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# Utilization of Radarsat in integrated catchment management

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**Abstract** This paper discusses the development and validation of an algorithm for extracting soil moisture data from Radarsat images in a form suitable for hydrological simulations and forecasts. A total of seven ascending Radarsat images of the Châteauguay River basin were acquired approximately at 18:00 h local time, between 2 May and 10 November 1998. Soil moisture information was extracted at the field level from Radarsat C-Band SAR using a semi-empirical radar backscatter model. Soil surface roughness was evaluated at the basin scale using a test image and assuming known soil moisture conditions. Soil moisture maps were then produced at the basin scale. These maps are then extended to the root zone using correlation functions obtained from the Richards equation, thus producing basin-scale soil moisture maps suitable for hydrological modelling purposes.
**Key words** basin scale; hydrological modelling; Quebec, Canada; Radarsat; SAR; soil moisture; soil roughness

## INTRODUCTION

Effective integrated catchment management requires tools that can describe, hindcast and forecast quality and quantity impacts on the water resource due to various changes on the catchment. The most important tool is the hydrological model to which various other models will be linked. The collection of temporal data needed to initialize such models is a complex task since it must be collected repetitively over a potentially large territory with tremendous spatial variations. For such data, remote sensing has important potential applications. The use of synthetic aperture radar (SAR) data is particularly promising because of its sensitivity to water. This paper aims at the assessment of the potential of Radarsat C-HH SAR data for deriving soil moisture estimates at the catchment scale compatible with distributed hydrological models.

# METHODOLOGY

## Extraction of soil moisture maps

Soil moisture is highly variable in both space and time and therefore has a profound influence on the hydrological response of a catchment. Some approaches have been developed to account for this spatial variability into hydrological models. A difficulty in using these approaches is to provide suitable data inputs. Synthetic aperture radar (SAR) data represent a promising avenue for monitoring soil moisture, and as such, can be very useful in hydrological modelling. However, in addition to being affected by moisture, SAR signatures are also sensitive to surface roughness, vegetation and topography. These factors tend to mask the SAR signal resulting from the hydrological variables. Several research projects have demonstrated the potential of SAR data to measure soil moisture at the field scale (e.g. Geng *et al.*, 1996; Pultz *et al.*, 1990). In particular, C-band backscatter values are affected by the occurrence of moisture in the upper 5–10 cm soil layer, with sensitivity decreasing as vegetation biomass, surface roughness, and radar incidence angle increase. Comparatively fewer studies have dealt with the determination of soil moisture at the catchment scale (Pietroniro *et al.* 1993; Rotunno Filho *et al.*, 1996).

Work presented in this paper is based on the semi-empirical model of Dubois *et al.* (1995), which predicts the backscatter response of bare fields for both copolarized HH and VV sensors as a function of the dielectric constant, surface roughness root mean square and sensor geometric properties. Constant sensor geometric properties were used herein, which reduces the model to express backscatter as a function of soil surface roughness and dielectric constant (which can be linked to volumetric soil moisture).

With data from only one sensor, surface roughness must be known in order to extract soil moisture data. In order to overcome this problem, the methodology proposed by Galarneau *et al.* (1998) is used to extract surface roughness based on the assumption that soil moisture can be accurately evaluated on a reference image. Once this is done, the computed surface roughness can then be used on other images to extract soil moisture at the basin scale.

## Estimation of root-zone soil moisture

The possibility of extracting soil moisture using C-band SAR data is generally limited to the upper 0–5 cm soil layer and can be as shallow as 0–2 cm for soils at or near saturation. However, partitioning precipitation into infiltration and runoff requires that soil moisture over the active root zone be known. In order to use Radarsat-derived soil moisture estimates in a hydrological model, it is therefore necessary to generate realistic estimates of root-zone soil moisture from surface moisture information.

In order to circumvent this problem, general soil moisture profiles were computed using the Richards equation with various combinations of soil properties, climatic conditions and percent vegetation cover. For each simulation run, the upper (0–5 cm) and the lower (root zone) average soil moisture values were extracted. Empirical (correlation) equations between upper and lower soil moisture values were produced, taking into account the factors affecting the soil water profile.

