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Monitoring agricultural soil moisture extremes in Canada using passive microwave remote sensing

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ABSTRACT

Current methods to assess soil moisture extremes rely primarily on point-based *in situ* meteorological stations which typically provide precipitation and temperature rather than direct measurements of soil moisture. Microwave remote sensing offers the possibility of quantifying surface soil moisture conditions over large spatial extents. Capturing soil moisture anomalies normally requires a long temporal record of data, which most operating satellites do not have. This research examines the use of surface soil moisture from the AMSR-E passive microwave satellite to derive surface soil moisture anomalies by exploiting spatial resolution to compensate for the shorter temporal record of the satellite sensor. Four methods were used to spatially aggregate information to develop a surface soil moisture anomaly (SMA). Two of these methods used soil survey and climatological zones to define regions of homogeneity, based on the Soil Landscapes of Canada (SLC) and the EcoDistrict nested hierarchy. The second two methods (ObShp3 and ObShp5) used zones defined by a data driven segmentation of the satellite soil moisture data. The level of sensitivity of the calculated SMA decreased as the number of pixels used in the spatial aggregation increased, with the average error reducing to less than 5% when more than 15 pixels are used. All methods of spatial aggregation showed somewhat weak but consistent relationship to *in situ* soil moisture anomalies and meteorological drought indices. The size of the regions used for aggregation was more important than the method used to create the regions. Based on the error and the relationship to the *in situ* and ancillary data sets, the EcoDistrict or ObShp3 scale appears to provide the lowest error in calculating the SMA baseline. This research demonstrates that the use of spatial aggregation can provide useful information on soil moisture anomalies where satellite records of data are temporally short.

1. Introduction

Soil moisture extremes in an agricultural context are conditions where too much or too little water is present to support production. This can manifest itself as wet extremes in areas where rainfall is excessive or soils have poor drainage characteristics, and this can have an impact on soil physical structure and hasten anaerobic microbial processes that reduce soil fertility (Ball et al., 1997). Poor soil moisture availability is associated with dry spells and drought, and this can lead to crop losses when they occur during key growth stages, soil and nutrient losses due to soil erosion, and the proliferation of pests (McGinn and Shepherd, 2003; Powell et al., 2007; Pruski and Nearing, 2002). Current methods to quantify these extreme events geospatially are largely based on *in situ* meteorological data collected at weather stations and are limited to the temperature and precipitation data that these typically provide. Moisture extremes can be difficult to monitor using *in situ* meteorological stations because precipitation patterns are highly variable in space and time (Boken, 2005). Soil moisture contains "memory" of precipitation events, such that the wetness retained in the soil after a rainfall event is temporally more persistent than the rainfall event itself (Koster and Suarez, 2001). For this reason, methods have emerged in recent years to quantify soil moisture extremes (rather than precipitation) using information simulated from land surface models, remote sensing measures and statistical learning methods to create anomaly indices (Loew et al., 2009; Narasimhan and Srinivasan, 2005; Sheffield et al., 2004). While surface soil moisture from satellites may not always be a good indicator of conditions at depth (Capehart and Carlson, 1997; Wilson et al., 2003), it can provide an indication of the spatial variability of rainfall events that sparsely distributed *in situ* stations networks cannot.

Passive microwave sensors capture surface soil moisture conditions at frequent temporal time scales but at coarse spatial resolution. While satellite remote sensing of soil moisture provides more spatially comprehensive data than can be provided by *in situ* measurements, these sensors do not have the temporal history that meteorological stations typically have, which often use a 30 year

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history or longer to establish baseline conditions to define an extreme. Indices of extremes have been found to be particularly sensitive to the record length of the meteorological stations used to calculate the indices, making the definition of a baseline a critical step in quantifying extreme conditions (Guttman, 1994; Heim, 2005; Wu et al., 2007). Satellite data have a spatial density which most networks of *in situ* sensors lack, which can be exploited to increase the number of observations in a data record. This approach, which is a variation on regional frequency analysis, uses data points pooled over a spatially homogenous area to establish a normal or baseline for a particular area, providing a broader pool of data from which to establish a probability distribution for the variable in question (Cooley et al., 2007). This method has largely been used with *in situ* measurements for applications such as flood forecasting (Cooley et al., 2007). To apply this technique to satellite surface soil moisture, a method to define homogenous regions needs to be developed to exploit this spatial density while maintaining the spatial detail that makes satellite data advantageous.

