Merged Spaceborne Radar and Thematic Mapper Digital Data for Locating Villages in Sudan

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Abstract
A multisensor digital data set of Landsat Thematic Mapper (TM) and Shuttle Imaging Radar-B (SIR-B) data was used for the location of villages in Sudan. The study area is southeast of Khartoum along the Blue Nile near Wad Medani, the second largest city in Sudan, an area where villages are not well mapped. Because of various spectral confusions, neither sensor alone can locate villages. These two data sets were digitally registered to each other and a parallelepiped classification strategy was utilized to accurately delineate the villages. Known villages from field visits were used for training signatures and as truth for accuracy assessment. This study demonstrates the synergism of sensor merger and illustrates the utility of the parallelepiped classification.

Introduction
Remote sensing has changed greatly over the past two decades because of advances in three primary areas. These areas are (1) the development of sensors capable of collecting information in new portions or utilizing combinations of portions of the electromagnetic spectrum, (2) the use of spaceborne platforms including orbiting and geostationary satellites and reusable systems such as the space shuttle, and (3) the incorporation of computers in many aspects of data acquisition and utilization. Spaceborne remotely sensed data may be particularly useful in developing countries where there frequently is a lack of current, reliable spatial information (NAS, 1977; Morain, 1991).

The purpose of this study was to use a multisensor data set of Landsat Thematic Mapper (TM) multispectral and Shuttle Imaging Radar-B (SIR-B) data for the location of villages in central Sudan. In this region, the best available maps are over 50 years old and were compiled at a scale of 1:250,000. Further, because of the influence of major irrigation projects and the basic nature of the cultural migration and agricultural practices, there has been considerable and ongoing change in the location of villages and in general patterns of land use. Effective support and management of this region requires current, reliable information on the location of villages and other land covers as may be provided by spaceborne remote sensing.

Study Area
This analysis was limited to an area along the Blue Nile River in central Sudan where coincident SIR-B and TM data had been acquired. Sudan, which is the largest country in Africa, has a total area of over 2,500,000 square kilometres. The large size of the country coupled with the difficulty of access in much of the country makes it an ideal situation for the application of remote sensing techniques to provide relatively recent and reliable information on the cultural and physical attributes of the country.

Specifically, the study area was approximately 25 km by 40 km, including the second largest city in Sudan, Wad Medani, and extending northwest from Wad Medani along the Blue Nile. Figure 1 shows the general location of the study area. Wed Medani is about 160 km southeast of Khartoum and has a population near 100,000. It is a service city for the Geneid Gezira irrigated agricultural schemes along the Blue Nile and extended west to the White Nile. This is an extremely successful area for the production of cotton and sugar cane.

Ground Truth
Truth information for this study was obtained by a field visit in 1988. Using enlarged SIR-B and Landsat TM prints with limited available maps, samples of the various land uses were documented on overlays to the hard-copy imagery. This information was then converted to a raster-based GIS format and registered to the fused TM/SIR-B data set (see Image Processing Section). There were four categories of basic land use incorporated in the GIS layer: urban, agricultural, natural vegetation, and background/other.

This area of Sudan is extremely flat and, except for the irrigated fields, contains very little vegetation. The housing is made of indigenous materials, primarily clay, which is similar spectrally to the bare soil. Figures 2a and 2b are ground photographs from this area. Figure 2a is a typical village with bare soil evident in the foreground. Figure 2b is an irrigated area being used for eucalyptus trees. Cotton and sugar cane are the typical crops.

The urban sites in this area included portions of Wad Medani and also villages of various sizes. There were only a few small areas of natural vegetation and, for the accuracy

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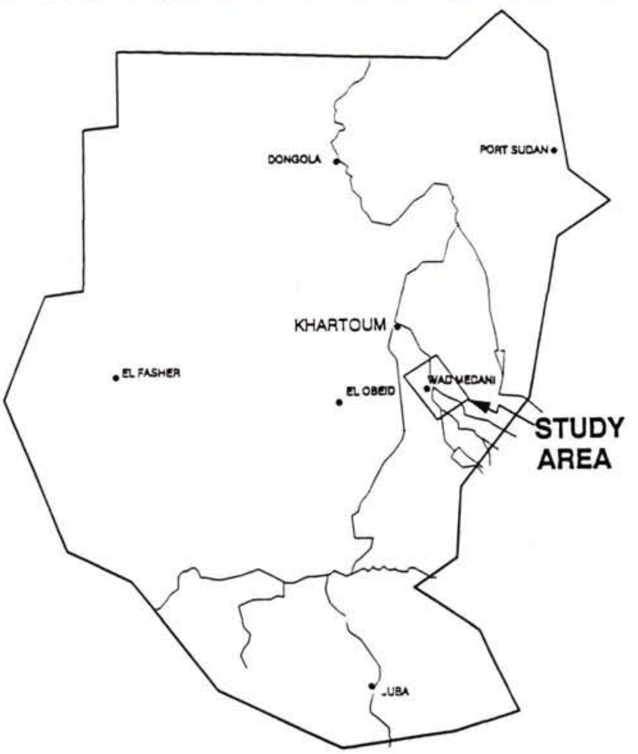


