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Extracting Urban Data from Seasat SAR Imagery: The Merit of Image Enlargements and Density Slicing

Digitally processed Seasat SAR Imagery of the Denver, Colorado area is analyzed with regard to the types of urban data that can be detected and/or inferred from satellite borne L-band systems. Black-and-white prints of the scene were generated at three scales to determine the advantages and detail discernable at each level of display. The imagery was then density sliced to evaluate the feasibility of producing a semi-automated land cover classification from the SAR data. Gray level classes were assigned colors to aid interpretation and subsequently compared with the black-and-white prints to assess the contribution of each technique and benefits of combining the data from both procedures.

Introduction

Many new methods are being explored and developed to improve the urban data base. Information is needed more rapidly and at a higher level of consistency and quality in planning for and monitoring the urban mileau. Of the techniques being examined with this objective in mind, remote sensing systems are receiving considerable attention. Although much of the remote sensing effort to date has focussed on visible and near infrared sensors the potential of radar imagery also deserves attention.

With the forthcoming launch of Shuttle-borne Space Imagery Radar (SIR) systems, radar data will become more readily available to the user community. In certain instances radar may prove to be the only sensor capable of providing data. Equally if not more important is an assessment of the potential of radar imagery as a complement to other sensor systems. Radar is unique in that it is the only active imaging system. As such, the question arises as to what distinct contribution to urban data collection can be made by radar as a function of its sensitivity to texture, spatial orientation, background contrasts, and other system/environment related parameters. In short, what can radar offer?

In this study digitally processed L-band Seasat SAR imagery is examined with regards to the merits of employing different image scales and density sliced imagery for urban data collection.

Methodology

The digitally processed L-band Seasat SAR 100 km x 100 km scene of the Denver, Colorado area was selected for analysis. This HH polarized image with twenty-five meter resolution was obtained on 6 August, 1978. Black-and-white prints of the scene were generated from the digital tapes at three different scales using an Image 100 interactive processing system: 1) 1:500,000; 2) 1:131,000; and 3) 1:41,000. The first scale depicted the full scene, the second scale provided an intermediate scale and area of coverage comparable to that of a high altitude photograph, and the third scale was the maximum enlargement possible without resampling the data.

The imagery at each scale was then density sliced using an interactive iterative classification approach to define meaningful urban land cover categories. Gray level classes were assigned colors to aid interpretation and subsequently compared with classes delimited by optical interpretation of the black-and-white prints previously generated. The purpose was to evaluate the feasibility of producing semi-automated land cover classifications with SAR data and to assess the contribution of each approach (i.e. optical interpretation and density sliced imagery) at each scale. The land cover classification system described by Anderson, et. al. in U.S. Geological Survey Professional Paper 964 (1976) was adopted to provide a basis for systematic comparison of the data. To determine accuracy all interpretation results were compared with aerial photography and existing land cover maps of the area.

Results

1:500,000 Scale. Examination of the black-and-white print of the raw data indicated that no meaningful land cover patterns could be discerned owing to excessive image noise believed to be inherent in the data. A three by three averaging algorithm was subsequently applied to the data and a second black-and-white film positive produced. At this scale the boundaries of urban built-up areas could be easily delimited owing to the high return of suburban housing in contrast to the darker tones of agriculture and other open space. Agricultural Land was identifiable only when several rectangular, cultivated fields were juxtaposed. At L-Band wavelengths Rangeland generated a smooth, low return response (dark gray to black). Since the surface roughness of this land cover type generally fell below the threshold necessary for more varied tone/texture response rangeland, pasture, and bare field borders were frequently indistinct. Forest was discernable in the mountains, along stream banks, and on low-land hills as textured, medium to light gray tonal areas. Water was not consistently detectable at this scale. Small water bodies (less than 2 km^2) could not be delimited consistently from surrounding land cover of grass, beach, bare soil, and rangeland. Larger resevoirs often produced a salt-and-pepper response rather than the expected black, no-return response owing the L-band signal sensitivity to rough and choppy water. Density slicing the image at this scale using the raw data and the smoothed data proved of minimal value due to overlapping signal response among categories. As a result, level slicing and color coding the data reduced the number of visual interpretation clues available to the interpreter.

