Classification of the Riverina Forests of south east Australia using co-registered Landsat MSS and SIR-B radar data

A.K.Skidmore, P.W.Woodgate & J.A.Richards
Centre for Remote Sensing, University of New South Wales, Kensington, Australia

Abstract: The Riverina forests of south east Australia have been extensively managed for 150 years as a productive source of railway sleepers and sawn timber. This study was the first Australian forestry application to evaluate the use of SIR-B radar (co-registered with Landsat MSS data) for mapping forest types and site quality classes. The techniques used for radar speckle reduction, registration of images and classification of cover classes are discussed. Results show that the classification accuracy was superior when the two data sources were used in combination rather than individually.

1. Introduction
The objective of the study was to map forest types and site qualities of the Riverina forests using SIR-B imagery as a data source by itself and in combination with Landsat MSS data.

The study area straddles the Murray River, which is the border between the States of New South Wales and Victoria in Australia (see Figure 1).

Figure 1 - Location of the study area

About 15,000 years ago, a 10m high fault line developed in a north-south direction across the course of the Murray River, effectively damming the river and causing the river to diverge into two arms, to the north and south. The huge triangular sedimentary delta that formed was subject to periodic flood inundation caused by the high winter/spring precipitation in the headwaters of the Murray River. This flood plain is now dominated by virtually pure monospecific stands of River Red Gum (Eucalyptus camaldulensis), due to this species' unique ability to withstand periodic flooding. In lower lying areas of the delta, shallow lakes and swamps are in various stages of silting up. Aeolian sand hills rise up to 12m above the flood plain and support tree species including Yellow Box (Eucalyptus melliodora) and Grey Box (Eucalyptus microcarpa). However, local variation in topography is generally less than 2m, and shadowing effects can be considered minimal or non-existant. Interestingly, at the time of the SIR-B overpass, the forest complex was experieincing an 80% flood of the total forest area. The Landsat image was recorded about a month later when the flood had just receded.

Three site quality classes have been defined for River Red Gum stands (Table 1). Site quality is the actual (or potential maximum average) height of trees in a forest stand, and is also an indication of the stand density. Stand density is a measure of stand basal area (i.e. cross sectional area of tree stems at 1.3m per unit area) or stocking. Table 1 also details the other major cover types in the study area.

This present forest structure has been modified by man's activities. The Aboriginal population regularly burnt the forest to maintain an open woodland condition of veteran trees, which enhanced the value of the forest for hunting. From the 1840's, European man used the forest for grazing runs and for timber. Current logging is on a selection basis, with some overmature trees being removed during logging to improve regeneration. Stands are uneven-aged and very variable in tree size and distribution as a result of this history. However, stand density (basal area or stocking) is correlated to site quality (see Table 1), with red gum (site quality 1) being the densest forest.

The study area was selected because the Centre for Remote Sensing at the University of New South Wales had acquired a clear

Table 1 - Major cover types in the Riverina Forests

Land cover type	Typical location of occurence	Definition and description of land cover type
River Red Gum Site Quality 1	Frequently flooded e.g. river bends. Areas with good access to subterranean water.	Dominant tree height (or potential tree height) of 31-45 m. Higher stand density (70 m^2/ha). Heavily stocked regeneration. Ground cover of leaf litter or grass.
River Red Gum Site Quality 2	Intermediate levels of the floodplain. Depth to watertable 6-9 m.	Dominant heights of 21-31 m. Increasing number of woody understorey plants. Moderate stand density.
River Red Gum Site Quality 3	Higher levels of floodplain. Depth to watertable > 9 m. Infrequent floods of short duration	Poor stand development. Open savannah woodland of <21 m in height. Woody understorey species more pronounced.
Yellow and Grey Box	Irregularly flooded and flood-free areas	Stands vary in dominant height from 6-30 m. Grass component in understorey.
Swamps and Giant Tussock Rushland	Watercourse and semipermanent swamps	Tussock grass formation of 2-3 m.

SIR-B radar image of the Riverina forests from the flight of Space Shuttle Challenger in October 1984. Comprehensive forest type and site quality maps already existed for the area, and were made available by the Forestry Commission of N.S.W. and the Department of Conservation, Forests and Lands of Victoria. A unique opportunity thus occured to generate forest type maps using SIR-B imaging radar combined with Landsat MSS data of approximately the same dates. Details of the Landsat MSS and SIR-B radar are described in Table 2.