Figure 1. Study site location in Sudan.

assessment, they were combined with the agricultural sites. The agriculture and natural vegetation were not significantly different spectrally. The background/other category was primarily the flat barren areas with low radar backscatter. This truth information was divided about equally between polygons used for training, the extraction of spectral signatures, and polygons used for accuracy assessment.

Data

Two primary data sets were obtained for this analysis. The first was digital radar data from the Shuttle Imaging Radar (SIR-B) system. The second was a standard seven-band digital image from the Landsat TM dated 18 November 1984.

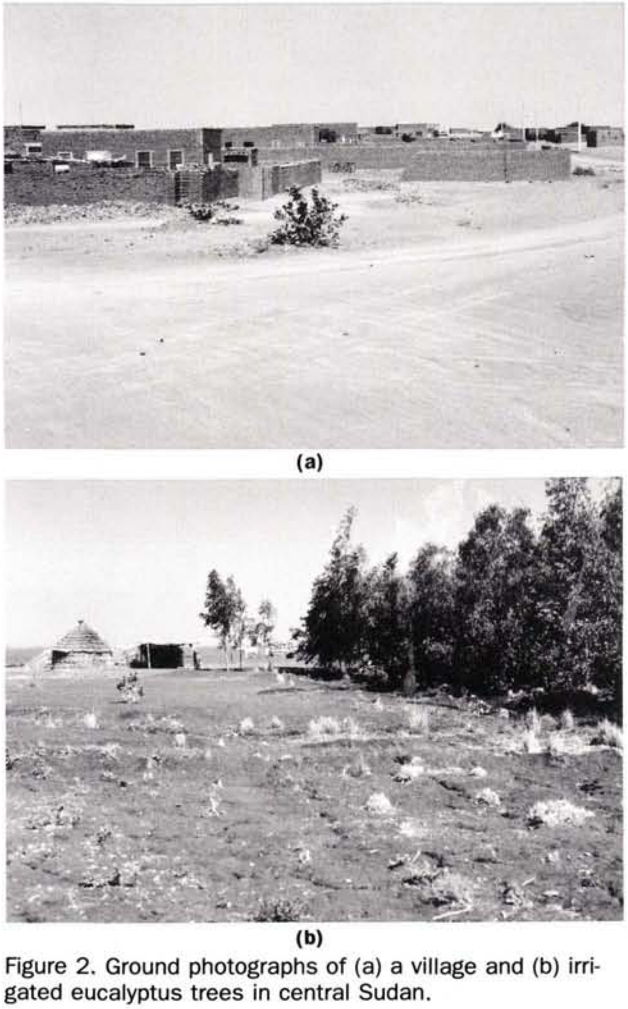
The SIR-B mission was flown in October 1984 and collected L-band (23.5-cm) synthetic aperture data. The SIR-B data were collected at variable look angles of between 15 and 60 degrees. The digitally correlated data were obtained in 20- to 30-km swaths at a 12.5-m spatial resolution (Cimino *et al.*, 1988).

Radar data are very effective at locating cultural features. Man-made features provide a high return, because of the high dielectric properties of some construction materials such as metal and the geometric shape of many cultural surfaces. Buildings often act as corner reflectors to the radar signal and, thus, have a high return. Lo (1986) used radar data from SIR-A to effectively map villages and other patterns of human geography in China.

Radar also produces high backscatter from vegetation, the result of the texture of the vegetative canopy and the dielectric properties of leaf moisture. The type of return is highly dependent on the nature and extent of the vegetative cover type (Elachi, 1988). The usefulness of radar imagery in vegetative studies, such as the identification of forest cover or crop types, has been demonstrated by Hoffer *et al.* (1985), Imhoff *et al.* (1986), Wu (1980), and Ulaby et al. (1982).