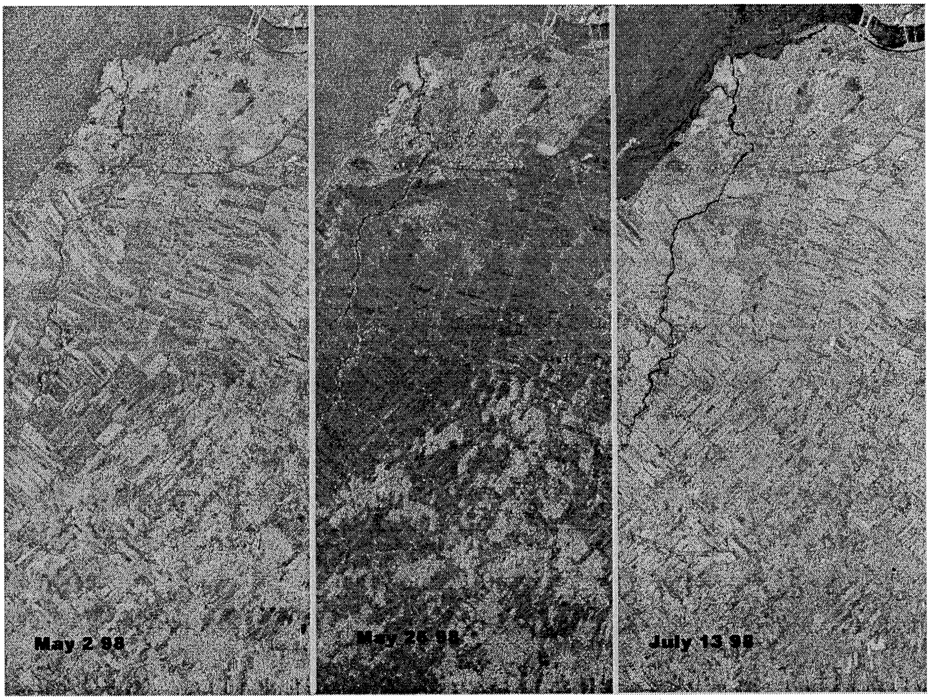


**Fig. 1** RADARSAT images of the northern part of the Châteauguay River basin.

## RESULTS

### Study site

The evaluation of the methodology is based using data from the Châteauguay River basin. The Châteauguay River flows into the St Lawrence River on the south shore of Montreal, Québec, Canada. The basin has a surface area of 2543 km$^2$ and is relatively steep and densely forested in its upper area and becomes very flat with a strong agricultural component in its lower area. The field study has been conducted in the northern, generally flat agricultural part of the basin.

### Soil moisture

A series of seven images of the Châteauguay River basin was acquired between May and November 1998. All images were in the Radarsat Standard S1 mode with a 27° incidence angle to minimize the effect of vegetation. Soil moisture was measured for the first 6 and 15 cm depth of soil using Time Domain Reflectometry (TDR) technology. A selected part of the first three images of the northern part of the basin are presented in Fig. 1. The three images present very contrasting soil conditions. On 2 May soils were humid whereas on 26 May soils were very dry in the surface following 10 days with little to no rain. The 26 May image appears much darker as a result. At the other end of the spectrum, the 13 July image is much brighter and represents near saturated soil conditions following a three-day period with heavy rain.

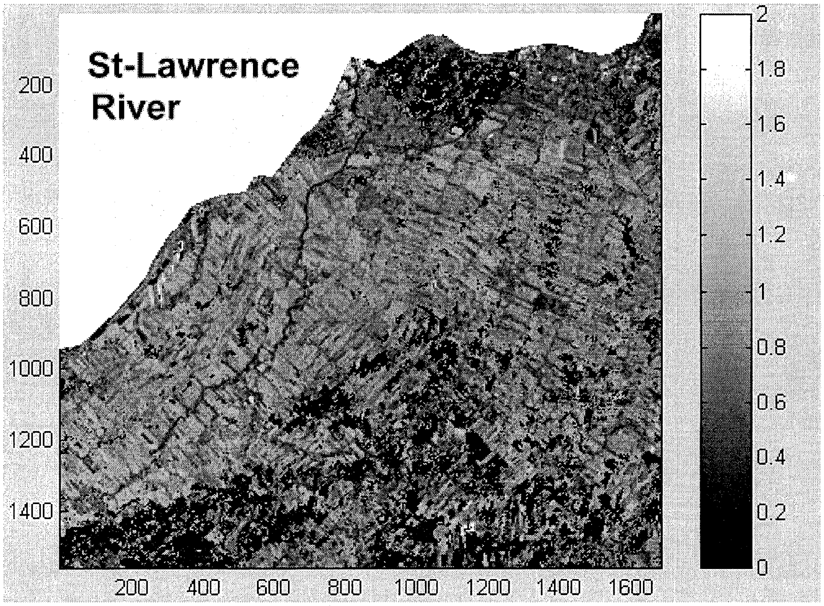


**Fig. 2** Soil surface roughness map of the Rivière des Anglais sub-watershed area. Forested areas, where the model is not applicable, are indicated in black.

