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N69-16108	
(ACCESSION NUMBER)	(THRU)
27	1
(PAGES)	(CODE)
CR# 99233	14
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-138
January 1969

Mr. Robert Porter
Acting Program Chief,
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith are two copies of:

INTERAGENCY REPORT NASA-138

SIDE LOOKING RADAR IN URBAN RESEARCH:

A CASE STUDY*

by

Eric G. Moore**

The U.S. Geological Survey has released this report in open files. Copies are available for consultation in the Geological Survey Libraries, 1033 GSA Building, Washington, D.C. 20242; Building 25, Federal Center, Denver, Colorado 80225; 345 Middlefield Road, Menlo Park, California 94025; and 601 E. Cedar Avenue, Flagstaff, Arizona 86001.

Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. R-09-020-024, Task No. 160-75-01-35-10
**Department of Geography, Northwestern University, Evanston, Illinois

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

INTERAGENCY REPORT NASA-138

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by

Eric G. Moore**

*Prepared by the U.S. Geological Survey (USGS) for the National Aeronautics and Space Administration (NASA) under NASA Contract No. R-09-020-024, Task No. 160-75-01-35-10. Work performed by Northwestern University for the USGS Geographic Applications Program under USGS Contract No. 14-08-0001-10654.

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SIDE-LOOKING RADAR IN URBAN RESEARCH: A CASE STUDY

by

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ABSTRACT

Previous studies have shown that side-looking radar is of considerable value in geoscience investigations. A discussion of the properties of side-looking radar concludes that in the urban context the system is particularly suited to the performance of three types of task: (1) the collection of data when the timing of the overflight is critical; (2) the preliminary surveying of large cities to determine the gross pattern of internal land use; and (3) the preliminary surveying of large regions to determine the location and areal extent of small urban centers together with the nature of the linkages between these centers.

The main part of the paper examines the capabilities of AN/APQ-97 radar imagery of Chicago in both HH and HV polarization modes with regard to the compilation of a land use inventory. The main conclusions are (1) the linear elements of the transportation network are clearly defined; the HV proves to be more useful than the HH as high returns from adjacent buildings on the latter prevent accurate interpretation; (2) the gross patterns of industrial, residential and open space land use are identified although it is not possible to map local boundaries of different land use types in detail; and (3) attempts to identify commercial land proved to be surprisingly unsuccessful, the cardinal effect introducing considerable difficulties into the recognition process.

Finally, it is stressed that it is necessary to undertake similar experiments using other radar systems. In particular, attention should be focused on designing systems which are appropriate to the data desired in contrast to present procedures which attempt to determine what data can be extracted from one specific system.

SIDE-LOOKING RADAR IN URBAN RESEARCH: A CASE STUDY

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In recent years many studies have demonstrated the value of side-looking radar in geoscience investigations.[1] In this report attention is turned to its capabilities in studying certain man-made features of the earth's surface, namely the internal structure of a large metropolitan area. The research is part of an ongoing program aimed at evaluating the content of imagery derived from a variety of remote sensors operated over urban areas.

The research reported here is essentially sensor-oriented rather than problem-oriented. The basic question asked is '*Given an image produced by a specific sensor, what data relevant to the internal structure of an urban area can be extracted from that image?*' This constitutes a first, exploratory stage in evaluating the potential of a remote sensing system. Answers to such a question can do no more than suggest some of the types of problems to which a sensor might be applied. A second, more rigorous, stage in evaluating the utility of a sensor must be its application to specific and significant problems formulated within the context of current urban planning and research.

Theoretical Utility of Returns from Side-Looking Radar

Each remote sensing system possesses advantages over other systems for certain purposes as a consequence of its own inherent characteristics. In the case of side-looking radar, four features are of particular importance:

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[1] See, for example, the many items cited in the bibliography of Ellermeier and Simonett (1965).

1. The active nature of the system permits the strength of the emitted signal to be controlled, and thus the magnitudes of the returns are not dependent on the amount of light or other radiated energy available.
2. In comparison with returns in the visible and near-infrared ranges of the spectrum, radar signals suffer little attenuation on their path through the atmosphere. In combination with (1), this means that radar possesses a virtual all-weather, day-and-night capability.
3. Modern side-looking radar is capable of imaging far larger areas in one pass than can be achieved using conventional aerial photographic techniques from the same altitude. The implication is that small-scale generalized imagery can be obtained frequently and at low cost compared with other methods.
4. Radar imagery may be regarded as a series of line samples of surface backscatter. The electro-magnetic impulses which are converted into the gray-tones of the imagery may be directly recorded as digitized values in the same manner as data obtained from a flying-spot scanner. This property greatly increases its potential value for automated data-processing.

