SIGNIFICANCE OF DUAL POLARIZED LONG WAVELENGTH

RADAR FOR TERRAIN ANALYSIS

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ABSTRACT

The scattered return recorded by imaging radars is primarily sensitive to target structure or roughness and composition or complex permittivity. The relative degree of penetration or the depth of material to which the return is sensitive also varies directly with the sensing wavelength. Most analysis of radar imagery involves an attempt to separate changes due to roughness and permittivity and to separate roughness into vegetation and ground (volume or surface scatter) components. Where vegetation can be eliminated as a factor, the surface return can be analyzed for variations in roughness or composition (primarily moisture content). Long wavelength systems with improved penetration capability have long been considered to have the potential for minimizing the vegetation contribution and enhancing the surface return variations. L-band (25 cm wavelength) imagery of the Arkansas geologic test site provides confirmatory evidence of this effect. However, the increased wavelength increases the sensitivity to larger scale structure at relatively small incidence angles. The regularity of agricultural and urban scenes provides large components in the low frequency-large scale portion of the roughness spectrum that are highly sensitive to orientation. The addition of a cross polarized channel is shown to enable the interpreter to distinguish vegetation and orientational perturbations in the surface return.

New Technology None

INTRODUCTION

The Landsat and Skylab programs have vividly demonstrated the utility of spacecraft data for earth resource applications. These applications include mineral and petroleum exploration, agricultural and natural vegetation discrimination, land use and landform classification and a host of others (Matthews, 1978). A recurrent theme in the reports of these applications is the necessity of timely data acquisition and the desire for a measurement parameter responsive to moisture. Radar has long been proposed as the logical extension of the current orbital remote sensing capability. The frequency range and active mode of operation of radar provide the desired day-night all-weather sensing capability. This operational advantage coupled with the capability of rapid data acquisition has led to extensive use of airborne radar as a substitute for photography, particularly in remote and cloud-shrouded regions of the world. This type of application involves interpretation of the scene geometry as transformed by the image system. Discrimination of areas and regions is utilized, but little identification is attempted by other than heuristic methods. Virtually all commercial uses of radar are based on operational convenience and the advantage afforded by having selectable angles of incidence and orientation to enhance terrain shadowing.

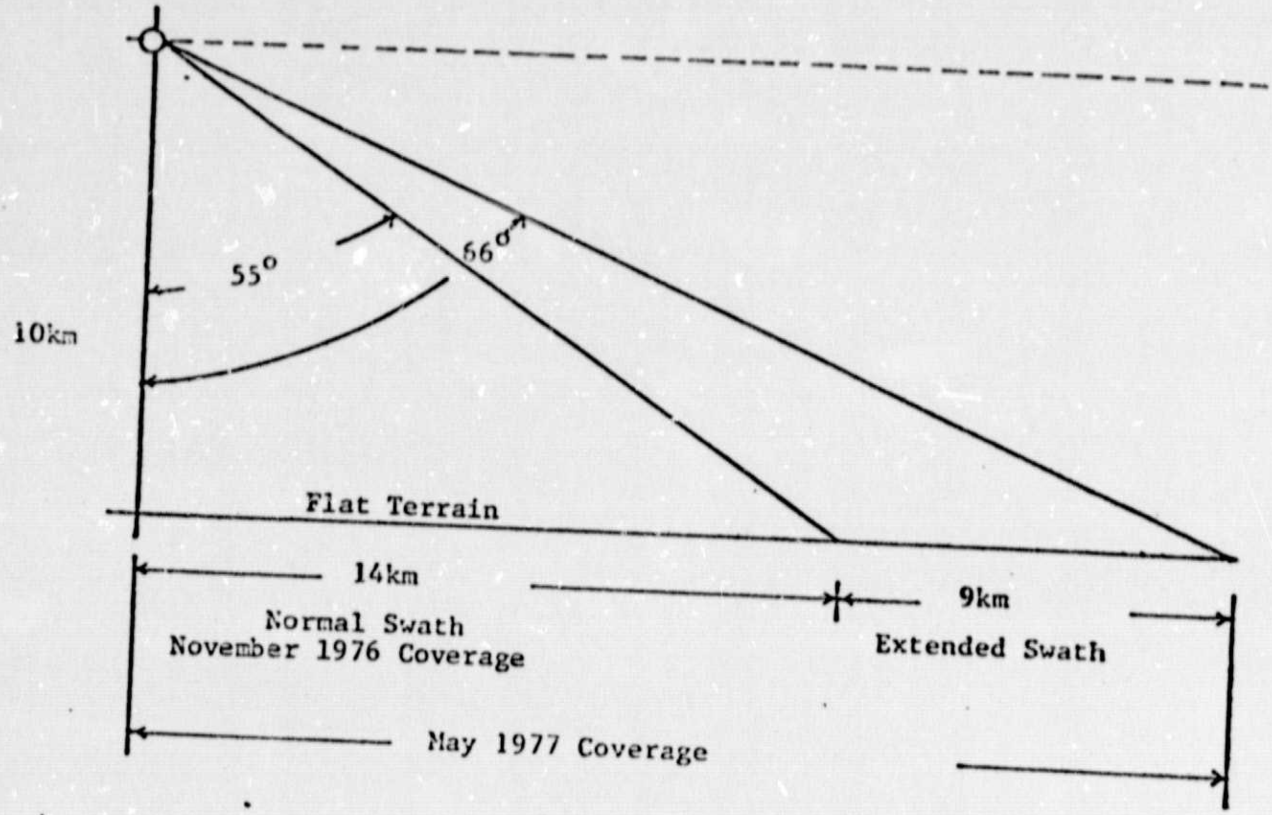
For several years, researchers in radar remote sensing have attempted to identify specific applications that make use of the unique information contained in the scattered return produced as a result of the terrain-sensor interaction. Briefly stated, the unique features of the radar return are a sensitivity to roughness (structure) at the wavelength scale, a sensitivity to moisture content (composition) caused by the relatively high permittivity of water, and the ability at lower frequencies to penetrate a significant depth of material. Applications development involves relating roughness or permittivity changes to desired properties of the terrain and selection of the system operating parameters to enhance these changes. System specification and image analysis primarily involve attempts to separate changes due to roughness and permittivity, and then to separate roughness into vegetation and ground (volume or surface scatter) components. Because both types of variation are expressed as changes in intensity, this separation requires multiparameter, multisensor, or a priori information of the target.