Similar high radar backscatter between villages and vegetation is observable in the SIR-B image of the study area (front cover, top). The front cover images are oriented such that north is to the upper left, an azimuth of about 330 degrees. The Blue Nile is very apparent moving right to left in the image. The high return features are either cultural features or vegetation, either natural vegetation or agriculture. Wad Medani is the large, very high return area at the extreme right within a major bend of the Blue Nile. Even in Wad Medani, there are some large irrigated orchards near the river which can not be distinguished from the urban features.

Some features much smaller than the nominal spatial resolution of the sensor can occasionally be seen. For example, the high return straight linears parallel to the bottom of the image. These are transmission lines, a canal, and a railroad. Because they are oriented almost directly perpendicular to the SIR-B illumination, they have very high backscatter. For linear features, the strength of the signal return is strongly influenced by the look direction of the sensor. There will be a higher return for corner surfaces which are parallel



(a)

(b)

Figure 2. Ground photographs of (a) a village and (b) irrigated eucalyptus trees in central Sudan.

TABLE 1. MERGED DATA SCENE SENSOR DESCRIPTIVE STATISTICS

Band	Wave Length (micrometers)	Min	Max	Mean	SD
TM1	0.45-0.52	70	218	102.0	13.0
TM2	0.52-0.60	27	115	52.2	9.6
TM3	0.63-0.69	24	153	77.2	19.6
TM4	0.76-0.90	2	147	69.5	14.7
TM5	1.55-1.75	1	243	110.3	34.1
TM6	10.4-12.5	135	202	185.0	10.0
TM7	2.08-2.35	1	212	66.5	23.6
SIR-B	235.0	14	255	95.4	41.1

to the sensor flight line. This change in response, depending on the geometry between the surface and the radar, is a limitation and has promoted the concept of multi-azimuthal collection of radar data.

There are also a number of villages in the scene with high and generally mottled returns. These villages are often near the river or within the Geneid Gezira, but also can be found in the bare plains in the upper portion of the image.

The agricultural areas include both high and low returns, but are most evident due to their rectilinear patterns. These are very obvious along the lower left portion of the scene. The high return agricultural features are active fields, generally cotton or sugarcane. In addition, there are some areas of rapidly growing forest plantations, mostly eucalyptus. The low return fields are fallow.

There are very limited areas of natural vegetation in this region, most of them near the rivers. The low return areas in the upper left are extremely flat and devoid of almost any vegetation. This area has become increasing arid in recent years and grasses are only evident if there is rain.

The front cover image (center) is the standard TM false color composite made from bands 4,3, and 2 in red, green, and blue, respectively. The villages and urban areas are not identifiable on this image because much of the construction material — vegetation, bricks, and adobe — spectrally blend into the surrounding rural landscapes. Both the bare soil and villages provide similar blue-grey returns. Within the city of Wad Medani, some of the road patterns are evident, providing some indication of where the city is, but the isolated villages cannot be located. In this image, the vegetated areas are red toned.

The top and center front cover images suggested that neither the TM or SIR-B imagery alone can differentiate between the land-use patterns in Sudan. However, the merger of the TM and SIR-B data creates the classification possibilities that utilize the informational advantages of each sensor and differentiates the basic land-use patterns that are not clearly separable with shortwave or microwave imaging alone.

The contrast and complementarity between the SIR-B image (front cover, top) and the TM image (front cover, center) are quite apparent. This complementarity for locating urban areas can be seen in bottom front cover image. The bottom front cover image is a false color composite of SIR-B (Band 8) in red, the TM thermal band (Band 6, 10.4 to 12.5 micrometres) in green, and a TM mid-infrared band (Band 5, 1.55 to 1.75 micrometres) in blue. In this image, the bare soils are blue and yellow, the vegetation is red, and the urban areas are pink. Discrimination of the urban features is especially pronounced in Wad Medani where both the interior bare soils and the heavily vegetated areas near the Blue Nile can be separated from the urban areas. Villages, such as those across the river, can also be located by their pink tones.

Image Processing Techniques

All image processing and accuracy assessment was conducted on a 386 PC with ERDAS image processing software.

