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Satellite surface soil moisture from SMOS and Aquarius: Assessment for applications in agricultural landscapes

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ABSTRACT

Satellite surface soil moisture has become more widely available in the past five years, with several missions designed specifically for soil moisture measurement now available, including the Soil Moisture and Ocean Salinity (SMOS) mission and the Soil Moisture Active/Passive (SMAP) mission. With a wealth of data now available, the challenge is to understand the skill and limitations of the data so they can be used routinely to support monitoring applications and to better understand environmental change. This paper examined two satellite surface soil moisture data sets from the SMOS and Aquarius missions against in situ networks in largely agricultural regions of Canada. The data from both sensors was compared to ground measurements on both an absolute and relative basis. Overall, the root mean squared errors for SMOS were less than 0.10 $m^3\,m^{-3}$ at most sites, and less where the in situ soil moisture was measured at multiple sites within the radiometer footprint (sites in Saskatchewan, Manitoba and Ontario). At many sites, SMOS overestimates soil moisture shortly after rainfall events compared to the in situ data; however this was not consistent for each site and each time period. SMOS was found to underestimate drying events compared to the in situ data, however this observation was not consistent from site to site. The Aquarius soil moisture data showed higher root mean squared errors in areas where there were more frequent wetting and drying cycles. Overall, both data sets, and SMOS in particular, showed a stable and consistent pattern of capturing surface soil moisture over time.

1. Introduction

Remotely sensed observations of surface soil moisture are becoming increasingly available from a number of satellite missions, including those with soil moisture as their dedicated purpose, such as the Soil Moisture and Ocean Salinity mission (SMOS; (Kerr et al., 2012)) and the Soil Moisture Active/Passive mission (SMAP; (Entekhabi et al., 2010)). Other missions such as the Aquarius mission (Bindlish et al., 2015), Advanced Microwave Scanning Radiometer (AMSR-E/AMSR-2; (Imaoka et al., 2010; Njoku et al., 2003)) missions, and ASCAT /METOP-A (Naeimi et al., 2009; Wagner et al., 1999) all have or had soil moisture data sets that are available widely for research and applications use. This wealth of soil moisture information holds great potential for advancing the understanding of soil moisture and related biogeochemical cycles that have implications for a diverse array of applications, such as improving weather and climate prediction, hydrological flood forecasting and climate-related risk assessment. The challenge in making use of these data sets is in understanding the strengths and limitations of each data set, where it is capturing relative trends and where it is not. This research will compare surface satellite soil moisture from the SMOS mission and the now completed Aquarius mission, two L-band passive microwave sensors, to field-measured values, and assess the ability of the data sets to capture relative and relevant trends in moisture availability over a multi-year period.

A variety of modelling approaches, assumptions and methods of estimating ancillary variables are used to retrieve soil moisture information from active and passive microwave sensors, which leads to differences in estimated soil moisture that are over and above those resulting from differences in the electromagnetic fre-

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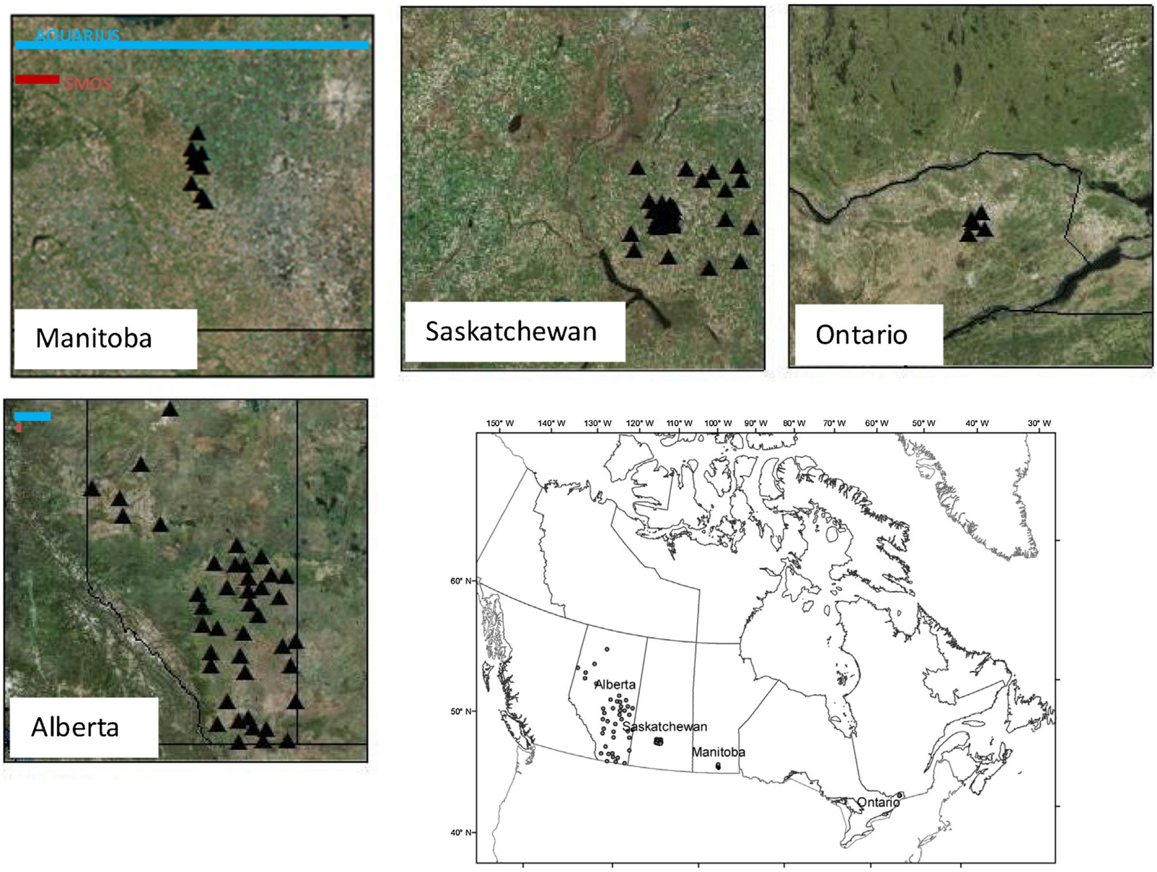