Long wavelength systems have been proposed as a means of enhancing several earth resource applications. Where signal return from vegetation can be eliminated, the longer wavelength provides roughness discrimination on a larger scale. The longer wavelength also has been proposed as a means of decreasing the roughness sensitivity (both surface and vegetation) of agricultural fields and thus enhancing sensitivity to soil moisture changes. An additional benefit may be increased penetration which provides the moisture estimate for an increased depth of the surface material. Because long wavelength radars may be less sensitive to vegetation changes and consequently more responsive to the underlying surface, their use could improve geologic mapping.

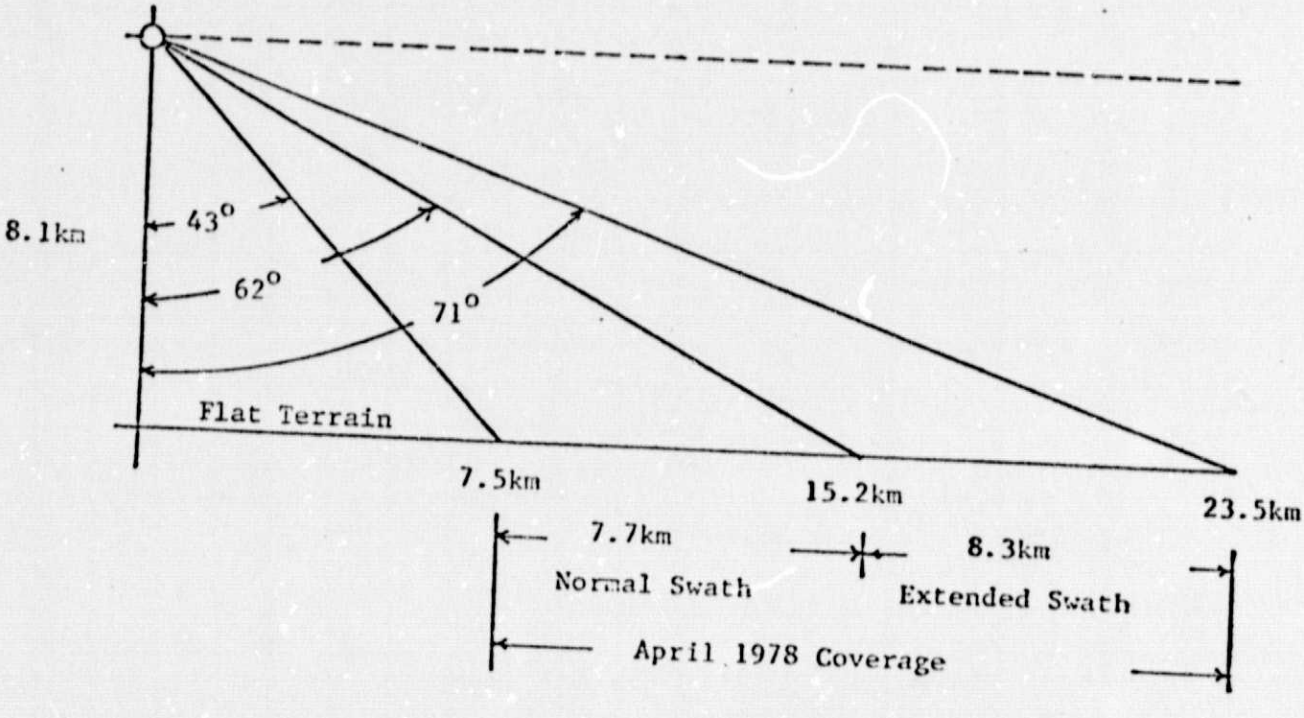
TEST SITE AND DATA DESCRIPTION

The Arkansas geologic test site is within the Arkoma basin, an east-trending structural trough extending westward across Arkansas into Oklahoma. In Oklahoma, this basin is occasionally referred to as the McAlester basin, whereas the Arkansas part is called the Arkansas Valley, which includes most of the test site. The northern flank of the Arkansas Valley is characterized by gently folded sedimentary rocks. On the south is a medial zone of moderate folding. The southern limit of the Arkansas Valley consists of a zone of very intense folding which has been further modified by thrust faulting because of proximity to the northern Ouachita Mountains. Vegetation cover within the test site ranges from agricultural crops and pastures in the lowlands to ground-masking deciduous, coniferous and mixed forest types in the highlands.

