031608-F

Polarimetric Radar Observations of Forest State for Determination of Ecosystem Process

Final Report

Technical Report 031608-F, 026511-F

JPL Grant: JPL-951869

Submitted To: Gregory T. Rosalia
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Submitted By: Dr. Fawwaz T. Ulaby
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1.0 Introduction 1

2.0 Research Objectives and Goals 1

3.0 Summary of Research Results 2

4.0 Students Supported and Publications 3

4.1 Journal Publications.. 4

4.2 Symposia and Workshops 6

4.3 Technical Reports 12

1.0 Introduction

This is the final report for research funded by NASA under JPL Grant JPL-951869 during the period March 30, 1989 to March 31, 1999. This report briefly presents (1) the objectives of the research, (2) a summary of the research effort and the technical results, and (3) listings of the students supported and the publications resulting from this effort. This project supported the efforts of 22 graduate students and resulted in the publication of 5 Ph.D. dissertations, 20 journal articles and 82 presentations at symposia and workshops. In addition, we gave over 20 interviews with print and broadcast journalists during the SIR-C/X-SAR mission. We also supported SIR-C educational outreach activities in conjunction with the SIR-C Ed program, the Ann Arbor Public Schools and two summer field programs for high school students supported by the Durfee Foundation through Earthwatch and the Johns Hopkins Center for Talented Youth.

2.0 Research Objectives and Goals

The goal of this research has been to determine to what extent the polarimetric orbital SIR-C/X-SAR system could ascertain several ecologically significant parameters of forest state. These include aboveground biomass, plant water status, and near-surface soil moisture. The objectives of the research were to establish theoretically the expected sensitivities, to experimentally validate and/or refine these expectations, and to develop and test inversion algorithms for estimation of biomass and moisture-related quantities. Test sites were chosen to be in Northern Michigan at the ecotone of the boreal and temperate forest such that a wide diversity of vegetation communities would be treated and thereby enhance the probability that the results would be geographically robust.

In order to accomplish these goals, the study was conducted in three phases. In the first phase, the dielectric and geometric properties of selected forest canopies were monitored on a diurnal and seasonal basis. These properties were then used by the MIMICS model to simulate radar backscatter as functions of frequency, polarization and angle of incidence. The simulation results were used to (1) determine experimentally testable hypotheses, (2) establish the experimental sampling protocols and procedures, and (3) create a simulated database for development and testing of inverse algorithms.

The second phase consisted of development and execution of airborne SAR experiments using the JPL AirSAR at test sites in Northern Michigan. Two principal test sites were established. A test site at the University of Michigan Biological Station at Douglas Lake near Pellston, Michigan was overflown a number of times in 1990. AirSAR data were acquired as a function of viewing geometry for several seasons and weather conditions. An additional test site was established at the eastern end of Michigan's Upper Peninsula. The landscape of this area is characterized by large patch sizes and is therefor ideal as a SIR-C/X-SAR test site. This area was also overflown by the JPL AirSAR a number of times to examine seasonal effects on dielectric and geometric properties that determine radar backscatter.

The third phase consisted of activities related to conduct of the SIR-C/X-SAR mission itself with flights in April and October of 1994 and subsequent analyses of the data. The analyses focussed upon (1) land cover classification and determination of community structure, (2) estimation of forest biophysical attributes such as tree height, diameter and stocking density, and (3) estimation of aboveground biomass, total carbon and monitoring of forest disturbances.

3.0 Summary of Research Results

In the first phase of this study we developed canopy scattering models and evaluated the models on the basis of data collected by the University of Michigan truck-mounted polarimetric scatterometer and the JPL AirSAR. These data sets consisted of measurements of both agricultural canopies such as corn, alfalfa and grasses and forest canopies of both needle-leaf and broadleaf trees. These models are presented in the Ph.D. dissertations of Kyle McDonald, Michael Whitt, Paul Polatin, and James Stiles. These models, inverse formulations and retrieval algorithms based upon model simulated databases have been extensively presented and published as listed in Section 4.

