Polarimetric C-Band Observations of Soil Moisture for Pasture Fields

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ABSTRACT - **Soil moisture information is an important parameter in hydrological modelling, although providing reliable data is difficult due to its spatial variability and dynamic nature. The ability to estimate soil moisture from Synthetic Aperture Radar (SAR) has been the topic of numerous investigations. To date, most of these investigations have been limited to single or multiple linear polarized configurations. However, Radarsat-2 will be launched in 2004 and will have fully polarimetric C-Band SAR capability.**

In preparation for a new generation of spaceborne polarimetric SARs, Environment Canada's Convair 580 airborne polarimetric C-band SAR acquired data over an agricultural area west of Ottawa, Canada on September 22, 2000, April 26, 2001 and May 20, 2001. Coincident ground measurements (soil moisture, biomass, and surface roughness) were collected over pasture on all dates and bare fields in the spring of 2001. Analysis includes linear polarizations ($\sigma°_{HH}$, $\sigma°_{VV}$, $\sigma°_{HV}$), circular polarizations ($\sigma°_{RR}$, $\sigma°_{RL}$, $\sigma°_{LL}$), as well as fully polarimetric parameters such as pedestal height, total power, phase difference, and polarimetric signatures. This paper presents preliminary results of the September 22, 2002 data.

I. INTRODUCTION

Remote sensing technology has been utilized to provide repeat measurements over large spatial areas; essential elements for environmental monitoring activities such as hydrological modelling. The high spatial and temporal variability of soil moisture makes this parameter difficult to measure using traditional ground point measurements. Radar remote sensing has all weather capabilities and is sensitive to moisture, therefore SAR data have been used to acquire information on hydrological parameters. Many researchers have studied the relationship between radar backscatter and soil moisture, however most studies have used single or multi-polarized data [1]. The difficulty involved in acquiring fully polarimetric data sets, due to the small number of acquisition systems, as well as the complexity of the data itself, have limited the research in this area.

II. STUDY AREA

The Mississippi River watershed, located just west of Ottawa, Canada, incorporates approximately 4,000 km^2 of contributing surface area. The Carp River watershed, one of the larger sub-watersheds within the Mississippi, covers a ground area of 1400 km^2. This sub-watershed has been the focus of many hydrological studies due to the mix of land cover (pasture, forest, agriculture, wetlands), and the availability of meteorological stations in the basin. Selection of pasture and bare field sites took into consideration the size of the field (minimum of 100 pixels), as well as the homogeneity of the surface topography and vegetation (pasture). A total of 12 pasture sites were selected distributed throughout the basin as seen in Figure 1.

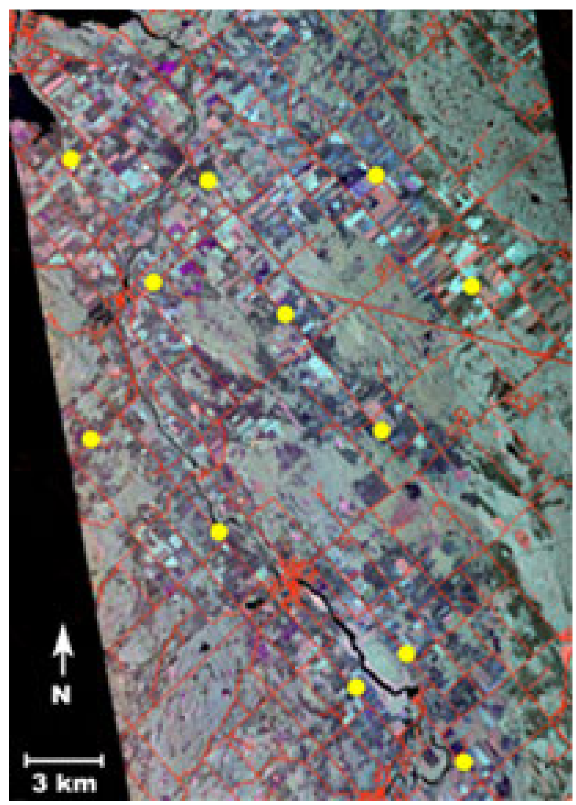

Figure 1 Image of September 22, 2002 Convair SAR data, with sampling site location
(Red – HH, Green – HV, Blue – VV)