Radar imagery at 25 cm wavelengths (Jet Propulsion Laboratory, L-band system) was obtained over the Arkansas test site on November 4, 1976, May 29, 1977, and April 13, 1978. The November data consisted of a single east to west swath (14 km wide) across the test site. The May coverage provided 10 north-south flight lines approximately 23 km wide and approximately 100 km long. The incidence angles of the coverage were modified for the April mission; it provided similar north-south flight lines but the swaths covered approximately 16 km. The SLAR geometry for the coverage acquired is shown in Figure 1. The November flight had a single polarization configuration (HH). The May flight provided dual polarization (HH and HV), and the April data consisted of the full polarization complement (HH, HV, VV and VH). The May data were obtained with the deciduous trees in full leaf in the uplands and most fields planted in the lowlands, the April flights duplicated



A. Configuration for November 1976 and May 1977 flights.



B. Configuration for April 1978 flight.

Figure 1. L-band geometry.

the May coverage at a time of almost complete defoliation. Contrasting terrain conditions would permit evaluation of the vegetation penetration capability and any consequent advantage it might afford.

RADAR IMAGERY

In the upland regions of the test site both the May and April imagery of forested areas showed a relatively uniform gray tone and cleared areas were uniformly dark. The pattern was the same for both the like and cross polarized images, and little difference in discrimination capability was apparent among the various polarizations. Figure 2B is an example of an L-band image (HH) from the May flights illustrating the appearance of the upland regions. Figure 2A shows nearly the same area as recorded by a Ka-band (HH) radar system. However, in the lowland areas, detailed examination of both polarizations produced by the May flights revealed several regions of anomolous return. In cultivated areas, well defined field patterns with intensity variations spanning the full range of the film were evident on the like polarized imagery. The cross polarized imagery of the same areas showed all fields as a relatively uniform low return with the field boundaries faintly visible, apparently because of fencing and vegetation on the boundaries. These returns are shown in Figures 3 and 4.

To investigate these anomalies, field checks of the areas including discussions with individual farmers were conducted in an attempt to establish the conditions at the time of overflight. Most of the fields in the areas were planted with soybeans which according to planting dates and crop calendar should have ranged from just emergent to a maximum height of six inches at the time of imaging. The only discernible

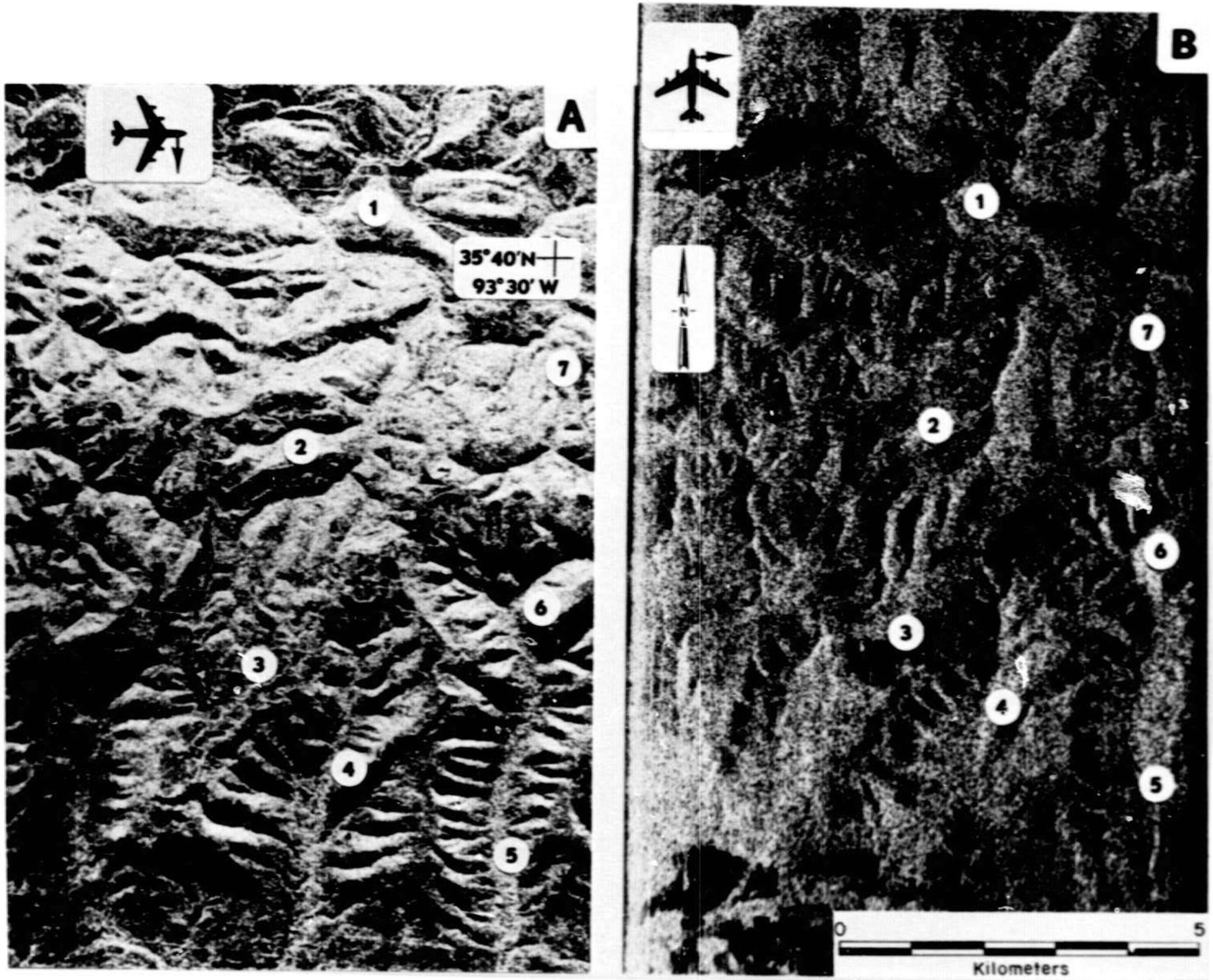


Figure 2. Radar imagery of Arkansas test site. A) Ka-band radar image; B) L-band image of approximately the same scene.