The second phase of the study examined the spatial and temporal behavior of radar backscatter from forest canopies observed by the JPL AirSAR during a large number of overflights beginning in 1990. We examined the within-class and between-class variance of radar response to various land-cover classes and forest types. The dependence of backscatter on structural properties (geometry) of the scene was exploited to develop a series of classification algorithms. We published upon use of supervised and unsupervised Bayesian, knowledge-based, and neural network classifiers. Superior results were achieved for hierarchical, physiognomic classification schemes using multifrequency and polarimetric data. We also examined the temporal variations in backscatter arising from seasonal changes in phenology and plant dielectric properties and from weather related effects such as temperate, cloud-cover and precipitation (rain and snow). These studies consisted of field measurements of the dielectric and geometric properties in conjunction with AirSAR flights. Analyses of the data showed that short wavelengths (i.e., C-band) are most affected by phenologic changes in the forest crown-layer while longer wavelengths (i.e. at P- and L-band) are most affected by changes in the dielectric properties of the trunk layer. Rainfall effects were found to be negligible at P-band, but become significant (up to 3-dB) at shorter wavelengths and the effects are dependent upon vegetation class. Consequently, SAR-based land-cover classification is weather independent only for very simple high-level categories (i.e., water, bare soil, short vegetation, trees, urban); tests of simple classifiers were found to yield high accuracy results (better than 90%) when the same decision rules were applied to different dates and different sites. However, the temporal variance of backscatter leads to non-robust algorithms for classification of forest types at the community level. At any given time, classification results were found to generally exceed 90% accuracy, but the decision rules are not stable with time if phenology has changed seriously (i.e., leaf-on and leaf-off) or if there is intercepted precipitation on the foliage. The results on the effects of forest structure and dielectric variations on radar backscatter and classification have been widely presented at symposia and published.

The third phase of the study developed and tested approaches to retrieve forest biophysical parameters from SAR-data. Prototype algorithms were developed and tested using AirSAR data acquired at the Duke Forest, Landes and Michigan test sites. Careful attention was paid to the calibration of the data and cross-calibration experiments were conducted linking the University of Michigan truck-mounted scatterometer the JPL AirSAR and the SIR-C/X-SAR instrument to reference targets (point targets and distributed targets). A multi-year effort at the Michigan test site provided what is probably the most detailed set of ancillary data ever on forest structural attributes. The strength of this data-base and antecedent

AirSAR experience allowed us to apply prototype algorithms to the very first data take of both the SRL-1 and the SRL-2 missions and create products within less than 24 hours of data acquisition. The products included land-cover classification, tree height, basal area and above ground biomass.

Subsequent analysis of the SIR-C/X-SAR data set examined the dependence of land-cover classification and retrieval of forest biophysical attributes (1) on scene properties such as season (spring vs. fall) and snow, wet snow, no snow), and (2) on sensor parameters of frequency, polarization and angle of incidence.

We developed a SAR-based technique for estimation of average tree height, basal area, timber volume, crown biomass, trunk biomass, and above ground biomass. These were extended to estimation of above and belowground biotic carbon pools. SAR-derived estimates were found to be at least as accurate as the supporting ground measurements and allometric models. Multi-temporal studies examined both (1) the stability of classification rules and the power of multi-temporal classification and (2) the capability of SAR to monitor landcover change, forest disturbance (i.e., harvest), and annual changes in biomass and biotic carbon sequestration. These studies are presented in the Ph.D. dissertation of Kathleen Bergen.

Finally, additional efforts developed new approaches to SAR image segmentation, speckle-suppression filters, and advances in SAR orthorectification. We examined the synergistic use of electro-optical data such as SPOT with SIR-C/X-SAR for purposes of land-cover classification. We reported upon the use of interferometric SAR for extraction of tree heights. We used SIR-C/X-SAR to evaluate the expected performance of future spaceborne SAR systems (i.e., Envisat, PALSAR, Radarsat 2 and LightSAR) for classification and retrieval of forest biophysical properties.

