ENVIRONMENTAL EFFECTS ON RADAR DATA OF AGRICULTURAL AREAS

B. Brisco, D. Bedard, and J. Naunheimer
Intera Information Technologies, Inc.,
2 Gurdwara Rd., Suite 200
Nepean, ON K2E 1A2
Tel: (613) 226-5442
Fax: (613) 226-5529

R.J. Brown
Canada Centre for Remote Sensing
588 Booth Street
Ottawa, ON K1A 0Y7
Tel: (613) 947-1263
Fax: (613) 947-1385

ABSTRACT

Timeliness is an important characteristic of data use within many agricultural applications. Synthetic Aperture Radar (SAR) is therefore an attractive source of data as these sensors can acquire imagery regardless of the presence of clouds or the lack of sunlight. This all-weather, day or night data collection capability of SAR also implies that these data may be acquired under different environmental conditions. This can have a significant effect upon the information content within these data. In this paper, the effects of rain, dew, time of day, and wind (or storm damage) on radar data of agricultural environments are reviewed. SAR data acquired under different environmental conditions may be used independently to monitor a particular event, such as to track storm damage, or it may be used synergistically with other data. The implications of these effects on agricultural applications are also reviewed with respect to Radarsat and other spaceborne SAR platforms.

RÉSUMÉ

Le facteur temps revêt une importance considérable pour l'acquisition des données utilisées dans nombre d'applications agricoles. Voilà pourquoi le radar à ouverture synthétique (ROS) constitue une source intéressante de données; ses capteurs sont en effet capables d'acquérir de l'imagerie même si le ciel est nuageux ou si le temps est sombre. Cette capacité de fonctionner par tous les temps, de nuit comme de jour, permet aussi au ROS d'être efficace dans diverses conditions ambiantes, ce qui peut avoir un effet considérable sur le contenu des données. L'auteur de cet article passe en revue l'incidence de la pluie, de la rosée, de l'heure du jour et du vent (ou des dégâts causés par les tempêtes) sur les données radar relatives aux zones agricoles. Les données ROS acquises dans diverses conditions peuvent être utilisées soit séparément pour surveiller un événement particulier, notamment pour évaluer les dégâts causés par une tempête, soit en combinaison avec d'autres données. L'auteur examine en outre l'incidence des facteurs susmentionnés sur les applications agricoles du Radarsat et des autres plates-formes ROS spatiales.

INTRODUCTION

Synthetic Aperture Radar (SAR) imagery has been studied for about 15 years in Canada for a wide range of applications including agriculture. The upcoming launch of Radarsat in 1995 and the supporting Radar Data Development Program (RDDP) have provided the impetus and framework to do the research and development necessary to effectively utilize this technology. The timely nature of SAR data acquisition is very attractive for agricultural applications, which generally require quick data turnaround due to the dynamic characteristics of crops and soils. Consequently, considerable work has been done by Canadian scientists in the area of radar applications for agriculture.

Due to the sensitivity of microwaves to water (plant and soil moisture, as well as free water) and crop canopy geometry, environmental effects due to weather events can have a significant impact on radar backscatter. The all weather, day or night capability for radar data acquisition and this sensitivity to environmental conditions means there is considerable potential to obtain radar data with significant and different environmental effects. This data may be used directly for environmental monitoring and impact assessment. SAR data acquired under different environmental conditions, such as before and during (or after) a rainfall, may also be used synergistically to increase the information content for a particular application. It is also important to understand the environmental affects on the "all-weather" radar data as it could impact on the uses of the data. For example, a rainfall just prior to image acquisition might limit the use of that data for monitoring vegetation condition. This paper reviews rainfall, dew, time of day, and wind (or storm) damage effects on radar backscatter from cultivated areas.

Specifically, the objectives of this study were twofold. The first objective is to evaluate the effect of changing environmental conditions on radar data information content for agricultural applications. Secondly, we want to evaluate the ability of radar data to determine the location and extent of damage or impact to cultivated areas caused by factors such as hail, wind, dew, etc..