1:131,000 Scale. At this scale the black-and-white image generated from the raw data (367 square kilometers) still contained excessive image noise obviating any interpretation attempts. Consequently, the data were smoothed as before to generate a useful product for study. Level II land cover categories (e.g., residential, industrial, transportation) were employed at this stage of the analysis.

Recently constructed residential subdivisions were readily delimited by optical interpretation of the black-and-white print as were most older, interior residential areas. (See Figure 1 and Table 1.) The commercial/

industrial core of the city and the concentration of downtown commercial activity were also apparent. However, small commercial blocks in residential areas and the boundary between the commercial core and interior residential areas was ambiguous. Confusion between commercial/service areas and residential land cover resulted in most of the error at this scale.

Portions of major arterial roads could be inferred from the linear dark lines traversing the urban area but not complete networks. Open space was distinguishable owing to the sharp contrast between its dark low return and the higher medium to light gray tones of built-up land cover. However, the exact use of the open space could not be consistently classified as recreation, cemeteries, or other open space. Instances where institutions, public facilities, or commercial buildings were surrounded by open space were also classified as simply open space from the radar image. Table 2 provides a summary of omission and commission errors for this scale.* Given the complexity of land cover types and the relatively low total percentage of incorrect identifications (12.1%) the potential of such SAR imagery for urban data extraction appears promising. Familiarity with the urban area land cover locations might enable more precise identification, but cannot be documented for the present.

Density slicing and color coding gray levels again proved of little use. Owing to the reduction in signal response variations fewer visible spatial relationships were available for interpretation and dissimilar land cover types were grouped together.

<u>1:41,000 Scale</u>. Six sub-areas of the entire SAR scene were selected to include a range of urban land cover types including: older, interior and new residential areas; single and multiple family housing; industrial; commercial and service activity; recreation and open space; and transportation. Each area encompassed some sixty-four square kilometers. Black-and-white prints of the raw data were generated for each scene and land cover classified according to Level II categories. New residential areas on the urban fringe were easily delimited owing to their bright return (see Figure 2). Older, interior residential areas were less distinct and confused at times with commercial and service activity and some industrial fringe areas owing to similar tone and texture responses on the imagery (Figure 3). Separate categories of recreation, cemeteries, and open space could not be consistently defined other than as "open space". Institution, schools, and public land were also confused with open space due to the low return of their grounds. The visibility of transportation elements was a function of their size, shape, orientation to flightline, and surrounding land cover. Only segments of major road networks were visible with portions of residential streets identifiable as dark lines or dashes in contrast to the higher return of surrounding housing structures. In commercial zones streets were generally obscurred by the bright return and signal blooming from buildings.

The visibility of Commercial and Service activity was a function of size and location. The contrast between the central business district,

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*% Omission = 100% - % correct

$$\% \text{ Commission} = \frac{\text{Total Number of Commission Errors}}{\text{Total Possible Responses} - \text{Total Possible Correct Responses}} \times 100$$

industrial center, and surrounding residential land was detectable but small commercial centers and blocks in residential areas were a major point of confusion (Figure 3). With the raw data at this larger scale the distinction between the business and commercial activity verses other land cover, particularly residential, was more pronounced than on the smaller 1:131,000 scale, smoothed data. Isolated commercial/industrial building in open areas were indistinct from residential development unless identification could be inferred from its spatial location and unusually bright signal response - a function of building size, complexity and orientation to flightline. For example, note the confusion among commercial-industrial, cemetery, and agricultural land covers in Figure 3.

In general some improvement in classification accuracy was possible compared to the smaller scale enlargements. The overall merit of the large scale imagery should be judged, however, in light of costs and information sought. Although the results are not conclusive it is suggested that a better synoptic view can be obtained at 1:131,000 scale, but for more exact delimitation of urban growth extent and direction the large scale may be preferable. For example, compare Figures 1, 2, and 3.