Table 2 - Description of the Landsat MSS and Sir-B radar

	Landsat MSS	SIR-B Radar
Source	Landsat-4	Space Shuttle
Acquisition date	17 November 1984	13 October 1984
Acquisition time	0930	0100
Pixel resolution	79 x 56 m	12.5 m
Wavelength	5 x 10-5 cm - 1.1 x 10-5 cm	23.5 cm
Incidence angle	orthogonal	32.7 - 39.3 degrees

Two obstacles had to be overcome to meet the objectives of the study. The first was radar speckle, which is an unavoidable product of the illumination of a surface by coherent monochromatic radiation. Despite the fact that SIR-B imagery was produced by averaging four independent looks, further speckle reduction was necessary prior to classification to prevent aberrant speckled pixels from causing misclassification. Secondly, spatial resolution differences between the Landsat MSS and SIR-B radar obviously complicated their co-registration.

Once the Landsat and SIR-B were successfully co-registered, maximum likelihood classification of the Landsat and SIR-B images was undertaken. Landsat and SIR-B images were also separately classified, as were the first three principal components of a principal components transformation of the combined Landsat and SIR-B images.

2. Methods

All processing of the SIR-B and Landsat data was performed on a Dipix Aries II image analysis system at the Centre for Remote Sensing, University of New South Wales.

A static average filter was chosen to reduce speckle. It consists of a grid cell moving over the raw radar image, the size of which is user specified (in our case a 2 x 2 cell). The algorithm calculates the average value for all pixels within the grid cell, and this value then becomes the new grid cell value, replacing all other pixel values. This filter effectively reduced the 12.5 m pixel size to 25 m, as well as lessening the speckle effect.

Co-registration of the two images was multistaged. The SIR-B image was rotated clockwise through 300 degrees to align it with the Landsat image. Next, the SIR-B image was registered to the Landsat image by a first order polynomial using 11 well distributed tie-points. Cubic convolution interpolation resampled the SIR-B image to the same resolution as the Landsat. Corresponding ground control points on the Landsat band 7 image and the basemap (a composite 1:100,000 topographic mapsheet with an Australian Map Grid (AMG) at 1 km intervals) were located and used to calculate a second order polynomial with acceptable residual errors. Geometric correction of both the Landsat and SIR-B images was performed with this single polynomial function. Cubic convolution interpolation was again used to resample the Landsat and Sir-B pixel size to 50 m intervals.

Three separate maximum likelihood classification strategies were attempted on the full five feature combined Landsat and SIR-B data set; on the first three principal components of the full five feature data set; on the four feature Landsat MSS data; and on the SIR-B data alone. A representative subscene encompassing all the major cover types (viz. Box forest, River Red Gum forests of site qualities 1, 2 and 3, swamp, water and agriculture) was selected to reduce the classification time.

The classified maps produced were quantitatively assessed for accuracy using a modified stratified random sample technique proposed by Kalensky and Sherk (1975). This strategy provides an estimate of mapping accuracy of the image (i.e. it accounts for positional accuracy) as well as the more frequently quoted classification accuracy. The sampling intensity was estimated using the procedure developed by Van Genderen et al. (1979), where taking 30 randomly located sample units per strata gives a classification accuracy estimate within 95 per cent confidence limits.

3. Results and Discussion

The static average filter used to reduce radar speckle did not degrade edges and boundaries to the same extent as a mean filter, which was also run on the data. The other advantage of the static average filter was that spatial resolution was reduced in one operation without having to interpolate using cubic convolution or nearest-neighbour and attract the respective disadvantages of these techniques (viz. an overly smoothed image or a reduction in spatial accuracy). Figure 2 shows the radar image after speckle reduction and geometric correction.

Co-registration of SIR-B radar and Landsat MSS proved acceptable, with residual errors of less than one third of a pixel. Visual comparison of the Landsat and SIR-B images, and the base-map indicated that the registration had been very successfull.

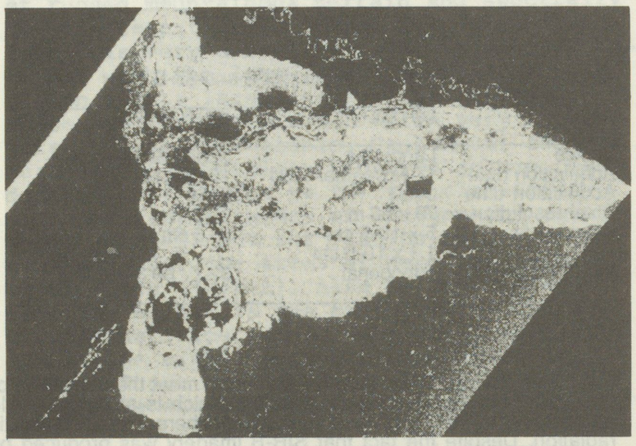

Figure 2 - Radar image after speckle reduction

The Landsat MSS and SIR-B images displayed many prominent features which could be readily ground truthed to known surface features. The Landsat colour composite showed differences in vegetation vigour within the forest, with the Red Gum site quality 1 and site quality 2 stands (which had recently been flooded) appearing much "redder". As the vegetation became drier (i.e. vegetation on higher ground) the tone became less dense and the colour lighter. Water and swamp areas on both the Landsat and radar appeared dark.