On the basis of the above comments, it is suggested that side-looking radar is particularly suited to three types of projects relevant to the study of urban areas:

i) the collection of data when the timing of the overflight is critical, i.e., postponements due to bad weather cannot be tolerated. For example, radar would appear to be the only feasible system for monitoring urban traffic flows from the air in real-time, or even for regular sampling at peak flow periods.

ii) the preliminary surveying of large cities or sets of cities to determine the gross pattern of internal land uses.

iii) conducting preliminary surveys of large regions to determine the location and areal extent of small urban centers together with the nature of the linkages between these centers. Of interest in this context is the application of the law of allometric growth to area measurements which leads to quite accurate estimates of population size [Nordbeck (1965), Wellar (1968)].

In addition to identifying the tasks for which radar possesses particular advantages, there is justification for providing a more general statement of the types of urban data that can be obtained with this sensor. In determining the specific instrumentation that is to be installed in orbiting spacecraft, limitations of space may not permit the inclusion of the most suitable instrument for each category of urban data required; it may be necessary to compromise by using the best 'all-round' instrument, and thus knowledge of the general capabilities of each sensor is required.

Discussion of the capabilities of side-looking radar is undertaken within the context of the second type of project outlined above, namely the determination of gross patterns of land use (including the transportation network) within a large urban area. Previous studies concerned with the application of side-looking radar to geoscience problems have shown that this sensor is particularly efficient in detecting linear elements in the ground pattern [e.g., stream channels (Beatty, et al, 1965) and fault lines (Feder, 1957)]. The work of Beatty (1965) and of Simonett and Morain (1966) has also shown that textural differences in returns from different crops provide important clues to the nature of spatial variation in crop types. This background suggests that the aim of obtaining data relevant to the structure of the transportation network and to the patterns of gross land use within the city are capable of realization, although the level of accuracy attainable is to be determined.

Basic Study Design

Image interpretation was undertaken within the context of inventory compilation. Data was extracted in a systematic manner; this would appear to provide the most useful guidelines for potential users of side-looking radar. The following land use categories were identified and the imagery was examined anew for each category to determine the nature of relevant data which could be extracted by visual interpretation procedures:

1. The Transportation Network
   a. Linear elements
      i) Railroads
      ii) Waterways
      iii) Roads: Expressways
         Other major arterials
         Section and sub-section roads
   b. Terminal facilities
      i) Railroad stations and marshalling yards
      ii) Wharves
      iii) Parking Areas
2. Other Major Land Uses
   a. Industrial (Manufacturing)
   b. Commercial
   c. Residential
   d. Parks and other open space

Interpretation Procedures

In an exploratory study in which identification is effected by visual inspection, it is not possible to completely isolate the various components of the recognition process. However, it is suggested that the following procedures, used in combination, form the basis of interpretation.

Analysis of Image Texture

> The "texture" apparent on a radar image....is composed of two separate components, namely a system component and a true (terrain) component. The system component arises from the number of pulses averaged per resolution element.... When very few pulses are averaged, as in the case of much synthetic aperture radar imaging, the wider is the spread of gray-scale values per unit resolution cell and the "grainier" the image appears on an enlargement.[2]
>
> All radar systems have some residual system texture....textures coarser than this residual or system component may reasonably be expected to reflect in part real differences in meso and macro terrain roughness characteristics (including shadowing) to which radar is sensitive (Simonett and Morain, 1966, p. 608).

In an urban area the "terrain roughness" is largely determined by the size and spacing of buildings and associated open space. Since different land uses are typically associated with certain recognizable spatial configurations of structures (including a lack of structures in the case of parks), it may be hypothesized that radar returns will help to differentiate between basic land use types.

Comparison of Like- and Cross-Polarized Imagery

Two cases must be considered in studying the effect of polarization of radar returns from a given terrain. (1) the radar return as a function of the polarity of the transmitted signal; and (2) the return as a function both of the polarity of the transmitted signal and of the depolarizing characteristics of the terrain.

The second case is pertinent in considering returns from the urban area, since the depolarization of the transmitted signal by the imaged surface is sufficient to be recorded on film. The relative depolarization produced by different surfaces may provide important clues as to differences in land use types. In the present study, this involves the comparison of two simultaneously produced images; one image is produced by the horizontally

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[2] Although the AN/APQ 97 is not a synthetic aperture system, such graininess is clearly visible in Figures 1 and 2.

polarized component of the return from a horizontally polarized transmitted signal (HH), and the other is produced by the vertically polarized component of the return from a horizontally polarized transmitted signal (HV).

Analysis of Spatial Association and Spatial Context

"Most human interpretive techniques rely heavily on spatial structure, the shape of objects, and their spatial relationships to other objects." [Holter and Legault (1964)] In the visual inspection of radar imagery, it is inevitable that these factors are intertwined with other recognition procedures; for example, experience suggests that high intensity returns (indicating a 'rough' terrain) adjacent to railroad tracks are more likely to be indicative of strip industrial than commercial development (the latter often shows up as an area of high return adjacent to main roads).

A major problem lies in the formalization of contextual statements so that reliable automated recognition procedures can be established. However, at present, the main task is to determine whether different types of phenomena can be recognized by any means or at any level; specific problems related to automation can be tackled subsequently.