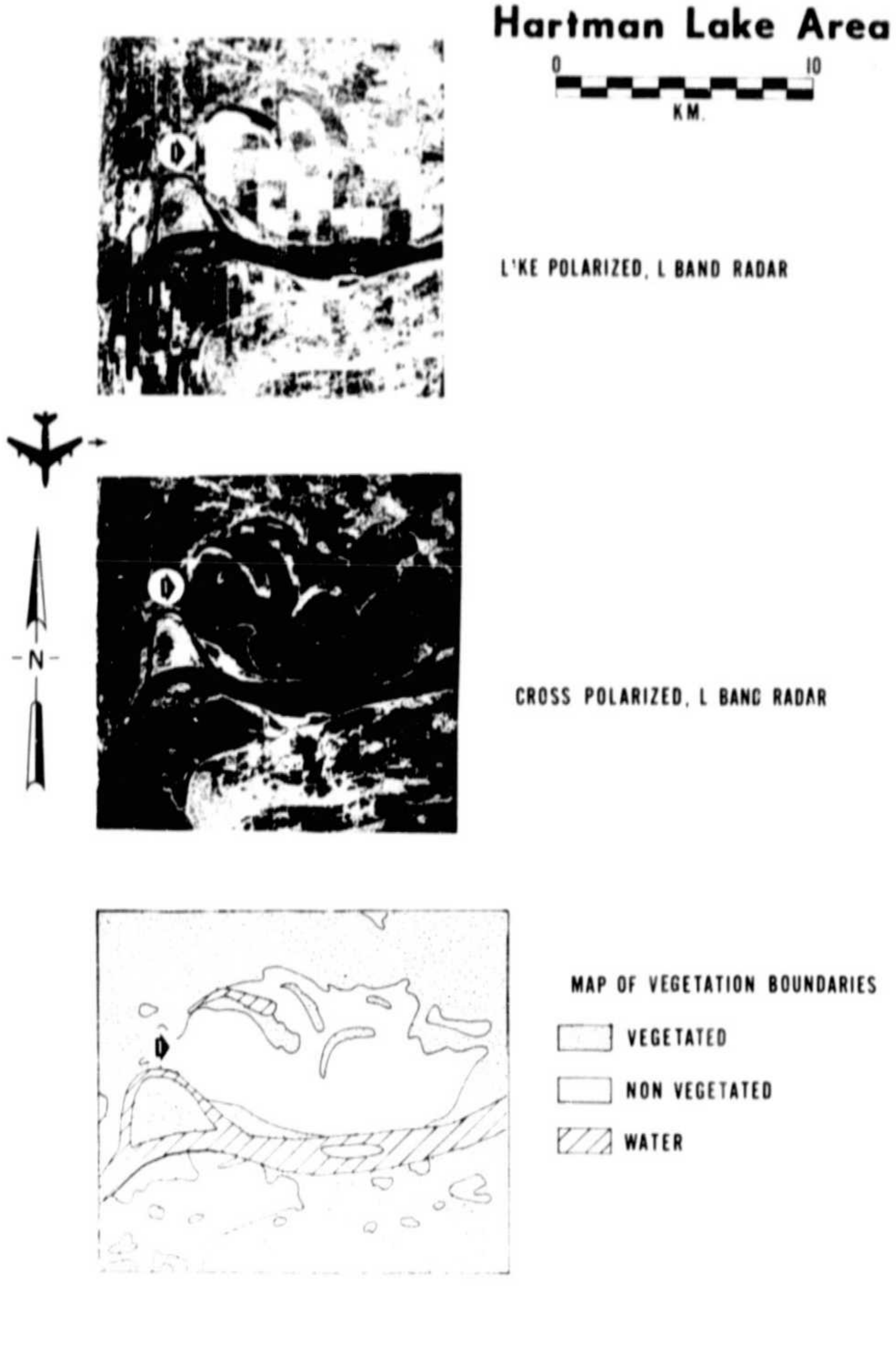


Figure 3. Anomalous returns from non-vegetated fields on like polarized L-band radar, normal swath mode configuration.