The density sliced images of the six sub-scenes were judged of minimal value compared to the black-and-white raw data prints - particularly in light of time and costs. Considerable information was lost by the assignment of colors and spectral class ranges to the data. Although six urban related categories (e.g. high return/urban commercial and residential) could be extracted the density range for each class varied among the study areas. Choppy water in resevoirs and small lakes resulted in a non-uniform response range and overlap with other land cover categories. Interpretation and classification of the density sliced image did not produce any improvement in accuracy when compared with data extracted from the black-and-white image generated from the raw data. This can be seen by comparing Figures 2 and 4 and referring to Table 3 (parts A-D).

The following total study sub-area classification accuracies indicate that Seasat SAR imagery at this scale does provide data of acceptable detail and precision for urban analysis. However, less confusion is apparent on the urban fringe (Area 1) than in the interior of the city (Area 2). Moreover, density slicing the data generates greater error. Study Area 1 (Density Sliced) 89.5%; Study Area 1 (raw data interpreted) 93.9%; Study Area 2 (raw data interpreted) 77.4%.

Summary

Seasat SAR data digitally processed at three different scales were examined in this study. To obtain useful imagery for analysis of the entire 100 km x 100 km scene (1:500,000) and a meso-scale (1:131,000) image it was necessary to employ an averaging algorithm to reduce noise inherent in the data. However, the raw data products were very satisfactory for interpretation of the large scale (1:41,000) imagery.

Until smoothing and averaging algorithms can be developed for incorporation into the data prior to level slicing and color coding it is believed density slicing will prove of little value for urban land cover analysis. Much valuable image texture and tone information are lost when slicing and coding techniques are employed. No improvement in accuracy or level of detail observable was apparent when such data were

compared with results of the optical interpretation of the black-and-white photographs generated from the data.

The merits of each of the three scales can be summarized as follows:

Macro-scale (1:500,000): Level I land cover classes can be delimited for synoptic mapping of urban areas. That is, agriculture, forestry, and rangeland adjacent to urbanized areas can be identified for incorporation into general planning inventories of growth direction and land cover change. The extent of urban built-up can be defined within acceptable mapping accuracies of this scale. As is the case with any data generated at this scale, little detail is apparent.

Meso-scale (1:131,000): More precise delimitation of the urban infrastructure is possible as Level II land cover category detail can be extracted. New residential areas can be determined as can the commercial-services/industrial core, but small, isolated commercial areas and the discrimination of older, interior residential areas from adjacent commercial zones (e.g. transition zone) is tenuous. At this scale open space is detectable and its use (e.g. recreation) often inferred from its size, shape, and spatial location in relation to the urban area. Elements of the transportation network are not consistently identifiable other than the large airport complex.

Micro-scale (1:41,000): At this scale the most precise measurement of urban growth patterns can be made. The location and extent of growth on the urban fringe is facile due to the contrast between recent residential development and surrounding open space. Even small, isolated, low-density housing developments can be detected. The contrast between interior residential versus commercial activity is generally apparent, but the similarity in gray tone/texture response still remains a problem. Open space is easily identified but defining its use is arduous. Classification of open space as to public, institutional, utilities, and extractive land use is imprecise. Transportation elements are visible and more of the transportation network is visible than any other scale. However, no single type or class of transportation is consistently visible. At this scale there is a loss of spatial association clues inherent at the meso-scale, but this problem could possibly be mitigated by mosaicking several micro-scale images.

Although the results of this study appear promising additional work is requisite prior to a definitive statement on radar's potential for urban land cover analysis. A relatively new urban complex is a semi-arid environment was examined in this effort. The question remains as to whether similar results could be expected in a more humid environment, an older urban settlement, one predicated on a different mix of economic activities, or in a smaller or larger metropolitan area.

However, digitally processed SAR imagery do provide useful information on the urban environment. Meso-scale and micro-scale enlargements provide distinct but complementary urban data. The textural component and the susceptability of the radar return to the angular, geometric patterns of man-made structures produce unique signal responses corresponding to urban land cover types. Research devoted to the possible synergetic effect of merging this textural component with the spectral information available with other sensors (e.g. MSS) certainly merits attention.