Inspection of the SIR-B image, and investigation of bispectral plots of cover class pixel dumps for the SIR-B and Landsat images, the following qualitative assessment of the range of radar brightness value responses for the cover classes was developed (Table 3).

Table 3 - Range of radar brightness values for the cover classes

Forest or cover type	Bright--------->Intermediate---------->Dark
	Box
	Red Gum SQ1
	Red Gum SQ2
	Red Gum SQ3
	Swamp
	Agriculture
	Water

Water, swamp and agriculture appeared dark as they acted as specular reflectors away from the satellite's receiving antennae. The forest complex is essentially uneven-aged, and so the density of the different forest types generally reflect the site quality (Forestry Commision of N.S.W.). In general, the denser the forest type (i.e. the higher the basal area or stocking), the brighter the radar response. This observation agrees with Hoekman (1985), who found that backscatter from X-band SLAR increased for increasing age (or density) for spruce plantations in Holland, (during the needle forming period for the tree). Wu (1984) also found that for L-Band SIR-A data, radar return strength is highly correlated with tree height or age (and hence density) for three types of pine forest in South Carolina, U.S..

Wu (1984) also found that X-band SAR had higher backscatter for cypress forests over standing water. This phenomena may be occuring over the Riverina forests, which were subject to an 80% flood at the time of the SIR-B overflight. This aspect is to be discussed in a forthcoming paper by the authors.

Supervised classification yielded the overall classification results shown in Table 4. Note that as the SIR-B data classification result was so poor, a detailed estimate of mapping accuracy was not attempted for that data source alone.

Table 4 - Overall classification results for the supervised classification

Data type	Overall classification accuracy
Landsat and SIR-B combined	65.1%
Landsat only	60.2%
First 3 principal components	56.4%

Landsat combined with SIR-B gave the best overall result. SIR-B obviously provided additional information which increased classification accuracy, but the amount of contributed information is poor in comparison to that obtained from the MSS. The Landsat and SIR-B in combination also gave the best individual class mapping accuracies, and the confusion table (after Kalensky and Sherk,1975) is shown in Table 5.

No other workers have attempted to map site quality classes for uneven-aged forests using remotely sensed data, so these results are not comparable with previous work. However, Benning et al. (1981) had limited success at classifying exotic forest types into age classes using Landsat data alone in New Zealand., with classification accuracies ranging from 16% to 58%; a poor result compared with that stated here. Inkster et al. (1980) used a four channel SAR over forested sites in Canada and estimated the resolution required for accurate forest mapping was 6 m. Guidon et al. (1980) used Landsat MSS data, an 11 channel airborne MSS and a four channel airborne scanner over rugged forest terrain, and showed higher classification accuracies were possible with the MSS imagery than with SAR imagery, which agrees with our results. The airborne MSS gave much better results than the Landsat MSS, due to the superior resolution and spectral range of this scanner.

Supervised classification of the first three principal components proved less accurate overall than the Landsat MSS data alone. Inspection of the eigenvector-eigenvalue matrix produced by the principal component analysis showed that 84.2% of the total variance in the first three principal components was due to the radar. The radar, which dominated the first three components, generally shows only minor discrimination of the forest.

Table 5 - Mapping accuracies for the supervised classification of the combined Landsat and SIR-B data.

Class		A	S	W	B	I	II	III	U	T	OM	P	CA
Agriculture	(A)	27								27	0	0	100
Swamp	(S)	3	11	1	7	1			6	29	18	62	38
Water	(W)		1	28			1			30	2	7	93
Box	(B)				23	1	1	2	2	29	6	21	79
Red Gum SQ1	(I)		4	1		19	6		1	31	12	39	61
Red Gum SQ2	(II)		2		2	2	21	1	2	30	9	30	30
Red Gum SQ3	(III)		2		12	1	7	7	1	30	23	77	23
Total No. of Pixels	(T)	30	20	30	44	24	36	10	12	209			
No. Comissions		3	9	2	21	5	15	3	12				
% Comissions		10	45	7	48	21	42	30	100				

U = Unclassified pixels
OM = number of omissions
P = percentage of omissions
CA = class mapping accuracy

There was some qualitative evidence to suggest that the remote sensing data was more accurate than some sections of the site quality and vegetation maps used for ground truthing and mapping accuracy assesment. A more detailed ground truthing exercise is needed to evaluate whether some misclassified pixels are actually correctly classified, and in fact it is the ground truth data which is inaccurate.