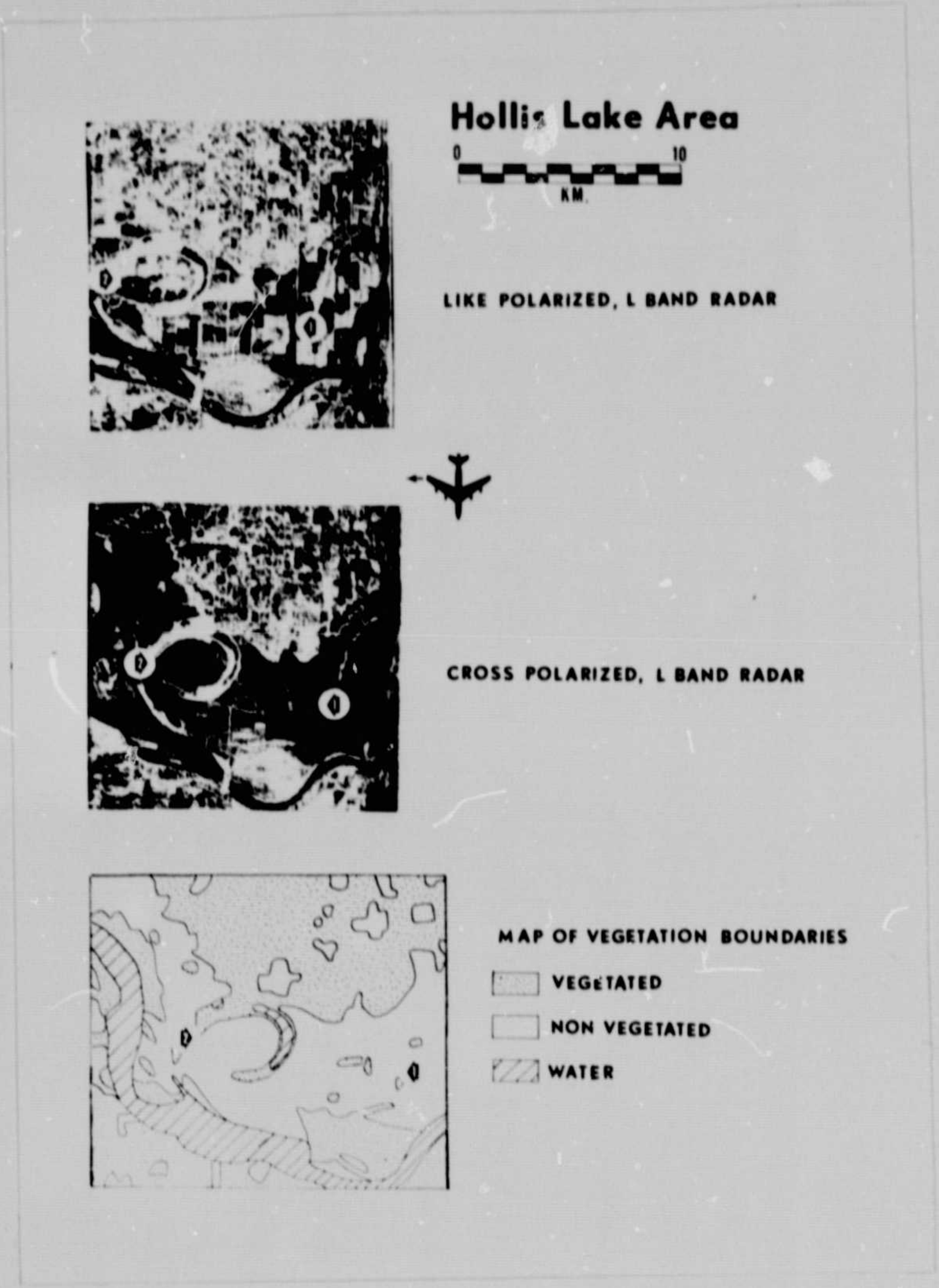


Figure 4. Anomalous returns from non-vegetated fields on like polarized L-band radar, normal swath mode configuration.

difference between fields was in row orientation. In every area examined this pattern corresponded directly with the return variations noted. Fields with rows parallel to the flight line were uniformly high return whereas those with rows perpendicular to the flight line were uniformly low return. The row pattern apparently causing this wide variation in return signal was basically that left by the planter and consisted of ridges approximately 8 cm high with 90 cm spacing. The height and definition of these ridges at the time of overflight were much less than those found later in the growing season after repeated cultivation.

Another region of anomalous return was found in the city of Fort Smith. A large regular area near the center of the city was well defined as a region of relatively low return on the like polarized image. The same area of the cross polarized image could not be discriminated. Again, field examination proved this effect to be due to orientation. Figure 5 shows the imagery and a street map of Fort Smith indicating that the region is defined by an approximately 45^{o} change in the street orientation.

RADAR INTERPRETATION

Field Patterns The cause of the anomalous field pattern was easily determined by post flight field inspection to be the uniformity of crops and cultivation. The row orientation sensitivity was neither new nor surprising (Schwarz and Caspall, 1968; Morain and Coiner, 1970). However, the magnitude of the variation, spanning the full dynamic range of the image film, resulting from such relatively small row heights was startling.