Rectification

The Landsat TM and the SIR-B data were downloaded and the general study area was subsetted from each. Both images were then co-registered to each other using several linear and polynomial rectification algorithms. Nine common control points for co-registration were identified between the two images. Because central Sudan has little topographic relief, and because the SIR-B data were imaged at a low incidence angle and were, therefore, relatively "planimetric," the first-order linear transformation provided the best overall scene-to-scene registration.

Merger

The TM and SIR-B data were then merged together into a common image file format, with the SIR-B data inserted as an eighth frequency band. All TM bands were resampled using a nearest neighbor approach to the 12.5-m pixel size of the radar data. This created a co-registered, resampled, eight-band data set from which all analyses could proceed. Table 1 contains the basic sensor recorded statistics for the eight bands after registration of all pixels within this subscene. The large standard deviation for the radar data is not surprising given a knowledge of the study area and the nature of radar interaction with this type of environment. There are areas, cultural and vegetated, with very high backscatter and also flat bare soils with very little return. The TM mid-infrared bands (5 and 7) also have relatively high standard deviations. The standard deviation for the thermal data (band 6) is relatively small, but greater than the standard deviation frequently encountered with this band in other locations.

Training and Truth Files

The ground truth data on the location of villages, bare soil, and agricultural fields had been obtained in cartographic overlay form from field visits. Training sites were subsetted from the larger truth files and both were digitized into common raster GIS formats.

Signature Extraction

Signature extraction algorithms were performed on the agricultural, urban, and other basic training sites to determine the nature of spectral signatures of each class and to ascertain the best classification procedure. Table 2 contains sample signatures for the primary land covers in this scene.

An examination of this table confirms what had been observed visually from the imagery. The urban and other (bare soil) sites are not separable in any of the TM bands. The best separability of the TM bands was, perhaps, band 6 with its low standard deviations. This was surprising and may be a function of greater shading in the urban areas, the existence of at least some vegetation in the villages, or possibly due to the morning thermal changeover that is occurring in arid environments at the time of Landsat overpass. The coarse spatial resolution of band 6, 120 m, and the great temporal variability of the thermal signatures makes it less reliable and very data dependent for classification. The urban and other signatures can be separated with the SIR-B data. The ur-

TABLE 2. SPECTRAL SIGNATURES FOR SELECTED COVER TYPES*

Cover	TM1	TM2	TM3	TM4	TM5	TM6	TM7	SIR-B
Agric 1	87	40	47	86	82	162	35	168
	10	7	15	22	17	7	12	42
Agric 2	89	41	51	75	82	165	38	161
	10	8	15	14	23	9	14	38
Urban 1	106	56	82	74	129	183	80	151
	5	4	7	4	12	2	9	60
Urban 2	116	60	85	75	118	182	74	153
	7	6	8	6	10	2	8	46
Other 1	103	56	85	72	129	191	79	77
	3	2	4	3	6	1	3	17
Other 2	100	55	87	72	132	189	79	78
	4	4	8	6	14	2	8	17

*mean/standard deviation

ban areas having mean values of 151 and 153 in SIR-B and the bare soil mean values of 77 and 78.

The agriculture and urban signatures are not separable in the radar data but can be separated in several of the TM bands, particularly bands 5 and 7. TM Band 4, the near infrared band, did not display as much signature contrast as might have been expected, given the basic nature of vegetation versus arid soil reflectance.

The classification strategy becomes one of first separating out the urban and other sites from the agricultural sites using TM bands and then separating the urban areas from the other (bare soil) areas using the SIR-B data.

Classification

Because there exists an inherent separability in the training signature histograms, the decision was made to use a parallelepiped classification procedure. Parallelepiped classification is sometimes known as the box decision rule or level-slice procedure and is based upon the range of values in the training set to define the classification parameters in multidimensional data space (Campbell, 1987; Mather, 1987).

Pixels are examined individually and are classified in specific categories based on the spectral value ranges of selected bands. If the signature categories are carefully designed, the parallelepiped classifier can be manipulated to use basic Boolean (AND, NOT, OR) logic in the overall classification procedure. When using complementary, but complex data sets, such as SIR-B and TM, there is an inherent appeal in using a simple classification logic that can draw upon the basic synergistic nature of the fused individual sensors.

The parallelepiped procedure is also less computationally intense and, therefore, faster and requires less CPU resources, than some other traditional classification procedures such as maximum-likelihood or Bayesian classifiers. For comparison, a maximum-likelihood decision rule was applied using eight supervised spectral signatures. That analysis required about 50 times as much processing time, eight hours versus 10 minutes, and produced an overall accuracy 4 percent lower than that of the parallelepiped classification.