Fig. 1. Location scale of in situ soil moisture monitoring sites in agricultural regions of Canada. Comparison of SMOS (red bar) and Aquarius (blue bar) spatial scale (top left corner) compared to in situ monitoring locations (black triangles) for the selected networks in this study. Manitoba, Saskatchewan and Ontario networks shown at the same scale; Alberta mesonet shown at larger scale to capture full extent of network. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Error Statistics for SMOS and Aquarius surface soil moisture compared to in situ measurements at network locations.

Site	SMOS			Aquarius		
	aRMSE	cRMSE	*R*	aRMSE	cRMSE	*R*
Ontario	0.07	0.08	0.80	0.17	0.05	0.63
Manitoba	0.11	0.12	0.51	0.12	0.12	0.70
Saskatchewan	0.05	0.05	0.75	0.09	0.08	0.79
Alberta (average)	0.10	0.10	0.60	0.15	0.09	0.47

quency and engineering used to collect the radiometric information (Owe et al., 2000). Passive microwave sensors such as SMOS, SMAP and Aquarius measure brightness temperature, which is impacted by differences in surface soil moisture, but is also based on factors such as surface temperature, vegetation water content and surface roughness and/or topography. Most radiative transfer models that are used to estimate surface soil moisture from passive microwave satellites are developed over bare to low biomass vegetative surfaces. The uncertainty in land cover data sets, which leads to uncertainty in the distribution of different contributing areas within the sensor footprint, results in uncertainty in the estimation of the contribution of each land cover to the brightness temperature measurements. Additionally, models to retrieve soil moisture over forested regions are less robust, leading to further uncertainty. The strategies used to estimate these ancillary variables such as land cover and vegetation water content can lead to different estimates of surface soil moisture from different satellites and different retrieval methods.

Numerous studies have looked at the validation of SMOS soil moisture data since the launch of the sensor in 2009. Several studies found that SMOS soil moisture tends to underestimate soil moisture or exhibits a dry bias, particularly in arid areas, when compared to local measurements (Al Bitar et al., 2012; Dall'Amico et al., 2012; Djamai et al., 2015; Jackson et al., 2012; Lacava et al., 2012; Sanchez et al., 2012). The SMOS soil moisture retrieval algorithm tends to overestimate the moisture relative to ground measurements following large rainfall events, a fact that has been attributed to physical differences in the sensing depth of the sensor versus the in situ measurements (Jackson et al., 2012). SMOS soil moisture has been shown to be more sensitive to moisture at the very surface (0–5 cm) than to soil moisture measured horizontally at a 5 cm depth (Adams et al., 2015). Overall, root mean squared errors (RMSE) between SMOS soil moisture and in situ have been reported between 0.02 $m^3 m^{-3}$ and 0.10 $m^3 m^{-3}$, with differences often higher where significant forest, wetland or open water is present in the foot print of the SMOS pixel (Al Bitar et al., 2012). The temporal correlation of SMOS with the in situ soil moisture time series in the above-mentioned studies varies considerably depending on the geography and climatology of the sites that are examined, the number of in situ monitoring sites present within the radiometer footprint, the time period over which the data are assessed and other factors such as Radio Frequency Interference (RFI). Several researchers have looked at the accuracy of SMOS over sites in Canada during intensive field campaigns, including the Can-Ex field campaign over a 12 day period in 2010 (Gherboudj et al., 2012; Magagi et al., 2013) and the 42 day SMAPVEX-12 experiment in 2012 (Adams et al., 2015; McNairn et al., 2015). Over a two month