III. Data acquisition

Environment Canada's Convair 580 aircraft was employed to acquire C-band (5.3 GHz) polarimetric data with incidence angles range from 30 to 65 degrees. Data was processed and calibrated with CCRS software, to produce a 6-meter resolution image product, with a calibration accuracy of one decibel [2]. Polarimetric information was also extracted using CCRS software to generate C-band polarimetric parameters and co-polarization plots for each pasture site. The list of parameters generated include: $\sigma°_{HH}$, $\sigma°_{VV}$, $\sigma°_{HV}$, $\sigma°_{RR}$, $\sigma°_{RL}$, $\sigma°_{LL}$, co-polarized pedestal height, total power, and co-polarized phase difference. A total of three image dates have been acquired in the fall and spring of 2000/2001, however due to the complexity and intensity of data processing, only the September 22, 2001 has been analyzed to date.

Extracting target information from radar polarimetry is based on the control of the polarimetric properties of radar wavelengths and the measurement of reflected energy [3]. Linear co-polarized values (HH, VV) represent the amount of energy received at the antenna in the same polarization as transmitted (after interaction with the target). The linear cross-polarized parameters (HV, VH) represent the amount of energy from the transmitted linear wave (H or V) that has been changed from the original orientation, or re-polarized into the orthogonal polarization (V or H) [4]. The HV and VH responses are assumed to be equal due to the theory of reciprocity and therefore only HV will be analysed in this study. Pedestal height increases with significant volume and multiple scattering and is a measure of the unpolarized wave component [5].

Coincident ground measurements of volumetric soil moisture (TDR and gravimetric samples), weather conditions, and biomass were taken for each data acquisition. For each study site, 3 soil moisture samples were taken at 5 locations within the field, for a total of 15 volumetric soil moisture samples per pasture. Only the 12 pasture sites were sampled on the September 22, 2001 data acquisition; however for the two spring acquisitions, the 12 pasture and 10 bare fields sites were sampled.

IV. Results

Table 1 presents the polarimetric parameters for the pasture sites. The analysis of the co-polarization plots, linear
and circular polarizations, as well as other polarimetric parameters show very similar results over all the pasture site sites. Due to the common land cover type (pasture), similar moisture and weather conditions (single date), the radar responses for these sites are expected to be similar. Linear co-polarized backscatter ($\sigma°_{HH}$, $\sigma°_{VV}$) exhibit similar values, within 1.4 dB of each other, whereas the cross-polarized backscatter ($\sigma°_{HV}$) is approximately 7.5 dB lower. For the circular polarizations, $\sigma°_{RR}$ and $\sigma°_{RL}$ are within 1 dB, and the $\sigma°_{RL}$ are within 2 db of the $\sigma°_{RR}$ and $\sigma°_{LL}$ values.

The ranges of polarimetric values between the sites are minimum, within one standard deviation of the mean. There appears to be little difference in the linear and circular polarizations between sites with higher soil moisture (44%) and sites with lower soil moisture (31%); although the soil moisture range is quite small, only 14% difference in volumetric soil moisture between the sites on September 22, 2001 acquisition. The pedestal height parameter varies only slightly between the sites, and with an average value of 0.45. Volume scattering is occurring in the target from the soil and the vegetation. The polarization plots for the pasture sites also show similar results and structure. A normalized co-polarization plot is presented in Figure 2. These plots are taken from site F, and represent the average structure of the polarimetric plots for the pasture sites.

Of the major contributors to radar backscatter from the target parameters, incidence angle is one that has not yet been considered in this investigation. The surface roughness effect is minimized as the vegetation in the pasture fields remains relatively stable throughout the year, and all the pasture fields have been chosen to represent similar vegetation species and biomass volumes. The study sites are distributed over a range of incidence angles, which should be considered when analyzing the results.