The Imagery Used

Active microwave systems can be constructed to yield returns over a wide range of the electro-magnetic spectrum (from wavelengths of approximately 2 mm to 1 meter). The emitted signal may be polarized in a number of different ways (Ellermeier, et al, 1966) and the return signal may be recorded both in terms of the direction of polarization of the original signal and of the orthogonal polarization. The theoretical variety of returns that could be studied is considerable. In this report, attention is focused on returns from an AN/APQ-97 system which operated in the K-band (c. 3mm-3cm) and which possessed HH and HV polarization modes.

The imagery was obtained from a flight over Chicago, Illinois (NASA Test Site 43) in the summer of 1966. The study area comprises a strip along the shore of Lake Michigan, some 25 miles from North to South, stretching from South Evanston to the Illinois-Indiana border. The NNW-SSE flight-line roughly paralleled the lake shore so that the study area extends a uniform 6-8 miles inland to a point where the returns become too distorted to be of value.

A medium gain setting was used to obtain good contrast levels for the HH returns. No compensation was made for the HV with the result that the level of contrast is markedly lower for this polarization.

Both positive and negative transparencies as well as positive prints were available for both polarizations. The majority of the interpretation was performed using the positive transparencies as the resolution was marginally better than for the positive prints when utilized with light table and magnifying glass. The remainder of the interpretation was undertaken using enlarged positive prints, although, as may be seen in Figures 1 and 2, grain constitutes a considerable problem.

The Empirical Analysis

Extraction of data from the available imagery is considered for each of the land use categories specified in section B. Where the level of accuracy in interpretation is readily apparent (as in the case of the railroad network) only subjective comments are provided. Where the level of accuracy is more difficult to determine (as in the case of industrial and commercial land) comparisons are made between 'predicted land use' derived from the imagery and 'observed land use' recorded by the Northeastern Illinois Planning Commission.