EFFECTS OF RAINFALL AND DEW ON RADAR DATA

Seasat provided the first dramatic evidence of the sensitivity of spaceborne SAR data to rainfall and the resulting increase in free canopy water and soil moisture (Ulaby et al., 1983). The areas with higher moisture content caused increased radar backscatter and subsequently brighter areas on the image. This study demonstrated the improved spatial mapping of rainfall events with spaceborne SAR data when compared to ground-based weather station observations. The feasibility of soil moisture estimation with radar data has long been recognized (Ulaby et al., 1974) with an example of quantitative estimates of soil moisture from SAR imagery provided by Pultz et al., (1990). A detailed review by Dobson and Ulaby (1986) can be referred to for more details on the suitability of different radar configurations and the effects of surface roughness and vegetation on the radar sensitivity to soil moisture.

Another aspect of the effects of rain on SAR imagery relates to crop identification and monitoring. Several studies have shown that the overall crop classification decreases with increased soil moisture content (Shanmugan et al., 1981; Shanmugan et al., 1983; Paris, 1983). However, Brisco et al., (1989) and Fischer et al., (1992) show that some crops can exhibit improved separability on SAR imagery when free water is in the canopy or under different soil moisture regimes. Both studies reported better grain separability in data acquired during or just after a significant rainfall (greater than 10 mm). Fischer et al., (1992) also found better hay separability when the soil was wet, improved corn and pasture separability from other crop types under moist soil conditions, and increased soybean discrimination with dry soil moisture conditions. The crops considered in this study were corn, soybeans, grain, hay and pasture. The 0-5 cm volumetric soil moisture content ranged from greater than 35 % (ie. near saturation) for the wet soil condition to approximately 15-25 % for the drier soil condition. The Fischer et al., (1992) study also reported overall classification accuracy increasing by about 15 % when using all the SAR data acquired under the different environmental conditions. In a similar approach using ERS-1 data Weydahl (1992) suggests using wet and dry SAR data for monitoring tillage events for soil conservation monitoring applications. This is because the "dry" SAR data discriminates harvested from non-harvested fields while the "wet" SAR data may help to distinguish residue covered fields from bare surfaces because of enhanced dielectrical differences. The bare soils are most susceptible to erosion.

Studies have been conducted with calibrated ground-based scatterometers in order to quantify the effects of rain on canopy backscatter. Allen and Ulaby (1984) measured a 2-3 dB increase in X-band backscatter from wheat, corn, and soybean canopies after artificially spraying the canopies with water to simulate rainfall. They concluded that more experimental data are required to study the effects of varying system parameters and crop development on the radar response in order to account for these types of environmental effects in model development and validation. Sofko et al., (1989) also reported significant increases in radar backscatter from a wheat canopy during a rain event. They found about 2-4 dB increases in canopy backscatter after the rain with like polarization being more sensitive than cross polarization and that the change in backscatter was greater at L-band than Ku-band. The lower frequency penetrates a greater crop volume and thus the soil contribution can also increase the backscatter whereas the higher frequency is just responding to canopy conditions.

In general, the magnitude increase in backscatter varies from crop to crop with lush crops showing less increase than sparser crops which reduces the dynamic range of the scene. This tends to decrease overall crop discrimination but, as shown above, but can sometimes increase the identification accuracy of a particular crop. Additional studies with spaceborne SAR's will greatly increase our knowledge of this phenomenon.

Dew can have a very similar effect to rainfall on the backscatter from crop canopies. Gillespie et al., (1990) reported 2-4 dB increases in S° from a wheat field following a dew event. The best detection of the dew event was C-HH at 20 degrees incidence with a view direction parallel to the crop's row direction. This ability to monitor dew events has exciting potential for agrometeorology and pest management applications as well as the improvement in crop separability when combined with "dry" data as mentioned above. Dew is a mechanism for some types of pest dispersal and thus more effective management could be delivered if the spatial distribution of an important dew event (ie. during a disease outbreak) could be provided.

In summary both rain and dew increase the radar backscatter of agricultural targets with some sensitivity to the radar configuration. This response can be used to extract information about the weather event itself from SAR data or it can be used to obtain different information for other applications such as conservation farming or crop identification.