References

Anderson, J. R., Hardy, E. E., Roach, J. T., and R. E. Witmer (1976), A Land Use and Land Cover Classification System for Use with Remote Sensor Data, U.S. Geological Survey Professional Paper 964, U.S. Government Printing Office, Washington, D.C., 28 pp.

TABLE 1: Confusion Matrix of SAR Interpretation Accuracy at 1:131,000

Actual Ground Cover	SAR Interpreted Land Cover: CI/I	CS	FOP	R	W	Total Actual Acres
CI/I	10,960		301	384		11,645
CS		1,014		2,192		3,206
FOP	164	465	13,591	2,301		16,521
R	2,219	2,959	301	55,403		60,882
W					959	959
Total Acres by SAR	13,343	4,438	14,193	60,280	959	93,213

(CI/I) commercial-industrial; (CS) commercial and services; (F) recreational; (O) open; (P) public; (R) residential; (W) water.

TABLE 2: Summary of Omission/Commission Error (1:131,000)

	Omission Error	Commission Error
CI/I	5.9%	2.9%
CS	68.4%	3.8%
FOP	17.7%	0.8%
R	9.0%	15.1%
W	0.0%	0.0%

Total % incorrect identifications = 12.1%

TABLE 3

Key: (A) agricultural; (F) recreational; (G) cemetery; (O) open; (C) commercial; (E) extractive; (I/CI) commercial-industrial; (P) public; (R) residential; (T) transportation; (U) utilities; (W) water.

(A) Comparison of Large Scale SAR Interpretation Accuracies

	Study Area 1 (Density sliced)		Study Area 1 (raw data)		Study Area 2 (raw data)	
	Omission Error	Commission Error	Omission Error	Commission Error	Omission Error	Commission Error
AFGO	1.0%	15.9%	0.3%	0.2%	49.7%	0.0%
C	100%	0.0%	--	--	16.8%	13.3%
E	100%	0.0%	100%	0.0%	--	--
I/CI	100%	0.0%	--	--	0.0%	6.6%
P	100%	0.0%	100%	0.0%	100%	0.0%
R	12.0%	1.9%	5.2%	5.7%	26.9%	9.6%
T	--	--	--	--	0.0%	0.0%
U	100%	0.0%	100%	0.0%	--	--
W	3.5%	0.2%	0.0%	0.1%	--	--

(B) Confusion Matrix of Study Area 1 (density sliced)

SAR Interpreted Land Cover

Actual Ground Cover	AFGO	C	E	I	P	R	U	W	Total Actual Acres
AFGO	2764					28			2792
C	32					4			36
E	60								60
I						8			8
P	140					12			152
R	404					2968			3372
U						16			16
W	16							436	452
Total Acres by SAR	3416					3036		436	6888

(C) Confusion Matrix of Study Area 1 (raw data)

Actual Ground Cover	SAR Interpreted Land Cover: AFGO	E	P	R	U	W	Total Actual Acres
AFGO	2620					8	2628
E	28						28
P	180						180
R	192			3516			3708
U	24						24
W						484	484
Total Acres by SAR	3044			3516		492	7052

(D) Confusion Matrix of Study Area 2 (raw data)

Actual Land Cover	SAR Interpreted Land Cover: AFGO	C	I/CI	P	R	T	Total Actual Acres
AFGO	360	4	228	60	64		716
C		952			192		1144
I/CI			1860				1860
P		140			156		296
R		664	128		2156		2948
T						260	260
Total Acres by SAR	360	1760	2216	60	2568	260	7224