Some research has been undertaken to determine the optimal combination of wavelength, polarization, resolution and look angle for agricultural applications (De Loor, 1974; Ulaby, 1975; Brakke et al., 1981; Dobson et al., 1983), though much still needs to be done in forestry. Reliable models to describe radar backscatter from forests also need to be developed.

4. Conclusions

The highest overall classification accuracy of 65% was obtained with co-registered Landsat MSS and SIR-B radar data. SIR-B provides additional information for delineation of forest types and site quality classes for the Riverina forests of Australia, though the amount of extra information is limited. Stand structure appeared the main factor affecting radar backscatter from forests.

Acknowledgements

Mr T. Lee provided assistance in running the static average filter which he developed on the Dipix system, at the Centre for Remote Sensing, Unversity of New South Wales. Ms L. Bischof provided valuable advice on the operation (and peculiarities) of the Dipix system.

We are also grateful to The Forestry Commission of N.S.W. and the Department of Conservation, Forests and Lands, Victoria, who made available ground truth maps and reports of the study area.

Literature cited

Benning V.M., Ching N.P., Bennetts R.L., Ellis P.J., Beach D.W. (1981)New Zealand land use cover and forestry mapping from a satellite. Proc. Second Aust. Rem. Sens. Conference, Canberra. p2.1.1-2.1.5.

Brakke T.W., Kanemasu E.T., Steiner J.L., Ulaby F.T., Wilson E. (1981). Microwave radar response to canopy moisture, leaf area index and dry weight of wheat corn. Rem. Sens of Environ. II:207-220.

De Loor G.P., Jurriens A.A., and Gravesteigh H. (1974). The radar backscatter from selected agricultural crops. IEEE Trans. on Geoscience Workshops GE-12(2):70-77.

Dobson M., Ulaby F.T., Moezzel S. (1983). A simulation study of the effects of land cover and crop type on sensing soil moisture from an orbital C-band radar. Int. Geoscience and Rem. Sens. Symp., Vol 1., TA-1-3.

Forestry Commision of N.S.W. (unpub). Murray Management Plan (Draft). Forestry Commission of N.S.W., P.O. Box 2667, G.P.O., Sydney, N.S.W. 2001, Australia.

Fung A.K. and Ulaby F.T. (1983). Matter-energy interaction in the microwave region. In Manual of Remote Sensing, Vol. 1, Chapt. 4:115-164.

Guidon B., Gentle M.R., O'Callaghan J.F., Briggs I.C., Dreiven G. (1980). Integration of MSS and SAR data of forested regions in mountainous terrain. Proc. 14th Int. Symp. on Rem. Sens. of Environ. Vol. 3, pp. 1673-1690.

Hoekman D.H. (1985). Radar backscattering of forest stands. Int. J. Rem. Sens. 6(2):325-343

Inkster D.R., Lowry R.T., and Thompson M.D. (1980). Optimal radar resolution studies for land use and forestry applications. Proc. 14th. Int. Symp. on Rem. Sens. of Environ. Vol. 2, pp. 865-882.

Kalensky z. and Sherk L.R. (1975). Accuracy of forest mapping from Landsat CCT's. Proc. 10th. Int. Symp. on Rem. Sens. of the Environ. Vol. II pp. 1159.

Ulaby F.T. (1975). Radar response to vegetation. IEEE Trans. Antenna. Propagation., AP-23(1):36-45

Van Genderen J.L., Lock B.F., Vass P.A. (1978). Remote sensing statistical testing of thematic map accuracy. Rem. Sens. of the Environ. 7:3-14.

Wu S. (1984). Analysis of synthetic aperture radar data acquired over a variety of land covers. IEEE Trans. on Geosci. and Rem. Sens. GE-22(6):550-5578.

Remo
in the

V.I.Suk
All-Unior

ABSTRAC
USSR fo
terizir
photogr

Large-
of the
comple
half o
carrie
zone,
Middle
mic ac
forest
range
an inf
te is
and re
growin
and in
agricu
lands,
The
the fo
anthro
hand p
a prim
nal us
rest r
But in
inform
ub veg
change
of all
the ac
means
to rev
change
techno
their
out, a
gies a
dern r
develo
method
Info
ation
vestig
and me
satell
serie
tions
zonal
with
1km a
vatio
it po
tion
centi
In
tion
ing s