DIURNAL EFFECTS ON RADAR DATA

Diurnal fluctuations in radar backscatter related to movement of water in the plant/soil system as a response to the diurnal sun cycle have been measured by Ulaby and Batlivala (1976) and Brisco et al. (1990). Ulaby and Batlivala (1976) measured grain sorghum fields, which had been flood irrigated, several times during several 24 hour periods in order to monitor the changing soil moisture. Changes of up to 5 dB not related to the soil drying were attributed to plant effects. Brisco et al. (1990) measured the diurnal radar backscatter of a wheat field during vegetative and more mature growth stages. They found higher correlations of radar backscatter with plant moisture early in the growing season and with soil moisture when the vegetation was at a lower moisture content. Way et al. (1991) have also reported large diurnal variations in the dielectric properties of walnut trees with subsequent changes in radar backscatter. Weber and Ustin (1991) describe the diurnal water relations of walnut trees and the implications for remote sensing.

This diurnal change in radar backscatter will be important to account for when using SAR data from a combination of daytime and nighttime acquisitions (for example ascending versus descending orbits from ERS-1). It may add to calibration uncertainties and to increased errors in models using SAR data to estimate geophysical parameters such as soil moisture. Additional research may also show how this diurnal radar backscatter change may provide information about the targets condition as well.

EFFECTS OF WIND AND STORM DAMAGE ON RADAR DATA

Wind and rain can cause reorientation of the canopy constituents which can alter the canopy geometric characteristics in addition to changing the dielectric properties. Measurements made with ground-based scatterometers have observed wind and rain effects on small grain canopies like wheat, barley, and rye (Van Kasteren, 1981; Allen and Ulaby, 1984; Ulaby et al., 1986; Bouman, 1988). Wind effects cause larger variations in radar backscatter than data acquired under calm conditions. This can lead to problems with both modelling and classification approaches to extracting information from the radar data as the variance in the target of interest is increased. Sometimes the wind effects are negligible however, and in some cases may even improve the estimate of S° by providing more independent samples by moving the scatterers in the crop canopy, which then reduces fading (Allen and Ulaby, 1984). In general, canopy dielectric properties are influenced by the presence of rain droplets while blow-down areas and wind damage create geometric changes in the canopy orientation. Thus weather effects such as hail damage, blow-down or lodging in grain crops, and the addition of water to both the canopy and the soil can affect the radar data.

SUMMARY

A review of environmental influences on radar data demonstrates that rain, dew, diurnal, and wind/storm related effects can cause significant changes in radar backscatter. The potential for these events to be "captured" in SAR data is increasing due to current spaceborne SAR's such as the European Earth Resources Satellite (ERS-1) and the Japanese Earth Resources Satellite (JERS-1) with their multi-temporal coverage and twice daily site coverage. The impending Shuttle Imaging Radar (SIR-C) project and aircraft programs using systems with versatile configurations can be used to increase our understanding of the influence of system parameters on these applications. Radarsat will also be useful to study or operationally monitor environmental events with its multi-mode, multi-beam capability. The multi-mode functionality will allow for large area, low resolution studies or applications with SCANSAR and higher spatial detail investigations with the fine resolution mode. The multi-beam capability will allow for a quick revisit schedule (3 days for most of Canada) providing incidence angle, which could range from 20 to 50 degrees, is not of critical importance to the application. By the EOS (Earth Observing System) timeframe effective environmental monitoring with SAR data may be common or even routine.

REFERENCES

Allen, C.T., and F.T. Ulaby, 1984, "Characterization of the Microwave Extinction Properties of Vegetation Canopies", Radiation Laboratory Technical Report, The University of Michigan, Ann Arbor, MI, 48109.

Bouman, B.A.M., 1988, "Microwave backscatter from beets, peas, and potatoes throughout the growing season", **Spectral Signatures of Objects in Remote Sensing**, Aussois, France", January 18-22, pp. 25-30.

Brisco, B., Brown, R.J. and Pultz, T.J., 1989, "The effects of free canopy water on crop separability", **Proceedings of IGARSS '89/12th Canadian Symposium on Remote Sensing**, Vancouver, B.C. July 10-14, pp. 424-428.

Brisco, B., R.J. Brown, J.A. Koehler, G.J. Sofko, and M.J. McKibben, 1990, "The Diurnal Pattern of Wheat Radar Backscatter", **Remote Sensing of Environment**, V. 34, pp. 37-47.

