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SAR TERRAIN CLASSIFIER AND MAPPER OF BIOPHYSICAL ATTRIBUTES

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1. INTRODUCTION

In preparation for the launch of SIR-C/X-SAR and design studies for future orbital SAR, a program has made considerable progress in the development of an SAR terrain classifier and algorithms for quantification of biophysical attributes. The goal of this program is to produce a generalized software package for terrain classification and estimation of biophysical attributes and to make this package available to the larger scientific community. The basic elements of the SAR terrain classifier are outlined in Figure 1. An SAR image is calibrated with respect to known system and processor gains and external targets (if available). A Level 1 classifier operates on the data to differentiate: urban features, surfaces and tall and short vegetation. Level 2 classifiers further subdivide these classes on the basis of structure. Finally, biophysical and geophysical inversions are applied to each class to estimate attributes of interest.

The process used to develop the classifiers and inversions is shown in Figure 2. Radar scattering models developed from theory and from empirical data obtained by truck-mounted polarimeters and the JPL AirSAR are validated. The validated models are used in sensitivity studies to understand the roles of various scattering sources (i.e., surface, trunk, branches, etc.) in determining net backscatter. Model simulations of σ° as functions of the wave parameters (λ , polarization and angle of incidence) and the geophysical and biophysical attributes are used to develop robust classifiers. The classifiers are validated using available AirSAR data sets. Specific estimators are developed for each class on the basis of the scattering models and empirical data sets. The candidate algorithms are tested with the AirSAR data sets. The attributes of interest include: total above ground biomass, woody biomass, soil moisture and soil roughness.

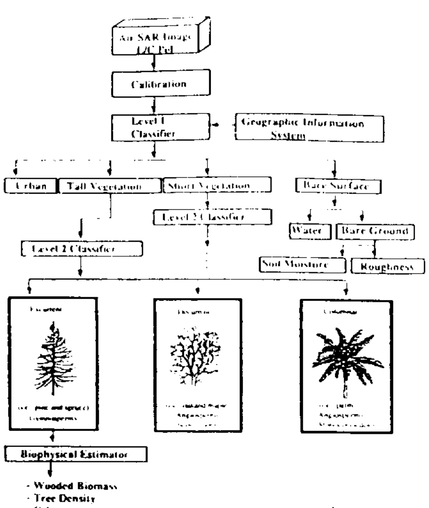

Figure 1. SAR terrain classifier

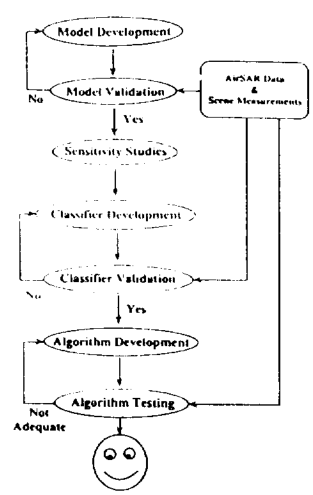

Figure 2. Development and validation process

2. LEVEL 1 CLASSIFIER

After calibration, an SAR image is classified in two stages. The Level 1 classifier operates at a pixel level to distinguish urban, tall vegetation, short vegetation and bare surfaces. The classifier has been designed for use with SIR-C/X-SAR. Hence, the data inputs are polarimetric L- and C-band data. JPL AirSAR 4-look data for Pellston, Michigan are used to train the classifier. The classifier uses: σ° (hh, vv and hv) at L- and C-bands, the peak co-polarized relative phase difference and texture. The FORTRAN classifier uses a knowledge-based, binary decision tree to differentiate the four terrain classes as shown in Figure 3. Figure 4 shows the classification of the training image. The classification accuracy is found to be in excess of 90% (see Table 1) for both the training data and independent test areas within the scene. Classifier errors generally involve assignment of short vegetation to either bare surface or tall vegetation classes. Application of the classifier to other images obtained at a SIR-C/X-SAR supersite near Raco, Michigan yield equally impressive results.

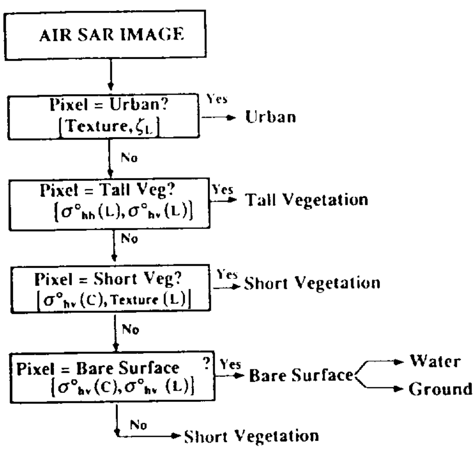

Figure 3. Level 1 classifier design

Figure 4. Classified AirSAR images from Pellston, MI. Urban = white, Tall Vegetation = light grey, Short Vegetation = dark gray, Bare surfaces = black.