Figure 3 shows histograms of the important bands for the agriculture/vegetation and urban training sites. Unique statistical signatures can be found in the training set data in various combinations of different bands. Owing to the inherent separability of the urban and agriculture signatures in combinations of different bands, the Boolean AND and OR logic of the parallelepiped classifier is well-suited to perform this type of classification. Especially important to this procedure was the unique signature found in the combinations of TM3, TM4, and TM6 for vegetation and TM1, SIR-B, and TM6 for urban areas. The statistical expressions of training set signatures, characterized by "tight" histograms, along with the Boolean logic of the parallelepiped decision rule, allow for an interesting, computationally efficient, and accurate method of classifying multisensor data sets.

Results

Table 3 lists the confusion matrix, showing the results of the parallelepiped classification for determining the basic urban-vegetation-other land-use categories. An overall classification accuracy of 94.1 percent was achieved. In contrast, a maximum-likelihood classification using the six 30-m TM bands only produced an accuracy of 69 percent.

These results show the potential of radar/MSS merger in mapping the basic land-use patterns in spectrally complex

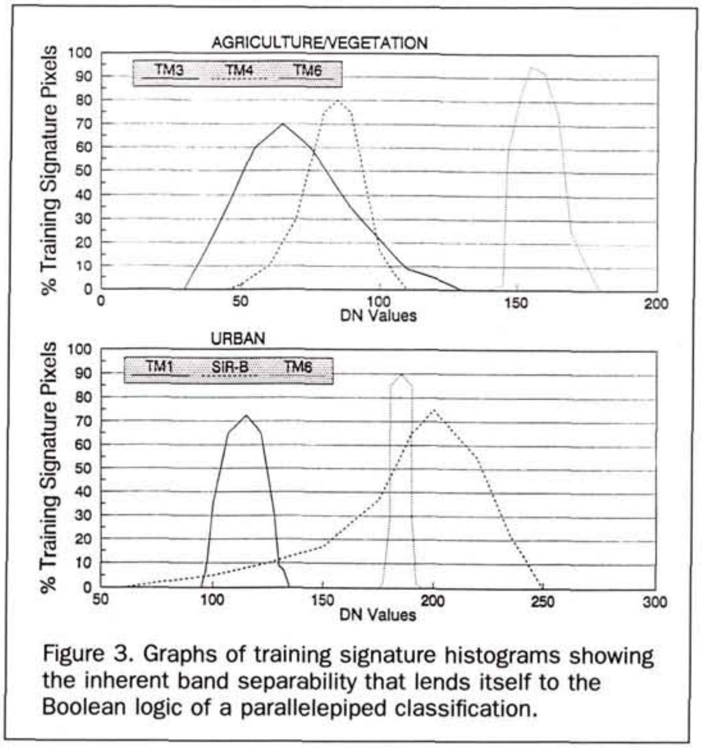


Figure 3. Graphs of training signature histograms showing the inherent band separability that lends itself to the Boolean logic of a parallelepiped classification.

TABLE 3. CLASSIFICATION ACCURACY CONTINGENCY TABLE (NUMBER OF PIXELS)

	Urban	Vegetation	Other	Totals
Urban	**16,248**	135	502	16,885
Vegetation	1,612	**3,415**	159	5,187
Other	334	0	**23,961**	24,295
Totals	18,194	3,551	24,622	46,367
Correct %	89.3	96.2	97.3	

Correctly identified pixels = 43,625/46,367 = 94.1%

and isolated arid regions. Also, because of the spectrally different and separable nature of radar and TM data, automated image processing techniques that require significantly less expenditure of computer resources, such as parallelepiped, may be successfully applied.

Radar imagery has tremendous potential as a supplement to the imagery obtained from the more conventional parts of the electromagnetic spectrum. In fact, only the very basics of radar data are being utilized, and its potential in a wide variety of applications have yet to be explored.

Future applications of this project will include a continued comparison of the parallelepiped accuracy with that of a maximum-likelihood and other classifiers, including a hierarchical approach, and an extension of basic land use to a more complex land-use and land-cover classification scheme. Further evaluation of the contribution of the individual bands and use of band subsets for classification will be undertaken. Another extension of this study would be the use of pre- and post-classification spatial filters to minimize the speckle effect of the SIR-B data. Other data sites and the recently available spaceborne radar data from ERS-1 and ALMAZ should also be explored.

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