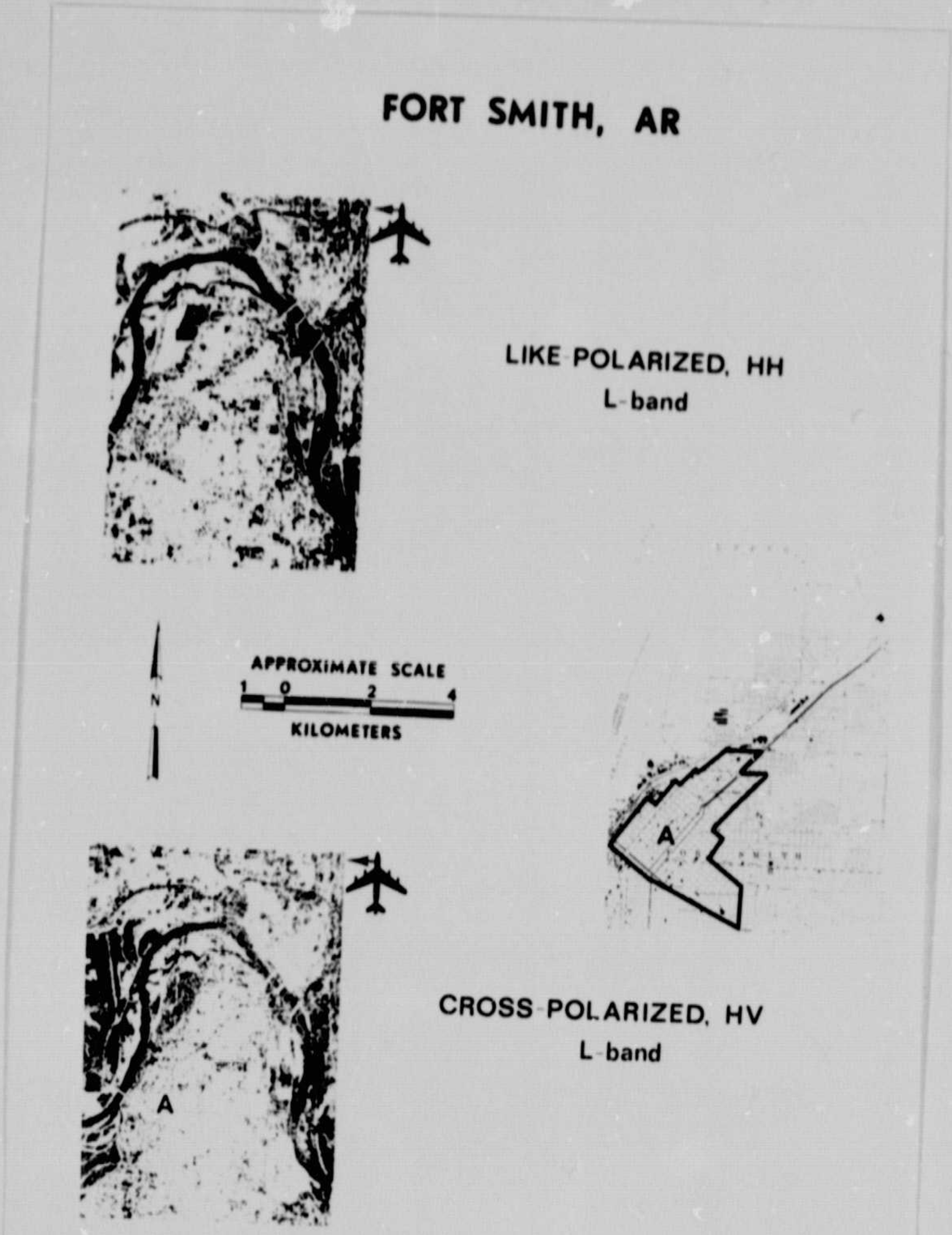


Figure 5. L-band radar image of Fort Smith, Arkansas.

Most observations of row orientation sensitivity have been at higher frequencies and/or in the presence of screening vegetation (Batlivala and Ulaby, 1975). Consequently, the ground return has been interpreted by a Kirchoff or physical optics model which is inherently a high frequency model. The usual interpretation is that the near side of the rows tends to orient a greater portion of the surface near normal to the incident radiation causing an increased specular return component. The frequency dependence of the orientation sensitivity is interpreted as being a consequence of the greater vegetation penetration capability of the lower frequencies which causes the ground to influence the return more at low frequencies and the vegetation to mask the ground and give a more uniform return at higher frequencies. The long wavelength and relatively low height of the furrows in the examples shown here violate the basic assumptions of the physical optics model rendering it unsuitable for this analysis.

The roughness scale and wavelength range in these examples are much more consistent with the Rice or small perturbation model which is inherently a low frequency model. Here the return is basically considered the summation from components in the surface roughness spectrum satisfying the Bragg condition (Barrick and Peake, 1968). Though both the physical optics and small perturbation models lead to Bragg scatter, the interpretation is more apparent in the small perturbation model and the scale is more compatible with this model. The surface obviously has a broadly uniform small scale roughness spectrum with an isolated large scale spike corresponding to the row periodicity.

The mechanism observed here is apparently simple Bragg scatter, however, there is no evidence of banding in the imagery such as would be expected if the individual modes or sidelobes of the Bragg diffraction pattern were discriminated. Because the surface is a composite of several roughness scales, some filling of the pattern apparently occurs to smooth out the distinct mode pattern expected from a single component.

The lack of corresponding well defined patterns in higher frequency imagery taken at times when most fields are fallow leads to the conclusion that there is a significant frequency dependence in the effect of row orientation even in the absence of vegetation. As the wavelength of the system approaches the period of the rows the lower order Bragg modes dominate the return. At shorter wavelengths the higher order modes are more effectively smoothed by the higher frequency roughness components. In essence this effect is simply another manifestation of "size filtering" in the rough surface radar return.

The lack of field definition in the cross polarized imagery is attributed to the almost complete lack of vegetation. The mechanism of depolarization requires a double-bounce or reflection, thus it is much more sensitive to volume scattering than to surface scattering, particularly one that fits the criterion of slightly rough.