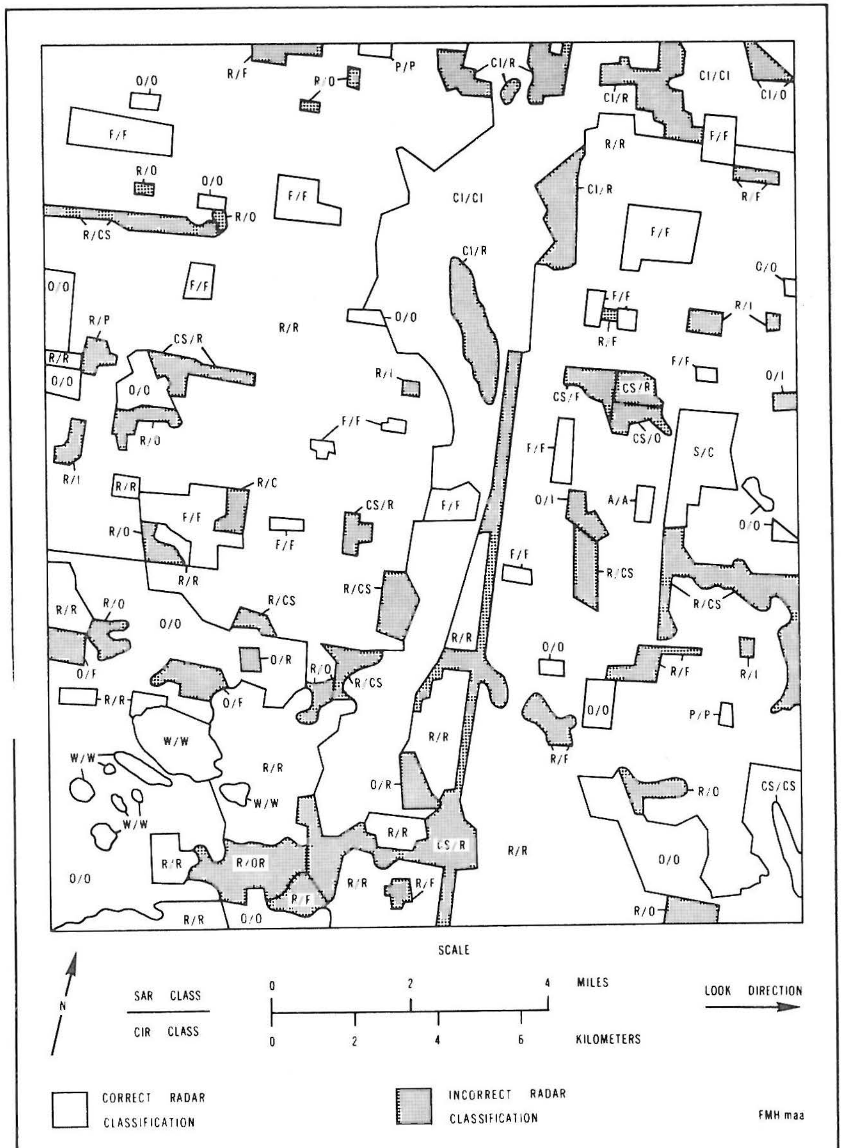

Figure 1. Classification Comparison (meso-scale). See Table 1 for key.