4.0 Students Supported and Publications

This research effort supported the following graduate students:
James Ahne
Kathleen Bergen
Ian Brodie
T.C. Chiu
Rueben DeLaSierra
Roger DeRoo
Josef Kellndorfer
John Kendra
Yanni Kouskoulas
Eric Ku
Y.C. Lin
Kyle McDonald
Adib Nashashibi
Yisok Oh
Paul Polatin
Paul Siqueira
James Stiles
Ahad Tavakoli
Eric Wilcox
Michael Whitt
Hua Xie

Andrew Zambetti

The following Ph.D. dissertations were derived from this research:

Kathleen Bergen, "Classification, biomass estimation, and carbon dynamics of a northern forest using SIR-C/X-SAR Imagery", 1997 University of Michigan dissertation.

Ian Brodie, 1993 Michigan Technological University, School of Forestry.

Kyle McDonald, "Modeling microwave backscatter from tree canopies", 1991 University of Michigan dissertation.

Paul Polatin, "Modeling and inversion of the radar response of vegetation canopies", 1993 University of Michigan dissertation.

James Stiles, "A coherent, polarimetric microwave scattering model for grassland structures and canopies", 1996 University of Michigan dissertation.

Michael Whitt, "Microwave scattering from periodic row-structured vegetation", 1991 University of Michigan dissertation.

In addition to the 6 dissertations, we have published our findings in 20 journal articles, presented the results in 82 papers at symposia and workshops, and documented data in 9 technical reports.

4.1 Journal Publications

Bergen, K.M. and M.C. Dobson, "Integration of Remotely Sensed Radar Imagery in Modeling and Mapping of Forest Biomass and Net Primary Production," accepted for publication in a special issue of Ecological Modeling in 1999.

Xie, H., F.T. Ulaby, and L. Pierce, "Performance metrics for SAR speckle-suppression filters," *IEEE Trans. Geosci. Remote Sensing*, submitted for publication.

Bergen, K.M., M.C. Dobson, L.E. Pierce and F.T. Ulaby, "Characterizing Carbon Dynamics in a Northern Forest Using SIR-C/X-SAR Imagery," *Remote Sensing of Environment*, 63(1):24-39, 1998.

Dobson, M.C., L.E. Pierce, and F.T. Ulaby, "Evaluation of SAR Sensor Configurations for Terrain Classification and Forest Biophysical Retrievals", Submitted to *Int. J. Remote Sensing*, March 1998.

Pierce, L.E., K.M. Bergen, M.C. Dobson and F.T. Ulaby, "Multi-Temporal Land-Cover Classification Using SIR-C/X-SAR Imagery," *Remote Sensing Environment*, vol 64, pp. 20-33, April 1998.

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Dobson, M.C., F.T. Ulaby, L.E. Pierce, T.L. Sharik, K.M. Bergen, J. Kellndorfer, J.R. Kendra, E. Li, Y.C. Lin, A. Nashashibi, K. Sarabandi and P. Siqueira, "Estimation of Forest Biophysical Characteristics in Northern Michigan with SIR-C/X-SAR,"*IEEE Transactions on Geoscience and Remote Sensing* V. 33, No. 4, 8877-895, July 1995.

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Kouskoulas, Y., L. Pierce, F.T. Ulaby and M.C. Dobson. "Classification of Short Vegetation Using Multifrequency SAR," Proc. IGARSS'99, June 28 – July 2, 1999, Hamburg, Germany.

Xie, H., F.T. Ulaby, L. Pierce and M.C. Dobson, "Performance Metrics for SAR Speckle-Suppression Filters," Proc. IGARSS'99, June 28 – July 2, 1999, Hamburg, Germany.