1. *The Transportation Network*

a. Linear Elements

i) Railroads: Chicago has an extensive rail network with a large number

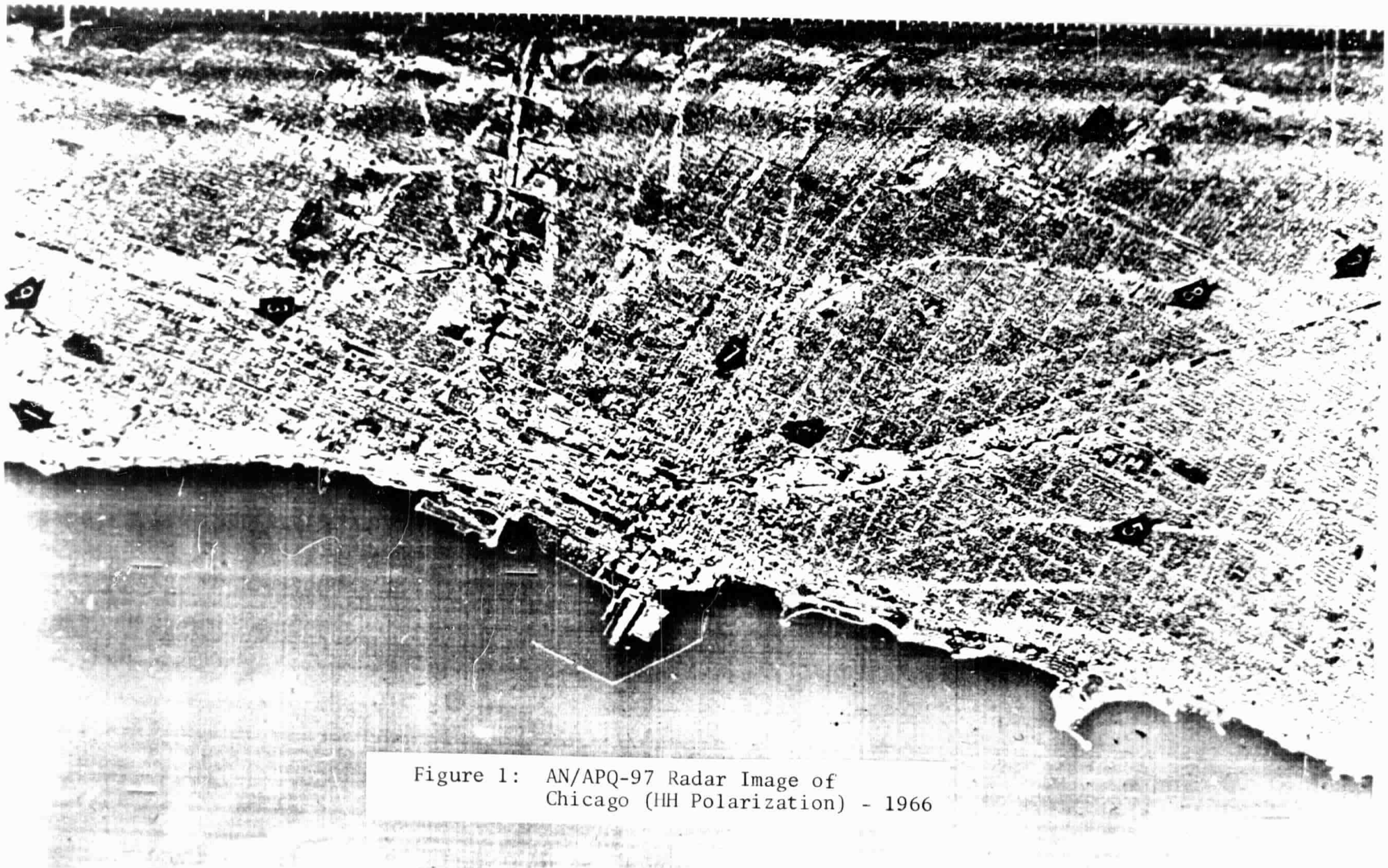

Figure 1: AN/APQ-97 Radar Image of Chicago (HH Polarization) - 1966

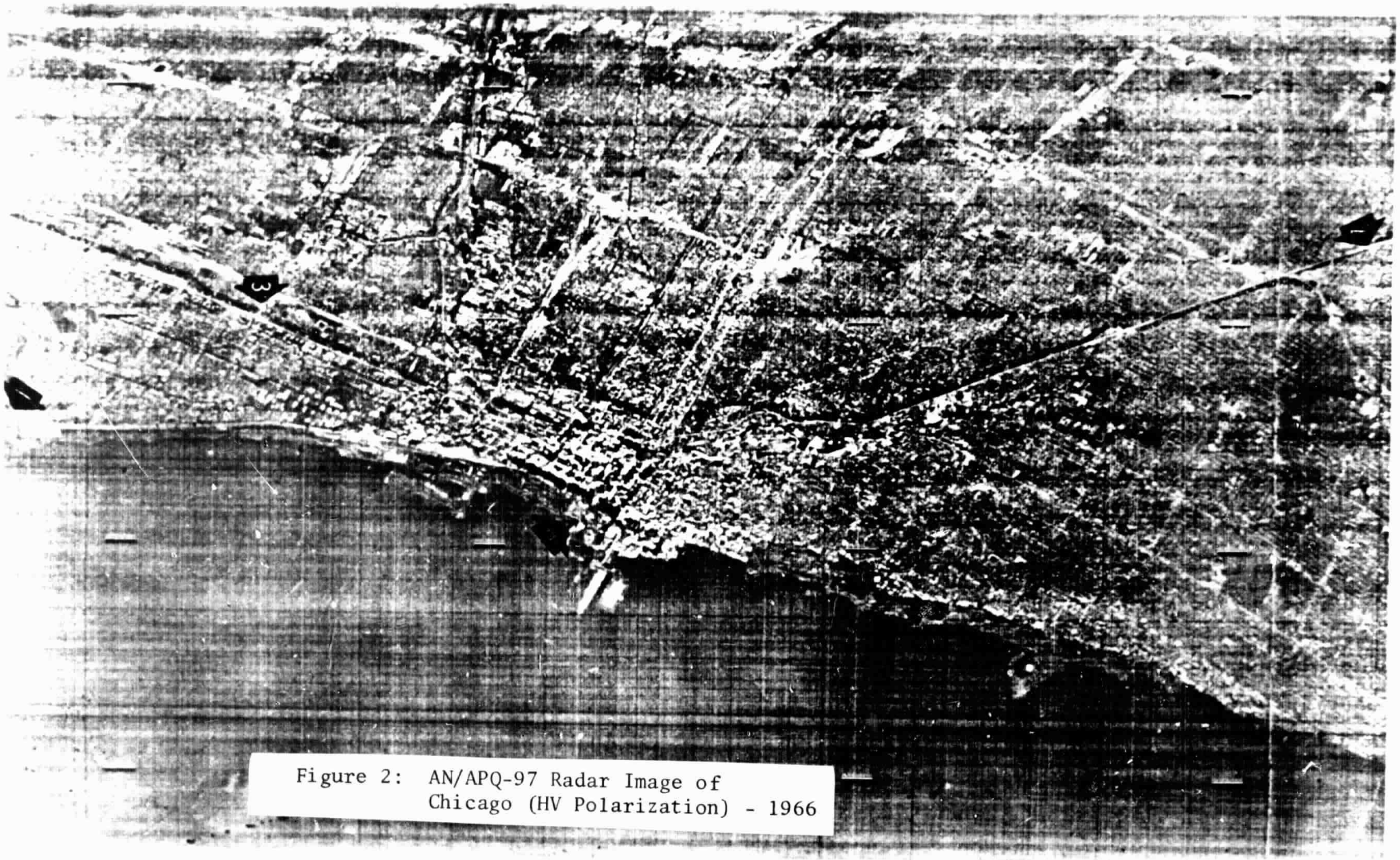

Figure 2: AN/APQ-97 Radar Image of Chicago (HV Polarization) - 1966

of railroads operating within the metropolitan area. The majority of the elements in this system may be identified in the imagery as continuous lines of high return. In some cases railroads may be confused with main arterial roads, but, in general, the following differences may be observed.