Dobson, M.C., and Ulaby, F.T., 1986, " Active Microwave Soil Moisture Research", **IEEE Transactions on Geoscience and Remote Sensing**, Vol. GE-24, pp 23-36.

Fischer, J.A., R.J. Brown and B. Brisco, 1992, "The Effects of Changes in Soil Moisture and Rainfall on SAR Data Crop Classification", **Proceedings of the Fifteenth Canadian Symposium of Remote Sensing**, Toronto, Ontario, pp 221-226.

Gillespie, T.J., B. Brisco, R.J. Brown, and G.J. Sofko, 1990, "Radar Detection of a Dew Event in Wheat", **Remote Sensing of Environment**, Vol. 33, pp. 151-156.

Paris, J.F., 1983, "Radar Backscattering Properties of Corn and Soybeans at Frequencies of 1.6, 4.75, and 13.3 GHz, **IEEE Transactions on Geoscience and Remote Sensing**, Vol. GE-21, pp. 392-400.

Pultz, T.J., R. Leconte, R.J. Brown, and B. Brisco, 1990, "Quantitative Soil Moisture Extraction from SAR Data", **Canadian Journal of Remote Sensing**, V.16(3), pp.56-62.

Shanmugan, K.S., F.T. Ulaby, V. Narayanan, and C. Dobson, 1981, "Crop Classification Using Multidate/Multifrequency Radar Data", Remote Sensing Laboratory Technical Report 360-17, The University of Kansas, Lawrence, KS, 66045.

Shanmugan, K.S., F.T. Ulaby, V. Narayanan, and C. Dobson, 1983, "Identification of Corn Fields Using Multidate Radar Data", **Remote Sensing of Environment**, Vol. 13, pp. 251-264.

Sofko, G., J. Sloboshan, M. McKibben, J. Koehler, and B. Brisco, 1989, "Variation of Microwave Radar Cross-Section of Wheat During the Initial Hours of a Rainfall", **International Geoscience and Remote Sensing Symposium / 12th Canadian Symposium on Remote Sensing**, Vancouver, B.C., July 10-14, pp. 1191-1194.

Ulaby, F.T., J. Cihlar, and R.K. Moore, 1974, "Active Microwave Measurement of Soil Water Content", **Remote Sensing of Environment**, Vol. 3, pp. 185-203.

Ulaby, F.T. and P.P. Batlivala, 1976, Diurnal Variations of Radar Backscatter from a Vegetation Canopy, **IEEE Transactions on Antennas and Propagation**, Vol. AP-24(1), pp. 11-17.

Ulaby, F.T., B. Brisco, and M.C. Dobson, 1983, "Improved Spatial Mapping of Rainfall Events with Spaceborne SAR Imagery", **IEEE Transactions on Geoscience and Remote Sensing**, Vol. GE-21, No. 1, January, pp. 118-121.

Ulaby, F.T., Moore, R.K. and Fung, A.K., 1986, "Microwave Remote Sensing: Active and Passive", Vol. III, Artech House, Inc., Norwood, MA.

Van Kasteren, H.J.W., 1981, "Radar Signatures of Crops. The Effect of Weather Conditions and the Possibility of Crop Discrimination with Radar", **Proceedings of Spectral Signatures of Objects in Remote Sensing**, Avignon, France.

Way, J., J. Paris, M.C. Dobson, K. McDonald, F.T. Ulaby, J.A. Weber, S.L. Ustin, V.C. Vanderbilt, and E.S. Kasischke, 1991, "Diurnal Change in Trees as Observed by Optical and Microwave Sensors: The EOS Synergism Study", **IEEE Transactions on Geoscience and Remote Sensing**, Vol. 29, No. 6, pp. 807-821.

Weber, J.A., and S.L. Ustin, 1991, "Diurnal Water Relations of Walnut Trees: Implications for Remote Sensing", **IEEE Transactions on Geoscience and Remote Sensing**, Vol. 29, No. 6, pp. 864-874.

Weydahl, D.J., 1992, "Temporal Change Detection in ERS-1 SAR Images", **International Geoscience and Remote Sensing Symposium Proceedings**, Houston, Texas, May 26-29, pp. 1346-1348.