This research describes an approach to calculate an indicator of soil moisture extremes for application over agricultural regions in Canada. Extremes are defined as moisture conditions that fall at the edges of the soil moisture dynamic range for a given location and time of year. The indicator, based on passive microwave derived surface soil moisture data, was calculated using two methods of defining homogenous regions, with various sizes of regions used in the comparison. The resulting indicators were evaluated to determine how stable these were in capturing soil moisture anomalies, how representative they were of *in situ* soil moisture and agro-meteorological conditions, and which scale was most consistent with established methods to monitor moisture extremes.

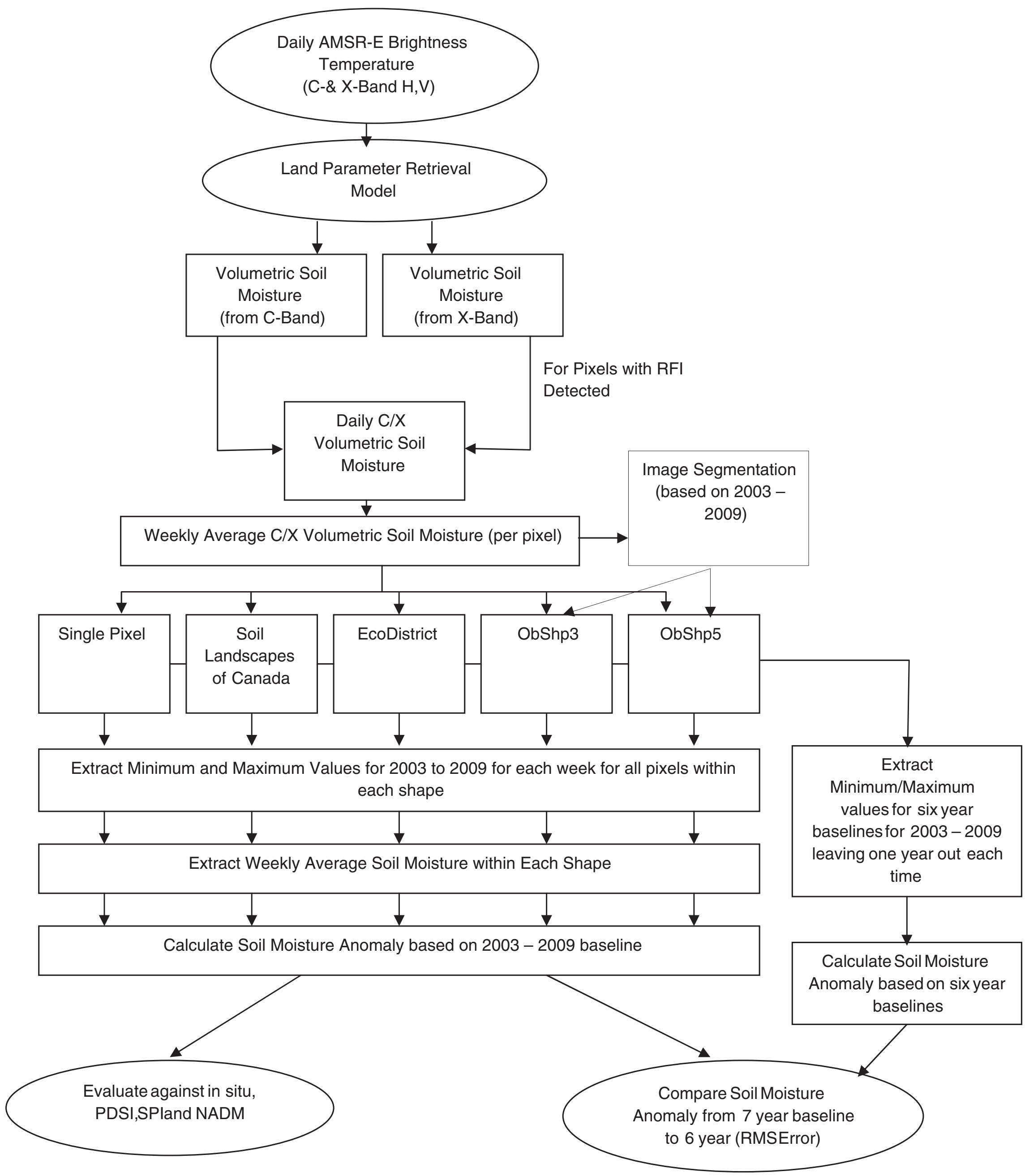

Fig. 1. Flow chart of data processing for the calculation of soil moisture anomalies.