1. Railroads are continuous lines of high return as the 'rough' nature of the ballast, ties, and lines produces a high degree of backscatter. In contrast, the high returns typical of many roads is irregular (discontinuous) since the backscatter is produced not by the road surface itself but by the buildings and vehicles associated with them; the latter are not associated with the road surface in a systematic spatial way. For the wider roads, and for the expressways in particular, returns are obtained from the smooth surface of the highway, and these are seen as dark areas of low reflectance.
2. Railroad lines tend to be characterized by large radius curves in contrast to the angular changes of direction typical of roads and streets.
3. The frequent widening of the tracks to accomodate junctions and sidings contrasts with the comparatively uniform width of roads.

In general, the HV polarization was found to be more reliable in identifying railroad lines, particularly in the cases where other features adjacent to the tracks produce high levels of backscatter on the HH (see, for example, the area near the University of Chicago marked with arrow 1 on Figures 1 and 2). The easier identification results from the fact that the backscatter for the rail lines in the orthogonal polarization remains high whereas that for the adjacent buildings is much lower than for the original polarization.

The southbound Illinois Central, the westbound C.P.S.& P. and Chicago and Northwestern, and the northbound Chicago and Northwestern are all clearly identified on the HV. A second Chicago and Northwestern line which parallels the Kennedy expressway provides a good example of the contrast between railroads and major arterials. The two routes cross one another several times; these cross-overs can be readily discerned as the high returns of the railroad stand out in sharp contrast to the low returns of the expressway (arrow 2, Figure 2).

One portion of the railroad network, the elevated rapid transit system, did pose problems of identification. The N-S Howard Street line cannot be detected on either polarization, whereas both the Lake Street and Congress Street lines which run westward from the Loop are clearly seen on both the HH and HV. The prime reason for this difference appears to be that there are many more multi-story buildings adjacent to the Howard Street line than to the other two and the resulting high backscatter makes identification impossible.

ii) Waterways - The Chicago River is linked to Lake Michigan along the northern edge of the Loop. This link is clearly seen on the HV. The remainder of the system comprising the North and South Branches of the river and the North Shore Channel can be clearly identified on the HH. On both polarizations the water stands out as being the target with the lowest energy return.

iii) Roads

a. Expressways - The width of the expressways means that peripheral backscatter does not obscure the low returns from the road surface itself. For the most part, the expressways which radiate from the Loop can be identified on both the HH and HV; as one nears the downtown area, however, industry crowding in on the expressway and an increase in traffic flow produce sufficiently high backscatter on the HH to make identification difficult; the HV has to be used to trace the paths of the expressways in the inner districts. The best example of this difference is provided by the Dan Ryan from the Loop to its junction with the Chicago Skyway (Arrow 3 on Figures 1 and 2).

b. Other Major Arterials - Most of the major non-expressway routes within the study area are visible on the HH although the ease with which they may be identified varies considerably. With the exception of roads such as Ogden and Forest Preserve Boulevard which are perpendicular to the flight path, the roads are identified by the high returns from adjacent buildings rather than by low returns from the road surface.

The influence of the cardinal effect is very noticeable in examining the road pattern. Those elements which are parallel or perpendicular to the flight line stand out much more clearly on the HH than those which conform to the normal N-S and E-W alignment. The most noticeable instances are sections of Milwaukee Ave. (Arrow 2 on Figure 1), Lincoln, and Clark, which are parallel to the flight line, and Ogden and Forest Preserve Boulevard which are perpendicular to the flight line.

c. Lower Order Streets - The basic street pattern corresponds to the section lines which run in a N-S and E-W direction. Virtually all of the section roads, most of the half section roads, and just a few of the quarter section roads can be discerned as strips of high backscatter. A point that is in need of further research is the contribution of the Gestalt concept of "closure" to the identification of the smallest elements in the road net. It is felt that many of these elements are only "seen" because they are continuations of easily distinguishable elements in another segment of the image.

b. Terminal Facilities

i) Railway Stations and Marshalling Yards - Individual stations cannot be identified on either polarization. In contrast, most junctions and marshalling areas can be easily recognized, particularly on the HV where high returns from adjacent industry are absent. However, even though the locations of these yards can be specified with a reasonable level of accuracy, only the most tentative statements can be made regarding the size of the yards, for most of the ancillary facilities in the form of service and storage sheds merge with surrounding industry (see, for example, arrow 4 on Figure 1 which points to the complex of railway lines and cattle yards in South Chicago).

ii) Wharves - These are sufficiently well defined by the incidence of strips of very low returns amidst the high backscatter of surrounding warehousing facilities and industry to permit quantitative statements of the amount of berthing space available. Since no controls were obtained at the time of overflight, this was not done, but such firm statements would seem to be feasible with this system.

iii) Parking Areas - Attention was focused on known downtown parking areas, particularly that in Grant Park on the shore of the lake. Although the latter does show up as an area of marginally different texture on the HV (arrow 4 on Figure 2) it is not felt that consistently reliable results could be attained as the nearness of tall buildings to most parking lots produces too much backscatter or shadow to permit ready identification of the parking areas.