Bergen, K.M., M.C. Dobson, L.E. Pierce and F.T. Ulaby, "Future Directions in Modeling Net Primary Productivity of Forest Ecosystems," North America ISEM Annual Meeting, August, Montreal.

Bergen, K. and M.C. Dobson, "Monitoring Forest Biomass, Harvest and ANPP Using SAR," Proc. Soc. Amer. For. Meeting, Traverse City, Michigan, Sept. 19-23, 1998, 10 pp.

Dobson, M.C. and K. Bergen, "Land-Cover Classification and Forest Biophysical Retrieval from SAR," Proc. Soc. Amer. For. Meeting, Traverse City, Michigan, Sept. 19-23, 1998, 9 pp.

Kobayashi, Y., K. Sarabandi, L. Pierce and M.C. Dobson, " Assessment of TOPSAR DEM for Extracting Tree Heights," IGARSS'98, July 6-10, 1998, Seattle, Washington.

Pierce, L.E., G. Samples, M.C. Dobson and F.T. Ulaby, "An Automated Unsupervised/Supervised Classification Methodology," IGARSS'98, July 6-10, 1998, Seattle, Washington.

Ulaby, F.T., "SAR Biophysical Retrievals: Lessons Learned and Challenges to Overcome," International Workshop on Retrieval of Bio- and Geo-physical Parameters from SAR Data for Land Applications, ESTEC, The Netherlands, 21-23 October, 1998.

Ulaby, F.T., "Terrain Applications of Multichannel SAR," ESLAB Symposium, ESTEC, The Netherlands, 15-20 September, 1998.

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Bergen, K., M. C. Dobson, L. E. Pierce and F. T. Ulaby, "Effects of Within-Season Dielectric Variations on Terrain Classification Using SIR-C/X-SAR," IGARSS'97, August 4-8, 1997, Singapore.

Dobson, M. C., L. E. Pierce, J. M. Kellndorfer and F. T. Ulaby, "Use of SAR Texture in Terrain Classification," IGARSS'97, August 4-8, 1997, Singapore.

Dobson, M. C., A. Kwarteng and F. T. Ulaby, "Use of SIR-C/X-SAR to Monitor Environmental Damages of the 1991 Gulf War in Kuwait," IGARSS'97, August 4-8, 1997, Singapore.

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Pierce, L., J. Kellndorfer, F. Ulaby and L. Norikane, "Practical SAR Orthorectification," IGARSS ‘96 Symposium, Lincoln, Nebraska, May 1996.

Ulaby, F.T. and M.C. Dobson, “Extraction of Multi-Level Terrestrial Information from Satellite Radar Observations,” Int. Symp. on Rem. Sens., 12th Fall Symp. of Korean Soc. Rem. Sens. and 5th Workshop of EMSA, Oct. 24-25, 1996, Cheju, Korea.

Ulaby, F.T. “Multi-dimensional SAR, Terrain Classification, and Biophysical Mapping: A Winning Combination,” IGARSS ‘96 Symposium, Lincoln, Nebraska, May 1996.

Ulaby, F.T., "Developments in Radar Remote Sensing Science", Light SAR Workshop, Sioux Falls, South Dakota, August, 1996.

Bergen, K. M., M. C. Dobson and L. E. Pierce, "Radar Aboard Space Shuttle Endeavor Images the Hiawatha for Purposes of Land-Cover Classification, Biomass Estimation and Detection of Forest Disturbance," Conference on Adding a Multiscale and Ecological Perspective to Wildlife and Vegetation Management in the Upper Peninsula of Michigan, Clear Lake, Hiawatha National Forest, Sept. 19 - 21, 1995, (Invited).

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Dobson, M. C., L. E. Pierce, and F. T. Ulaby, "Empirical Method for Estimation of Forest Biophysical Properties from Multifrequency Polarimetric SAR," 1994 International Geoscience and Remote Sensing Symposium (IGARSS'94), August 8 - 12, 1994, California Institute of Technology, Pasadena, CA.

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