V. Conclusions

With all other factors stabilized, an increase in dielectric constant will produce an increase in radar backscatter. Only small differences in radar backscatter are seen from all the pasture sites examined. This is an expected result, as all pastures have similar vegetation cover and biomass characteristics. As well, only a small range of soil moisture (14%) existed during the September 22, 2002 acquisition date. As the other acquisition dates are processed, a wider range of soil conditions (% of soil moisture) will be examined. Also, an incidence angle correction factor may be necessary as the sites are distributed over a wide range of incidence angles.

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TABLE 1
Polarimetric Data for September 22, 2001 Pasture Study Sites

Sites	Incidence Angle	Beta Nought Radar Backscatter						Pedestal Height	Soil Moisture
		HH	HV	VV	RR	RL	LL		
Site A	41.1	-12.98	-21.01	-14.43	-16.31	-15.6	-16.23	0.44	39.8%
Site B	59.7	-13.87	-21.78	-14.57	-16.91	-16.13	-16.98	0.49	35.2%
Site C	44.5	-12.85	-21.18	-14.25	-17.54	-14.64	-17.36	0.33	40.7%
Site D	55.6	-13.85	-20.86	-14.36	-17.23	-15.53	-17.15	0.46	44.4%
Site E	51.9	-13.03	-21	-13.63	-16.32	-15.09	-16.24	0.46	35.0%
Site F	49.7	-12.84	-20.18	-13.5	-16.49	-14.63	-16.1	0.43	38.1%
Site G	58.0	-14.78	-21.56	-15.05	-17.65	-16.66	-17.4	0.5	33.8%
Site H	34.5	-7.64	-15.08	-9.35	-10.14	-10.87	-10.45	0.46	38.3%
Site I	53.8	-11.69	-19.1	-11.49	-14.71	-13.29	-14.45	0.48	31.4%
Site J	49.0	-14.09	-22.02	-14.86	-17.72	-16.01	-17.66	0.43	30.2%
Site K	56.8	-12.22	-19.32	-13.11	-15.77	-14.16	-15.4	0.44	34.2%
Site L	60.2	-15.23	-22.31	-15.28	-18.13	-17.03	-17.87	0.5	35.8%
	Mean	-12.92	-20.45	-13.66	-16.24	-14.97	-16.11	0.45	0.36
	St Dev.	1.95	1.96	1.70	2.15	1.67	2.04	0.05	0.04

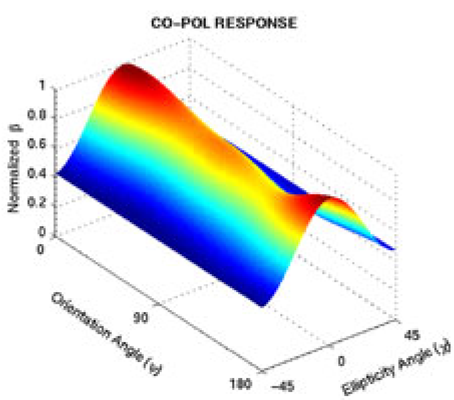

Fig. 2. Co-polarization plot for September 22, 2001 site F.

REFERENCES

[1] Engman, T.E. and N. Chauhan. "Status of microwave soil moisture measurements with remote sensing", in the Remote Sensing of Environment, 51, pp. 189-198, 1995.
[2] Hawkins, R.K. *et al.* "Polarmetric calibration results and error budget for SAR-580 system", in SAR Workshop: CEOS Working Group on Calibration and Validation, pp. 699-704, 1999.
[3] Boerner W.M., *et al.* "Polarimetry in radar remote sensing: basic and applied concepts, principles and applications of imaging radar", in Manual of Remote Sensing, edited by F.M. Henderson and A.J. Lewis, pp. 280-320,1998.
[4] McNairn, H., *et al.* "The effect of soil and crop residue characteristics on polarimetric radar response", in Remote Sensing of Environment, 80, pp. 308-320, 2001.
[5] Van Zyl, J.J., *et al.* "Imaging radar polarization signatures: theory and observation, in Radio Science, 22, pp. 529-543, 1987.