2. *Other Major Land Uses*

a. Industrial

In attempting to evaluate the usefulness of radar in the identification of industrial land use, an experiment was undertaken comprising four stages.

1. The construction of a tentative map of industrial areas north of the Chicago River from a visual inspection of the imagery. Experience suggested that industrial areas should be identified by a relatively coarse texture (compared with adjacent residential areas) with considerable internal variation in the amount of backscatter. These features should arise from the typical association of large buildings

with considerable amounts of open space, with the buildings lacking a common orientation within a given industrial area.

2. A comparison of the predicted industrial districts with those represented on the 1964 maps of the Northeastern Illinois Planning Commisssion.[3]
3. A re-examination of these areas on the imagery where gross errors of identification had been made in an attempt to improve recognition procedures.
4. A repetition of steps 1-3 for the area to the south of the Chicago River.

This procedure was considered to be a valid one as the researcher was a newcomer to the Chicago area, and had no prior knowledge to bias his predictions.

Figure 3 illustrates the extent of the overlap between "observed" and "predicted" industrial land use in the area to the north of the Chicago River. A number of points may be made:

i) It can be seen that the gross pattern of industrial land use is readily identified; however, it is almost impossible to fill in the detail at the neighborhood level.

ii) The internal variation in gray scale values for some areas is such that they were "seen" as a number of small discrete units rather than as continuous areas.

iii) The most difficult areas to identify were those which took the form of strip development along roads or railways. For example, the industry flanking the railway to the west of Ashland Avenue between Addison and Foster (area 1, Figure 3) is not visible on either polarization (arrow 5, Figure 1) yet the commercial strip development along neighboring

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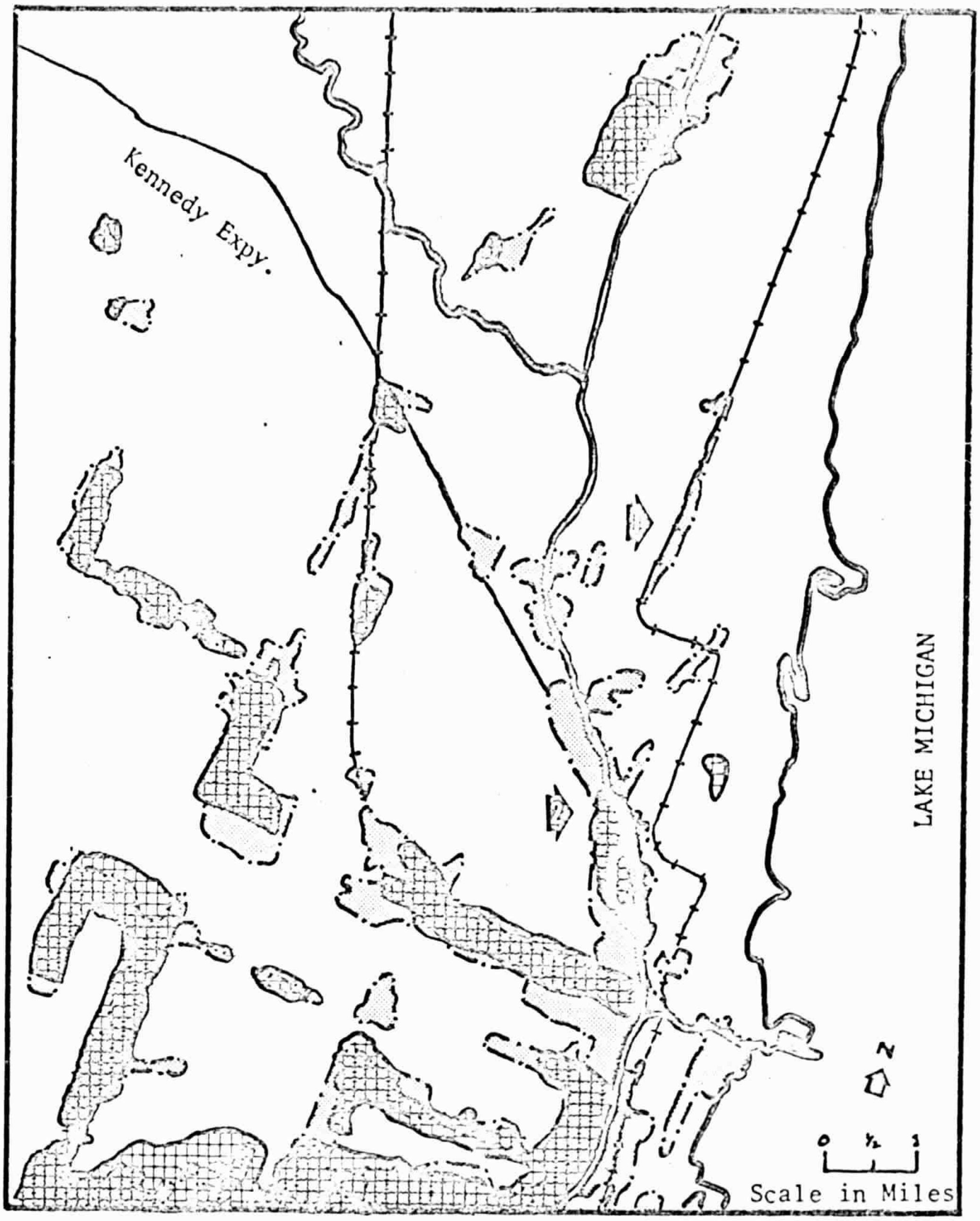
[3]These were the most recent land use maps available. Changes in the period 1964-1966 were not sufficient to have any significant effect on the recorded pattern.