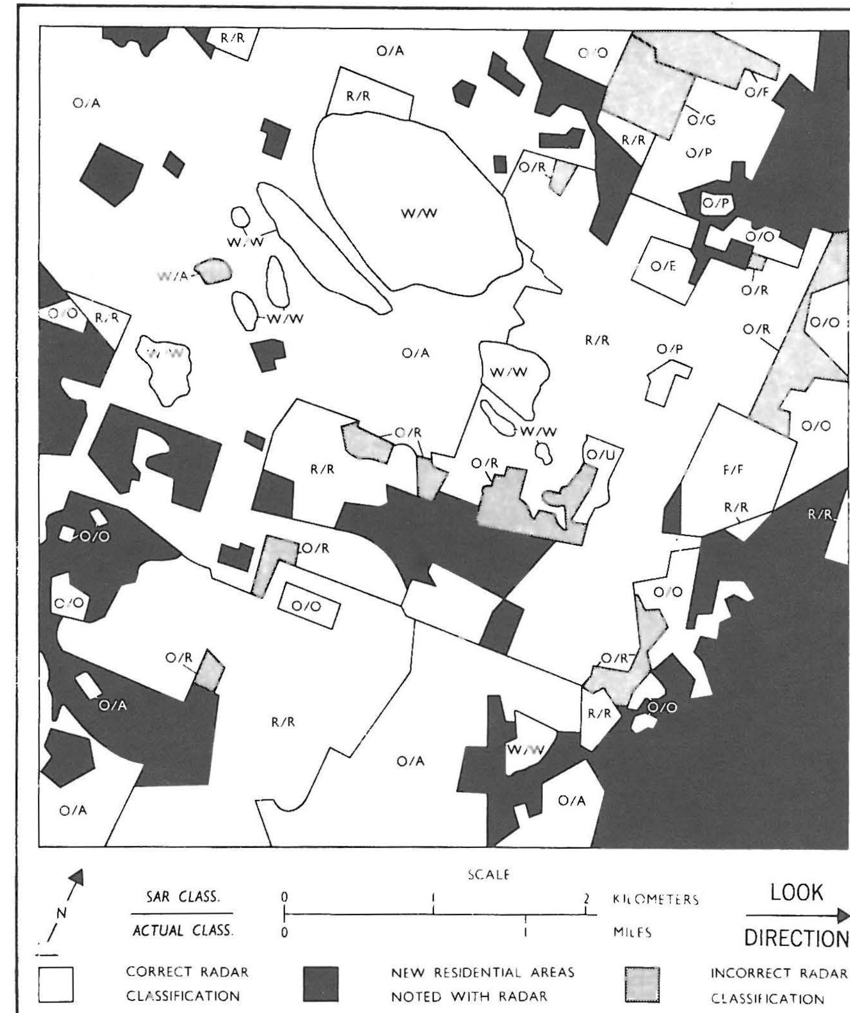

Figure 2. Classification Comparison, Study Area 1 (raw data). See Table 3 for key.