In those areas where the May coverage provided overlap of normal and extended swaths, returns in the far range of the extended swath were of diminished intensity in comparison with those from similar fields imaged in the normal swath. Confirmation of the belief that return intensity might also be incidence angle dependent was provided by the April 1978 imagery. The April coverage included two swaths of relatively large incidence angles (43^{o}-71^{o} Figure 1), and the anomalous return from bare fields was significantly reduced. The diffraction or grating effect caused by periodicity of the surface should, in general, be inversely proportional to incidence angle. As incidence angle is increased, higher modes are oriented in the backscatter direction (away from the radar) and these generally will decrease the return amplitude. Thus, the enhanced return due to surface periodicity and orientation would be expected to vanish at sufficiently large incidence angles. The decrease with incidence angle, however, will be additionally influenced by row height and spacing.

Cultural Features The anomalous pattern in the city of Fort Smith is an example of the "cardinal point effect" noted several years ago. When the large flat surfaces of buildings are oriented normal to the incident radiation, the surface and building act as a corner reflector enhancing the like polarized return. At angles other than normal the reflected energy is directed away from the backscatter direction.

The effect of enhancement can be seen in the Ka-band image of New Orleans shown in Figure 6. The same pattern in Fort Smith is found in the Ka-band image shown in Figure 7. In every case it is clear that the reflection mechanism does not tend to depolarize the signal, thus the patterns due to street orientation seen in the like polarized imagery are absent on the cross polarized imagery.

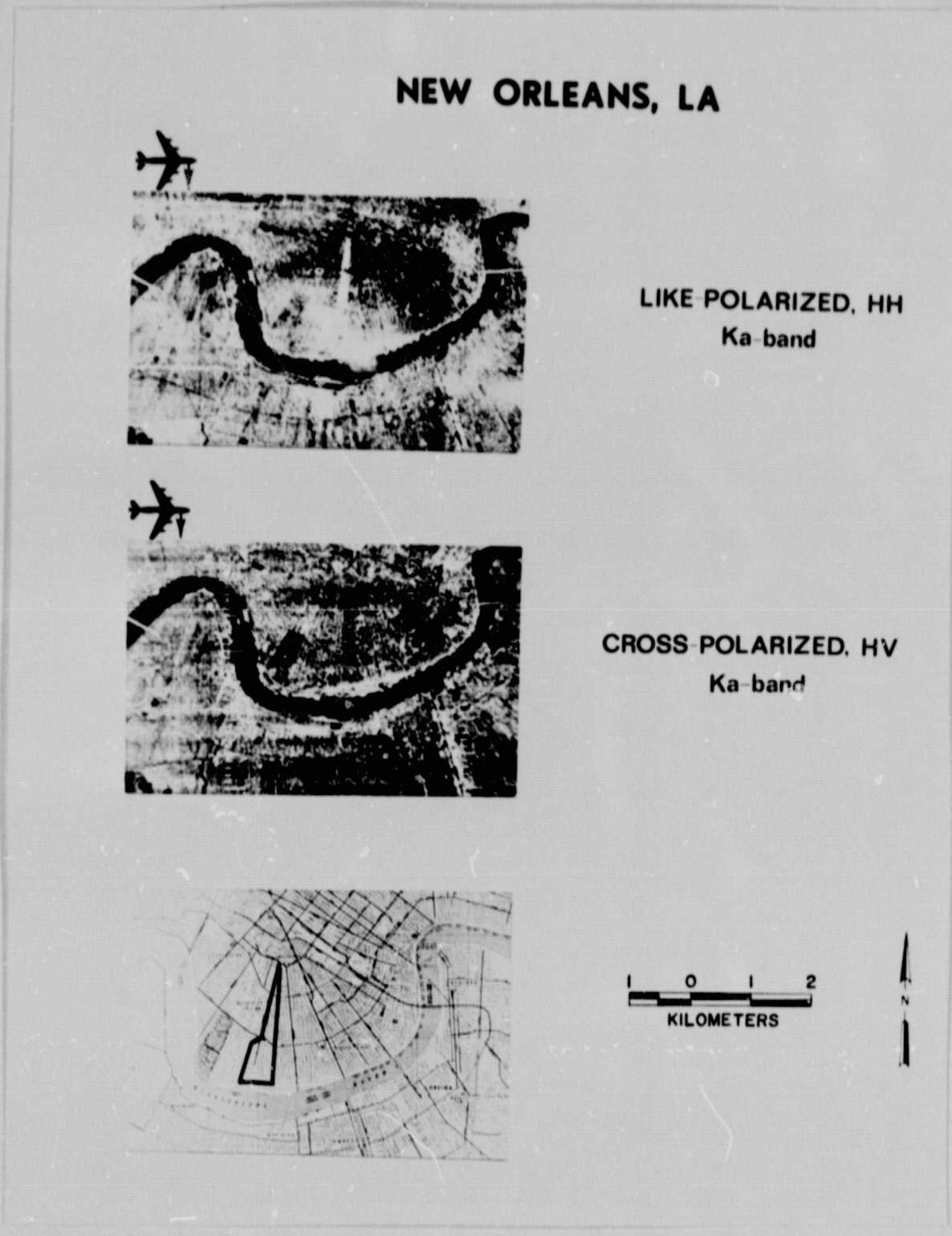


Figure 6. Ka-band image of New Orleans, Louisiana.