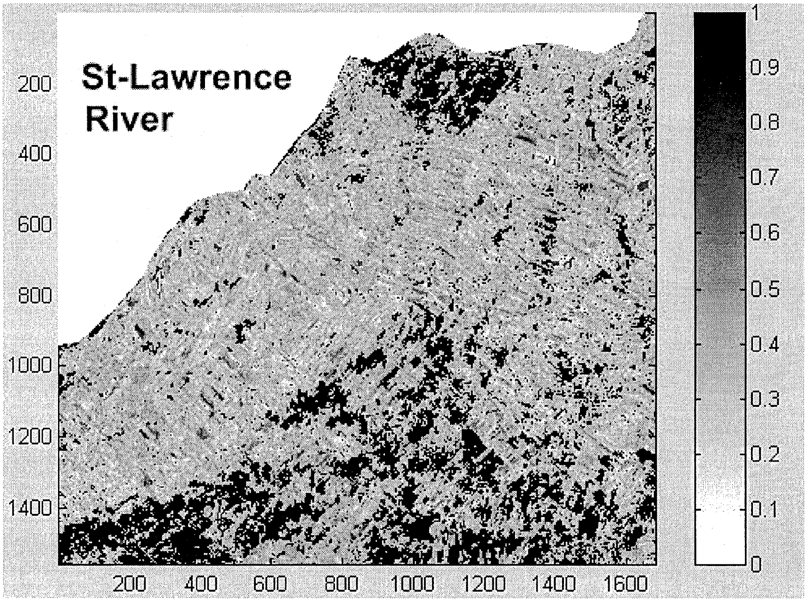


**Fig. 3** Soil moisture map for 6 August. Forested areas are shown in black.

The soil roughness map was obtained by inverting the Dubois algorithm. Inversion of the Dubois model to produce a soil surface roughness map of the Rivière des Anglais sub-basin from the 13 July image was made on a pixel-by-pixel basis assuming near saturation. The resulting soil texture map is shown on Fig. 2. Field

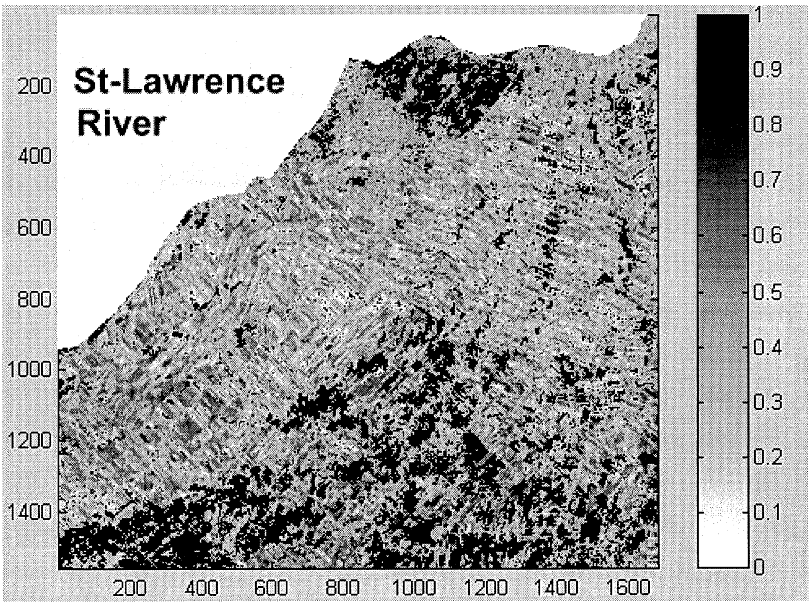


**Fig. 4** Soil moisture map for 17 October. Forested areas are shown in black.

boundaries can be clearly seen on the image. The calculated $h$ values ranged from 0.2 to 3.0 cm. The black areas correspond to forested areas, for which the model is not applicable. Using the surface roughness map, examples of soil moisture maps are presented in Figs 3 and 4. On all those maps, the black colour indicates forested areas. It is difficult to discern any spatial patterns in the soil moisture maps. This was to be expected since the topography is very flat. In such cases, surface soil moisture is affected by the local evaporation and evapotranspiration. A correlation coefficient of 0.96 with a slope of 1 is obtained between the measured average soil moisture obtained from the field measurements, against the average soil moisture obtained from averaging all the valid pixels values on the Radarsat derived soil moisture maps. This indicates a very good performance of the developed algorithm. Although there are deviations at the field scale, the Radarsat derived soil moisture at the basin scale is essentially the same as was measured.

## Estimation of root zone soil moisture

Hundreds of simulations were run in cases of low, medium and high daily potential evapotranspiration (PET), hydraulic conductivities from 1 to 60 mm $h^{-1}$ and none to moderately dense vegetation cover. Two types of relationships were investigated: the variation of the root zone soil moisture with the 0–5 cm soil moisture, and the variation of the ratio of the root/surface soil moisture with time since the last prolonged rainfall. The simulation results indicate that a correlation generally exists between surface and root zone soil moisture. This is particularly true when PET is low. This indicates that Radarsat-derived soil moistures maps can be incorporated into hydrological models.

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