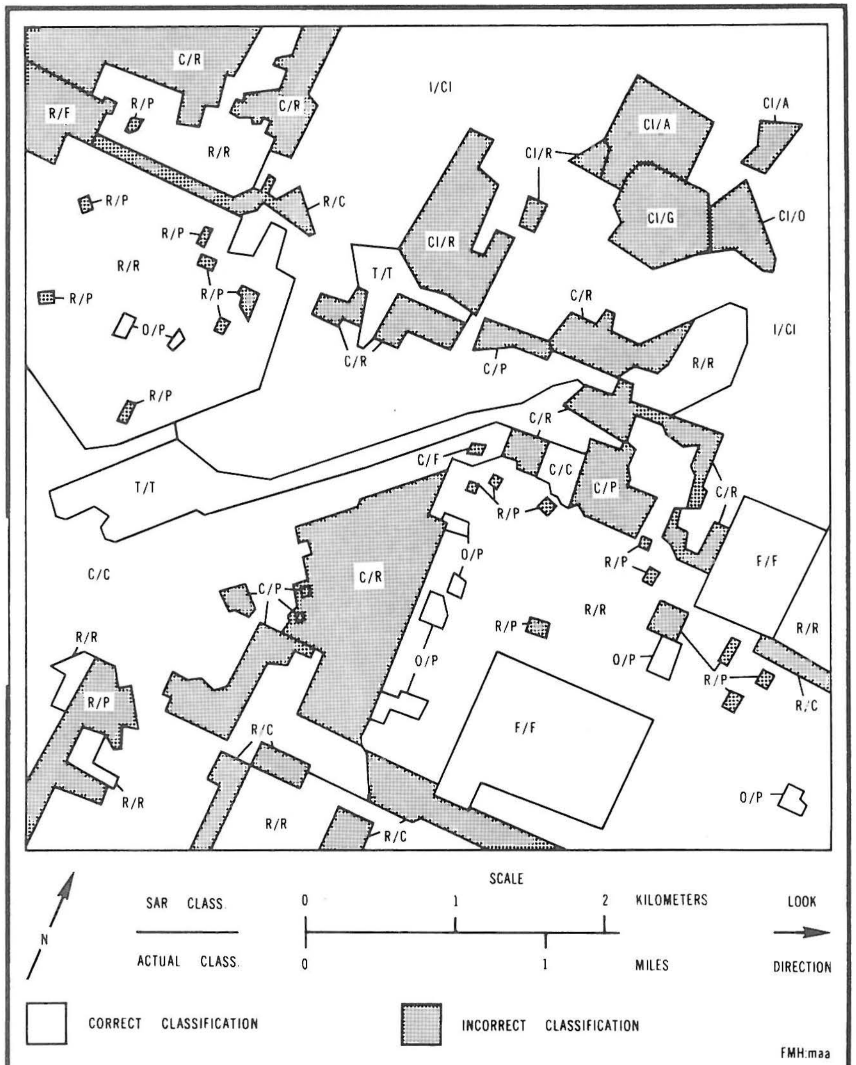

Figure 3. Classification Comparison, Study Area 2. See Table 3 for key.

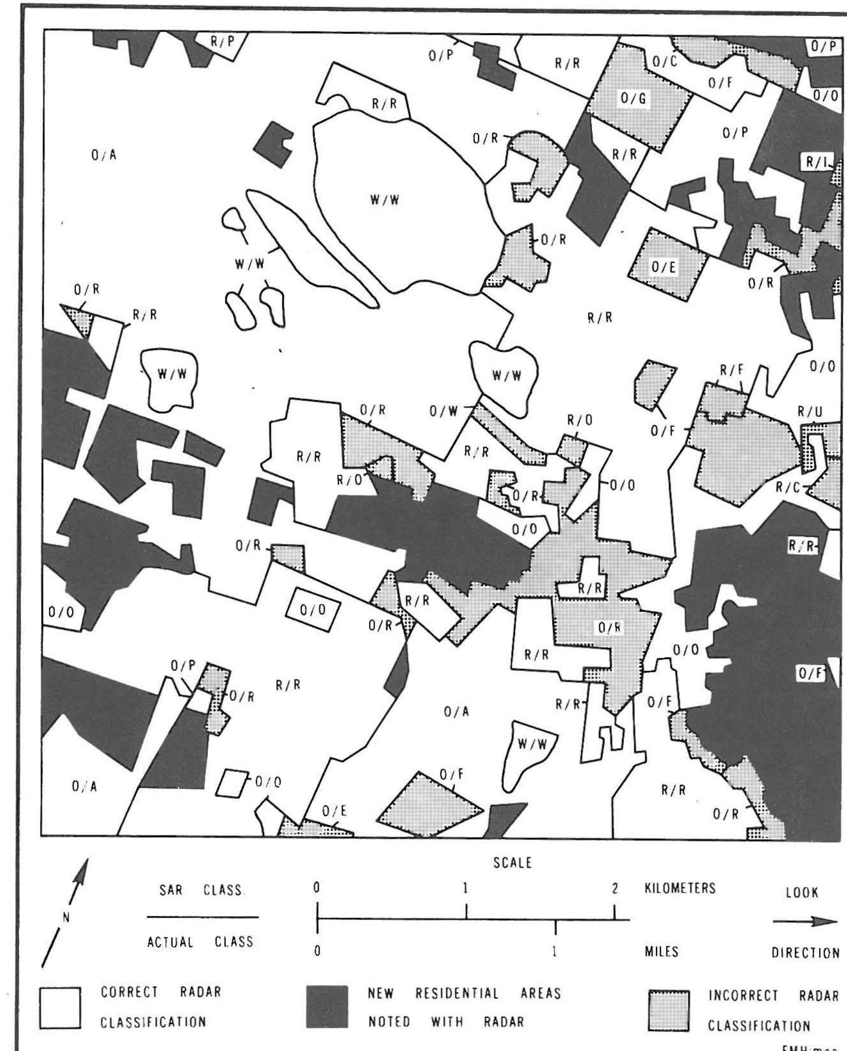

Figure 4. Classification Comparison, Study Area 1 (density slice). See Table 3 for key.