- Predicted Industrial Land Use

- Observed Industrial Land Use

PREDICTED AND OBSERVED AREAS OF INDUSTRIAL LAND USE IN NORTH CHICAGO

Figure 3

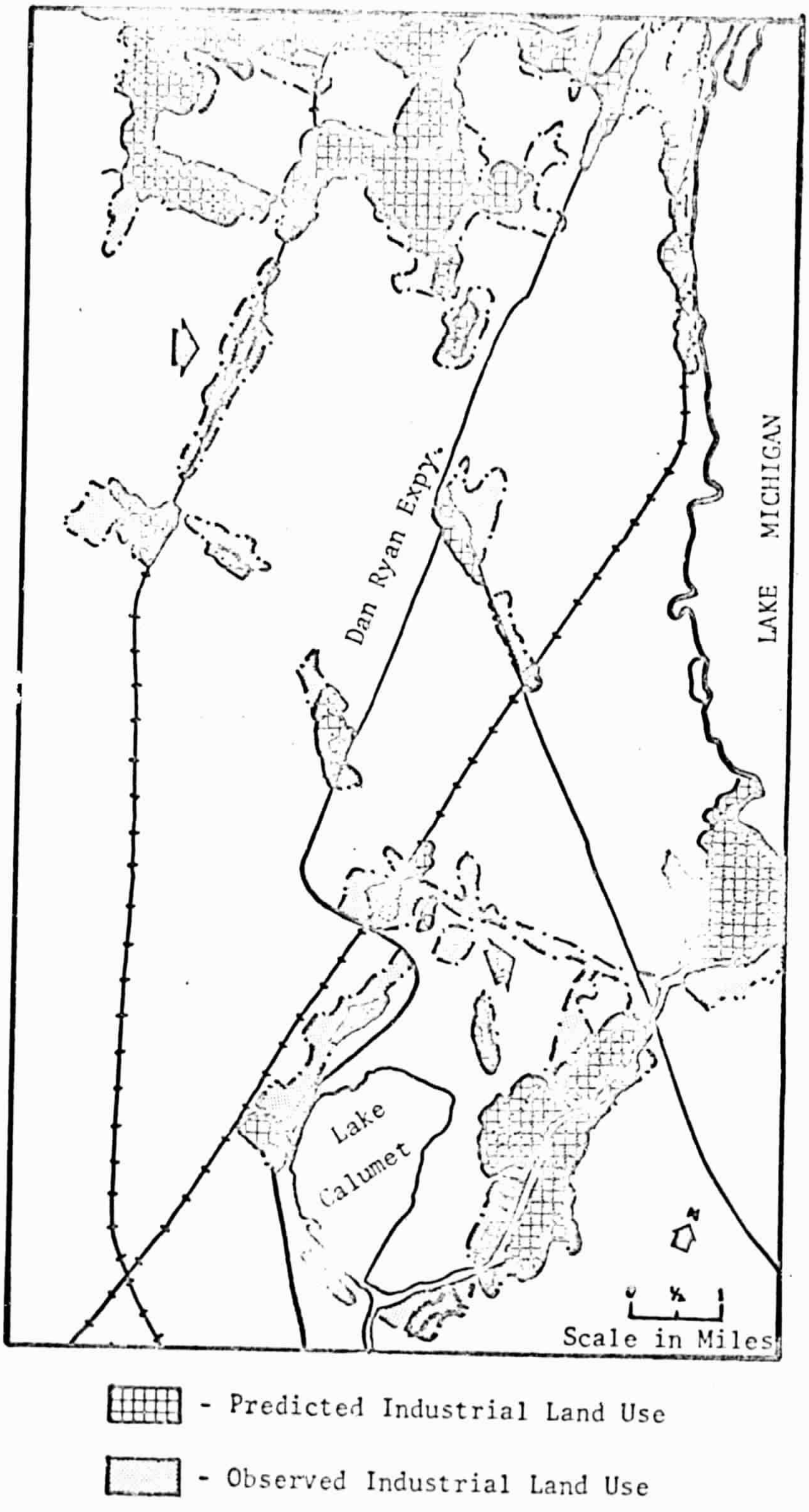
Lincoln is clearly visible. In other instances it was not possible to distinguish between high backscatter from industrial and commercial ribbon development.

