Temporal Soil Moisture Estimation of Pastures from Radarsat Data For Applications in Watershed Modelling

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Abstract- **Estimating the amount of water stored in a soil profile is essential in most water management projects and for assessing the hydrologic state of a basin. It determines infiltration during a rainfall event and controls evapotranspiration between storms. Rarely, however, are soil moisture data available for model input. In many cases, particularly watershed scale monitoring or modelling, soil moisture is inferred from more easily obtainable hydrologic variables such as rainfall, runoff and temperature.**

As such, there is a strong need for procedures to estimate soil moisture in a watershed independently from the models. These procedures must provide not only basin average estimates but also the spatial distribution within a basin in order to meet the requirements of emerging distributed models. Active and passive microwave imagery are both candidate sources for these data. Active SAR imagery, with its high resolution, is particularly attractive for use in areas of mixed land cover.

This paper addresses the potential of Radarsat to extract information on soil moisture in pastures in a mixed landcover watershed located in eastern Ontario, Canada. A series of 6 Radarsat Standard Beam Mode 1 images covering the watershed for the period of September 2000 through July 2001 were analyzed in relation to ground observations, weather radar and meteorological conditions. A method was then developed to produce soil moisture maps for input to a hydrological model.

1. INTRODUCTION

Soil moisture plays an important role in streamflow modeling. It determines infiltration during a rainfall event and controls evapotranspiration between storms. Rarely, however, are soil moisture data available for model initialization or verification. Values are sometimes estimated using antecedent precipitation index methods but are more often obtained as a result of some calibration process. Thus the data are chosen to make the hydrologic model work and do not necessarily reflect reality [1,2]. There is a strong need, therefore, for procedures to estimate soil moisture in a watershed independently from models. These procedures must provide not only basin average estimates but also the spatial distribution within a basin in order to meet the requirements of emerging distributed models.

Many studies have observed a relationship between surface soil moisture and radar backscatter [3]. However surface characteristics such as landcover type and soil surface roughness influence radar backscatter. Pasture fields are attractive as repeatable targets for index fields to estimate hydrological parameters in a watershed. In contrast to cropped fields, pasture fields rarely change from year to year and their roughness characteristics and vegetation cover are less variable within the year. This makes them attractive repeatable targets for hydrological index fields in a watershed [4,5].

This paper addresses the potential of Radarsat to extract information on soil moisture in pastures in a mixed landcover watershed located in eastern Ontario, Canada. A series of 6 Radarsat Standard Beam Mode 1 images covering the watershed for the period of September 2000 through July 2001 were analyzed in relation to ground observations. A method was then developed to produce soil moisture maps for input to a hydrological model.

2. STUDY AREA AND PHYSICAL ENVIRONMENT

The study site is an area of 250 km^2 centred on the Carp River watershed, which is located west of Ottawa, Ontario. The land surface of the study area is a level to gently undulating plain of marine and moraine deposits interrupted by local bedrock uplands. The soils of the study area are characterized by a mixture of marine and silty clay, fine sandy loam, sandy loam, and gravely to very gravely loam. The drainage of these soil types varies from good to very poor [6]. The land use of the lowlands is characterized principally by small urban areas, wood lots and agricultural land. The principal crop types in the study area are corn, grains, hay and beans. Within the study site, a number of small to medium-sized wetlands are present. The upland surfaces are exposed bedrock, covered mainly by forest (coniferous, deciduous and mixed). The upland surfaces are rising 30 m to 60 m over the lowlands.

The climate of the study area is characterized by warm summers and severe winters. The mean monthly temperature in the Ottawa area is as low as -16°C in January and as high as 27°C in July. The average date of the last frost in spring is May 11, and the first frost in fall is October 1, giving an average frost-free period of 130 to 140 days (Schut and Wilson, 1987). The mean annual soil temperature is 8°C to 15°C. The soil gains heat from mid-April to early August, then looses heat from September to March. In mid-January, the frost in the soil reaches a depth of 20 cm; it drops deeper until mid-February. Average annual rainfall is 850 mm and average annual snowfall is about 2500 mm.

3.Radarsat Data

Radarsat Standard Beam Mode 1 data, having an incidence angles range of 20-27° and a resolution of 30 m, were acquired on September 22, 2000, October 16, 2000, April 27, 2001, May 20, 2001, June 13, 2001 and July 7, 2001. All of the data were acquired in the ascending orbit (south to north) at approximately 18:00 EST on any given day. The selection of this particular orbit avoided potential periods of dew on the ground that could occur on the descending orbits at 06:00.

The Radarsat data were georeferenced, using a nearest neighbor transformation, to the 1:50,000 National Topographic Data Base (NTDB) roads and hydrography vectors using PCI image analysis software. A registration accuracy of approximately 1/2 pixel (12.5 meters) was achieved in the georeferencing procedure. Bitmaps (polygons) were created for all twelve ground-sampling sites, with careful attention to capture homogenous regions and to avoid transition areas around the sites. Average Beta Naught power backscatter values were extracted under each of the twelve bitmaps for all six Radarsat images. The PCI radar backscatter and incidence angle files were then exported as a GRID format for information extraction in ESRI's ArcGIS Geographic Information Software (GIS).