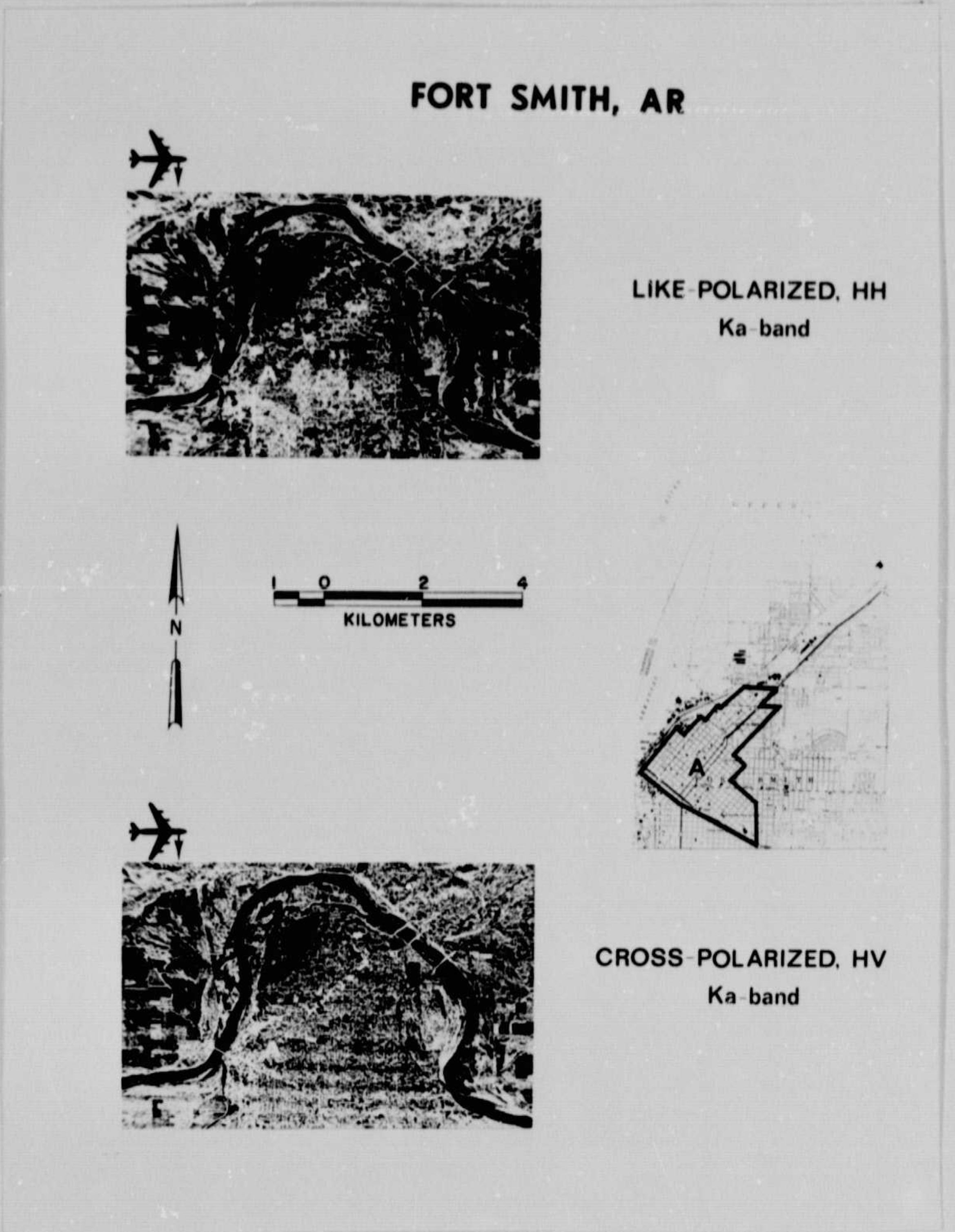


Figure 7. Ka-band image of Fort Smith, Arkansas.

SUMMARY

Long wavelength radar appears to offer some advantage in vegetation penetration. However, the increased wavelength increases the sensitivity to larger scale structure, especially at relatively small angles of incidence. The regularity of agricultural and urban scenes provide large components in the large scale portion of the roughness spectrum that are highly sensitive to orientation. The range of return variation due to the different orientation of relatively small rows is seen to equal or exceed what may be expected as a result of either soil moisture or vegetation differences. If long wavelength radar is to be used in an agricultural environment, it is essential that this effect be identifiable to allow meaningful measurements of soil or vegetation.

The addition of a cross polarized channel permits discrimination of vegetation and orientational effects. This capability would be essential for any agricultural application. Whether even this technique provides sufficient correction to allow the measurement of soil moisture cannot be determined. However, soil moisture measurement in the L-band frequency range, at relatively small angles of incidence, appears to be impossible without the use of cross polarized data.

REFERENCES

1. Barrick, D. W. and W. H. Peake, A Review of Scattering from Surfaces with Different Roughness Scales, Radio Science, Vol. 3, pp. 865-868, 1968.

2. Batlivala, P. P. and F. T. Ulaby, The Effect of Look Direction on the Radar Return from a Row Crop. Remote Sensing Laboratory Technical Report 264-3, University of Kansas, Lawrence, Kansas, May 1975.

3. Matthews, Richard E., ed., Active Microwave Users Workshop Report. NASA Conference Publication 2030, 1978.

4. Morain, S. A. and J. C. Coiner, Evaluation of Fine Resolution Radar Imagery for Making Agricultural Determinations, CRES Technical Report 177-7, University of Kansas Center for Research, Inc., Lawrence, Kansas, 1970.

5. Schwarz, D. E. and F. Caspall, The Use of Radar in the Discrimination and Identification of Agricultural Land Use, Proceedings Fifth Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, pp. 233-247, April 1968.