Table 1. Level 1 Classifier Results

Training Areas

	True Class			
Classified As	Urban	Tall Veg	Short Veg	Bare Surface
Urban	99.3	0.22	0	0.06
Tall Veg	0	98.32	0	0
Short Veg	0.50	1.46	94.74	0.87
Bare Surface	0.20	0	5.26	99.07

Independent Test Areas

	True Class			
Classified As	Urban	Tall Veg	Short Veg	Bare Surface
Urban	99.1	0	0.85	0.01
Tall Veg	0.1	98.04	2.84	0.01
Short Veg	0.63	1.96	90.77	0.18
Bare Surface	0.17	0	5.54	99.79

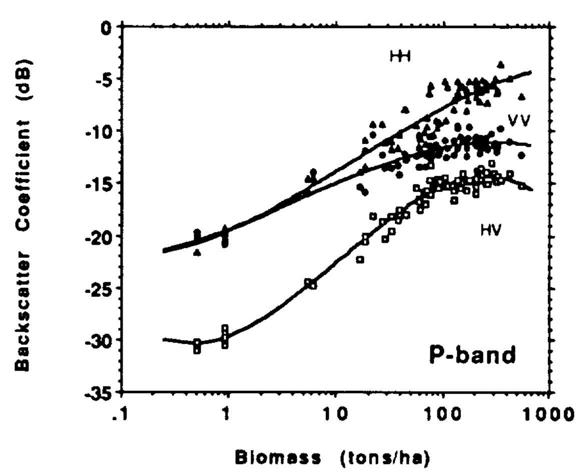

Figure 5. P-band response to forest biomass. Data from loblolly pines (Duke Forest) and maritime pines (Landes Forest).

3. LEVEL 2 CLASSIFIER

The Level 2 classifier is used to select appropriate estimator algorithms for a given pixel. It operates on the premise that multifrequency SAR is sensitive to surface and canopy structure (i.e., geometric attributes). AirSAR studies of pines at the Landes Forest in Bordeaux and the Duke Forest in North Carolina show a power-law dependence of σ° on aboveground biomass. σ° is found to saturate at biomass levels that scale with wavelength: P-band $\approx$ 100 tons/ha, L-band $\approx$ 50 tons/ha and C-band $\approx$ 10 tons/ha. The P-band response shown in Figure 5 indicates that biomass estimators are feasible below the saturation level. For the pine forests (excurrent tree form), AirSAR data indicates a dependence on crown structure only at C-band. Natural forests in particular are not mono-specie. Examination of AirSAR data from test sites in northern Michigan at Raco and Pellston demonstrates that the different branch and trunk structure of decurrent tree forms yield distinctive biomass relationships at long wavelengths. Hence, it is necessary to subclassify tall vegetation into distinctive SAR structural categories prior to application of estimator algorithms.

The level 2 classifier for tall vegetation is based upon model results using MIMICS, a 1st order vector radiative transfer model for closed canopies. Simulations for grass, shrubs, and excurrent and decurrent tree forms use growth models for canopies ranging from 0 to 200 tons/ha. The model yields modified Mueller matrices from which σ° and relative phase properties can be calculated for net backscatter as well as the component source terms. An example of the simulated data is shown in Figure 6.

Model results at P-, L-, and C-bands and $20° \leq \theta \leq 60°$ provide a number of potential classifiers for separation of tall vegetation into shrubs, excurrent trees and decurrent tree forms. Testing of these classifiers with mixed-specie AirSAR data from Raco and Pellston, Michigan shows the spectral gradient ($\sigma^\circ_{\lambda_1} - \sigma^\circ_{\lambda_2}$) to be a sensitive discriminant of tree form. The gradient from P-band to C-band yields the best results as shown in Figure 7. L-band is not a suitable substitute for P-band because of attenuation by the crown layer of branches and leaves.

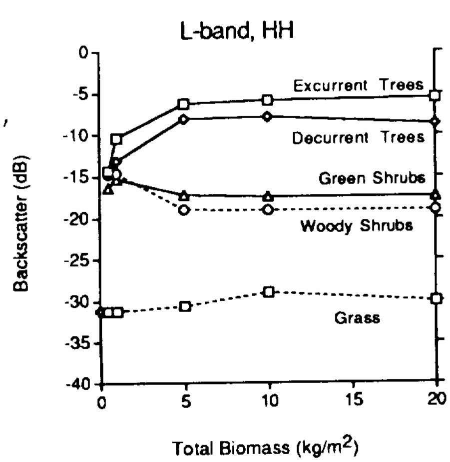

Figure 6. MIMICS simulations of backscatter from various vegetation classes at θ=40°.

