	2.6	2007-20
2701011	Guelph	51.3864	-106.0971	3	RG3	34.5	62.6	2.9	2007- 201320
2701012	Guelph	51.3564	-105.9351	3	RG3	23.8	72.4	3.8	2007- 201320
2701013	Guelph	51.2690	-106.6568	3	RG3	30.0	49.0	21.0	2007-20
2701014	Guelph	51.2468	-106.4460	3	RG3	25.0	54.0	21.0	2007-20
2701015	Guelph	51.3577	-106.5729	3	RG3	28.0	47.0	25.0	2007-20
2701016	Guelph	51.4020	-106.2385	3	RG3	39.8	52.2	8.0	201320 2017
2701017	Guelph	51.4749	-106.4268	3	RG3	10.6	48.3	41.1	201320 2017
2701018	Guelph	51.3292	-106.4025	3	RG3	10.5	63.7	25.9	201320 2017
2701019	Guelph	51.3824	-106.2853	3	RG3	39.0	31.2	29.8	201320 2017
2701020	Guelph	51.3588	-106.2386	3	RG3	33.6	60.6	5.8	201320 2017
2701021	Guelph	51.3409	-106.1918	3	RG3	54.5	34.1	11.4	201320 2017
2701022	ECCC	51.3817	-106.4159	4	TB3	26.2	60.5	13.3	2007-20
2701023	ECCC	51.3679	-106.4492	4	TB3	37.0	41.0	22.0	2007-20
2701024	ECCC	51.3706	-106.4960	4	TB3	34.0	50.0	16.0	2007-20
2701025	ECCC	51.4488	-106.4960	4	TB3	25.4	56.3	18.2	2007-20
2701026	ECCC	51.3727	-106.4253	4	TB3	28.6	57.3	14.1	2007-20
2701027	ECCC	51.3780	-106.4256	4	TB3	28.0	59.0	13.0	2007-20
2701028	ECCC	51.3872	-106.4994	4	TB3	42.0	41.0	17.0	2007-20
2701029	ECCC	51.3865	-106.5195	4	TB3	39.0	44.0	17.0	2007-20
2701030	ECCC	51.3958	-106.4262	4	TB3	31.0	46.0	23.0	2007-20

2701031	ECCC	51.3974	-106.4493	4	TB3	26.6	55.7	17.7	2007-20
2701032	ECCC	51.3904	-106.4262	4	TB3	15.7	52.0	32.3	2007-20
2701033	ECCC	51.3900	-106.4492	4	TB3	26.0	50.0	24.0	2007-20
2701034	ECCC	51.4164	-106.4184	4	TB3	29.0	49.0	22.0	2007-20
2701035	ECCC	51.4164	-106.4501	4	TB3	26.0	51.0	23.0	2007-20
2701036	ECCC	51.4084	-106.4277	4	TB3	33.0	46.0	21.0	2007-20
2701037	ECCC	51.4262	-106.4262	4	TB3	26.8	51.4	21.8	2007-20
2701038	ECCC	51.4265	-106.4718	4	TB3	13.8	57.0	29.2	2007-20
2701039	ECCC	51.4202	-106.4718	4	TB3	30.2	51.3	18.5	2007-20
2701040	ECCC	51.4277	-106.5428	4	TB3	31.8	46.1	22.1	2007-20
2701041	ECCC	51.4166	-106.4184	4	TB3	20.0	43.0	37.0	2007-20
2701042	ECCC	51.4370	-106.4258	4	TB3	12.7	70.1	17.2	2007-20
2701043	ECCC	51.3582	-106.5064	4	TB3	50.0	32.0	18.0	2007-20
2701044	ECCC	51.4416	-106.4262	4	TB3	24.6	59.5	15.9	2007-20

[a] TBRG types: Onset ~~RG3and~~RG3 and Hydrological Services TB3.

Table 2. Limits applied in QC1 – data removed

Parameter	Limits
Temperature (°C)	-60 < x < 60
Real dielectric constant (ε_r, unit-less)	0 < x < 90
Soil moisture, loam calibration (VWC, (m^3m^{-3}))	0 < x < 1.0

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Table 3. QAQC flags for manual review

Parameter	QAQC Checks
Temperature (°C)	x < 0
Real dielectric constant (ε_r, unit-less)	x < 2.4
Soil moisture, loam calibration (VWC, (m^3m^{-3}))	0.02 < x < 0.6
~~Conductivity (if available)~~	~~x < 0.2~~

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