4.Soil Moisture Sampling Program

Twelve relatively homogenous pastures were selected for in situ soil moisture and vegetation biomass measurements. Five sampling stations were identified and geo-referenced with a hand-held Global Positioning System (GPS) unit in each of the twelve pasture sites. The sampling stations were a minimum of 5 metres apart and within the same type of micro-terrain. Three samples were procured at each sampling station, within a 1-metre radius. This resulted in a total of 15 samples obtained from each sampling. Soil moisture values are presented in Table 1.

5.INPUT TO HYDROLOGICAL MODEL

Hydrologic models date back to the early 1970's and although hundreds of models have been developed, practically all use spatial averaging in the representation of the physical system. There are only a few models, called "*distributed*", that conceptually have a potential of maximizing returns of the remotely sensed inputs. The distributed model HYDROTEL was selected for this study [7]. HYDROTEL uses a square grid conceptualization for most of its operations. The model can also incorporate the optional concept of Homogeneous Hydrological Units (HHU's) to aggregate grid cells with similar regimes and yield a higher computational efficiency. The choice of running the model in either HHU or on a cell-by-cell mode is application dependent and is generally a function of basin size as well as the expected temporal/spatial variations. The key issue in conceptualizing the physical system is always to achieve an appropriate level of representiveness. For this study, it was decided to use the grid cell approach at a resolution of 1 km^2.

Regressions were calculated using the all of the field data and average backscatter and soil moisture for each individual date. The daily averages provide a model to estimate average soil moisture for the entire basin. Spatial variability within basin is maintained by using all of the data. The regression results are presented in Table 2.

In ArcGIS, the raster file containing the Beta Naught values for each image were manipulated to provide a product for input to the HYDROTEL hydrological model. A 1 km^2 grid vector file was created and the center UTM coordinates extracted for each grid cell within the watershed boundary. This provided a reference point for each soil moisture value extracted from the watershed.

A Landsat derived landcover classification was then used to identify the pasture areas. The pasture classification was then clustered, such that only pixels that were part of a cluster of greater than 100 pasture pixels. This clustering procedure eliminates odd pixels, which may have been misclassified. The pasture layer was then transformed to the 1 km^2 resolution by assigning the grid cell an average pasture backscatter value if at least one cluster, containing at a minimum of 100 pixels were contained in the grid cell. This resulting 1 km^2 pasture grid cell layer provided the basis to calculate the average pasture Beta Naught values for the watershed area at a km^2 resolution.

The raster calculator tool in ArcGIS was used to apply the regression equation to the 1 km^2 average pasture Beta Naught backscatter values producing soil moisture estimates. The soil moisture map data output format required for the hydrological model is an ASCII file, with one soil moisture percentage value for each 1 km^2 grid cell.

6.DISCUSSION

This paper addressed the potential of Radarsat to extract information on soil moisture in pastures in a mixed landcover

TABLE 1
Soil Moisture Conditions during Radarsat Acquisitions

2000	**2001**
Acquisition Date & Session	

	22-Sep	16-Oct	27-Apr	20-May	13-Jun	7-Jul
	1	**2**	**3**	**4**	**5**	**6**
Total Samples	180	180	180	165	165	150
Samples Retained	174	172	175	156	160	144
Number of Pastures Sampled	12	12	12	11	11	10
Maximum	44.4%	44.4%	54.5%	45.9%	32.1%	27.2%
Minimum	30.2%	28.4%	22.5%	11.6%	9.3%	15.9%
Average	36.1%	34.3%	38.2%	21.7%	19.1%	20.1%
Standard Deviation	4.0%	4.6%	8.4%	9.4%	6.8%	3.8%

TABLE 2
Regression Results

Data Set	No of cases	Multiple R	R2	Equation
Average soil moisture (%) and Backscatter (dB) by date	6	0.908	0.825	y = -8.49 - 9.46 (Vol SM)
Backscatter (dB), Incidence Angle, Field soil moisture (%)	68	0.651	0.424	y = 15.76 + 7.72 (Vol SM) - 1.04 (incd)

watershed located in eastern Ontario, Canada. Regression analysis was performed between Radarsat backscatter and soil moisture in pasture fields. Regressions were calculated using Radarsat backscatter and soil moisture for each individual pasture (r = 0.651, n = 68) as well as daily averages of backscatter and pasture soil moisture (r = .908, n = 6). Pasture fields were identified using a Landsat TM classification and a 1 km^2 grid was used to segment the watershed for input to the HYDROTEL hydrological model. The regression equation was applied to the 1 km^2 average pasture Beta Naught backscatter values producing soil moisture estimates. This 1 km^2 grid pasture soil moisture map is then used for input to the hydrological model. Model performance results will be presented at the time of the conference.

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