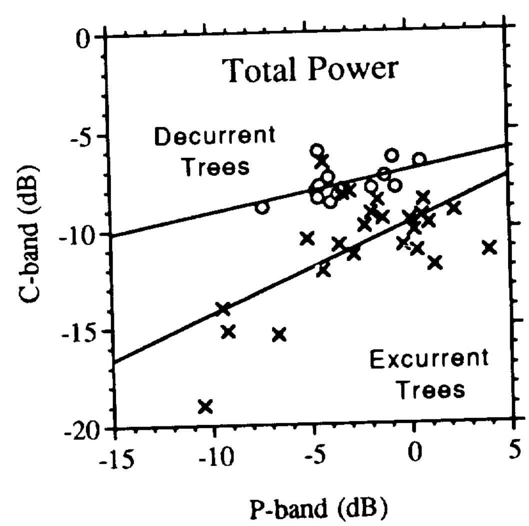

Figure 7. The spectral gradient is greater for excurrent tree forms.

4. LEVEL 2 MAPPER OF SURFACE PROPERTIES

A suite of estimator algorithms are being designed to operate on each sub-class. For vegetated regions, the algorithms yield estimates of biomass, stem density, canopy height, etc. For bare surfaces, estimator algorithms quantify surface roughness and near-surface soil moisture. The surface algorithms have been developed on the basis of truck-mounted polarimeter data. Semi-empirical formulations using polarization ratios yield estimates of surface roughness and soil permittivity. Soil moisture is inferred from permittivity. Some results of this algorithm are shown in Figure 8 for scatterometer data (Oh, 1992). Polarimetric SAR data is required and long wavelengths are preferred (i.e., P- and/or L-band).

5. CONCLUSIONS

An SAR-based terrain classifier and biophysical attribute mapper has been designed on the basis of theoretical models and empirical evidence. The level 1 and 2 classifiers take advantage of multifrequency, polarimetric SAR as a structure mapper. Tests of the classifiers on AirSAR data from two distinct sites in northern Michigan at different times of year produce excellent results.

Estimator algorithms for surface attributes have been developed and tested using scatterometer data. Evaluations of the algorithms using AirSAR data from Chickasha, OK and Davis, CA are currently underway. Estimator algorithms for canopy biophysical attributes are in development and will be tested on AirSAR data prior to the SIR-C/X-SAR launch in 1994. The classifier and estimators require polarimetric data at L- and C-bands. The addition of P-band is found to yield superior results for forested areas due to increased penetration and sensitivity to trunk attributes.

REFERENCES

Oh, Y., K. Sarabandi, and F.T. Ulaby, 1992, "An Empirical Model and an Inversion Technique for Radar Scattering from Bare Soil Surfaces," *IEEE Trans. Geo. Rem. Sens.*, vol. 30, no. 2, pp.370-381.

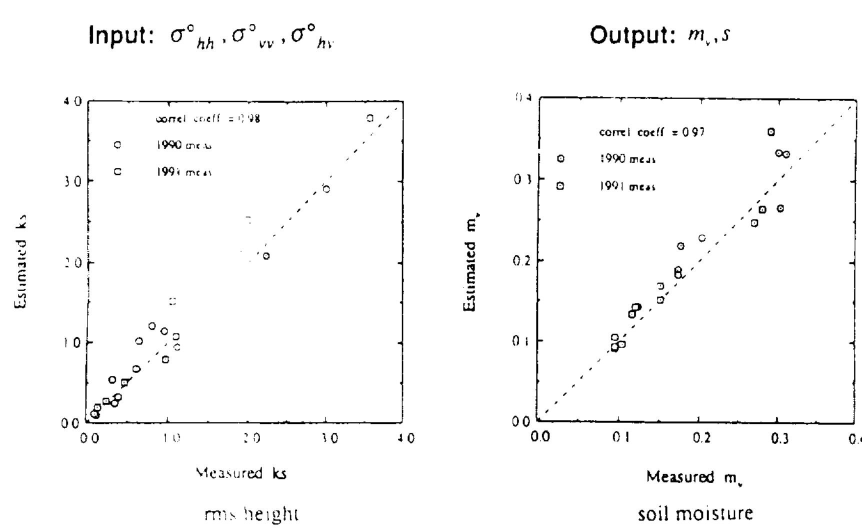

Figure 8. Results of surface estimator algorithm.