iv) The gain setting is an important determinant of the ability to recognize industrial area boundaries. The backscatter from the Blue Island section of the North Branch River (arrow 6, Figure 1) has produced a "white-out" effect such that it is very difficult to determine where industry begins and ends--as a result, errors of prediction (area 2, Figure 3) are considerable.

v) There is a considerable difference between the type of returns from manufacturing areas near the center of the city and those in the suburbs. In the inner districts, land values demand a more conservative use of space with multi-story buildings and relatively small amounts of open space surrounding them; this is in marked contrast to the large single-story structures of the suburbs which are located on extensive subdivisions. The two types of industrial development are indicated by arrows 7 on Figure 1; however, it is important to note that the inner industrial districts are still capable of differentiation from the surrounding residential areas on the basis of texture, as the closer packing of the buildings in residential districts produces lower internal variation of gray scale values.

vi) It is only when one considers the Loop, where all buildings are multi-story structures casting sizeable shadows, that it becomes impossible to make any statement as to the relative distributions of industrial and other land uses.

The exercise was repeated for the area south of the Chicago River; the corresponding "observed" and "expected" distributions are shown in Figure 4. The level of performance seems to be about the same as for the northern district



PREDICTED AND OBSERVED AREAS OF INDUSTRIAL LAND USE IN SOUTH CHICAGO

Figure 4

despite the learning stage. Once again the gross pattern of industrial land use is picked out. As before, the main errors occur in the identification of ribbon development. However, the area along the railroad between 55th and 71st lies at the margin of the severely distorted returns, and is therefore not a true test of the recognition procedure (area 1, Figure 4). The other district flanking 95th Street (area 2, Figure 4) was not classified as industrial because no evidence of large buildings is to be seen.

If quantitative statements as to the amount of industrial land in a given city are required, two needs must be satisfied:

1. The provision of rectified imagery. At present, the curvilinear distortion makes the location of industrial areas a difficult task.

2. Comparative imagery from a number of cities such that systematic errors can be identified on a statistical basis.

b. Commercial

It is convenient to regard the commercial structure of Chicago as comprising three components: the Central Business District, suburban nodal retail centers, and suburban ribbon development.

The Central Business District - The whole area of the Chicago Loop is well defined as the multi-story buildings produce a coarse textured return of alternating high backscatter and shadow. However, as mentioned above, it is not possible to distinguish between industrial, retail, administrative, and other land uses within the Loop.

Suburban Nodal Retail Centers - Since retail development of some form is to be found at a large number of street intersections, some kind of classification is necessary to provide a framework for evaluation. Berry (1963) has identified four types of suburban center: 1) major regional centers; 2) smaller shopping goods centers; 3) community centers; and 4) neighborhood centers.

Attention was focused on the two largest groups, the major regional and smaller shopping goods centers. The classified centers lying to the north of North Avenue were used as a test set;[4] they were located on the imagery, and it was found that they all coincided with high backscatter at intersections of major arterials (non-expressway roads). The high backscatter results from the great variety of surfaces (vehicles, signs, delivery ramps, and so forth), many of which will be orthogonal to the emitted pulse.

After this initial learning stage, an attempt was made to locate the major centers in the southern portion of the enlarged print (the area shown in Figure 4). Nine centers were identified; five of these locations corresponded with centers recognized by Berry. The remaining four locations comprised two industrial districts at the intersection of major roads and railways, one neighborhood center, and one at the intersection of two commercial "ribbons" which did not emerge as a separate retail node.

An additional factor entered into the generation of the four errors. Two of these mistakes occurred on diagonal roads (Archer and Milwaukee) not conforming to the general N-S and E-W alignment; particularly in the former case, it would seem that the cardinal effect is producing higher returns than if the same assemblage of structures were located at a N-S intersection.

From the evidence available it would not seem possible to locate shopping centers with sufficient reliability to provide the type of information required to test such urban retail models as that formulated by Dacey (1966). However, it is suggested that two steps might lead to improvement in data quality: (i) a small increase in resolution; and (ii) the use of "box-and-diamond" flight patterns to obtain controls for the cardinal effect.

Suburban Ribbon Development - The criterion used for identification of commercial ribbons was the existence of strips of high return flanking the

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[4]The source for the locations of centers was Figure 2, p. xvi in Berry (1963).

elements of the road network. An attempt was made to map these ribbons for the area bounded by the lake shore, Belmont, Cicero, and the Eisenhower expressway. Although the total lengths of commercial frontage are similar for the "predicted" and "observed" patterns,[5] Table 1 shows that on a more detailed examination the correspondence is not particularly satisfactory.

	Predicted Frontage	Not Predicted	
Observed Frontage	26.2	15.6	41.8 = Total Observed
Not Observed	18.3		
	44.5 = Total Predicted		

Table 1: Observed and Predicted Miles of Retail Frontage in the Sample Area

As yet, detailed study of the errors resulting from the identification procedure have not revealed any systematic form, and it has not been possible to improve on the above performance.

The impact of the cardinal effect is more noticeable in examining this aspect of land use than for any other. The outstanding example is provided by Milwaukee Avenue which parallels the flight line between Irving Park Road and Bryn Mawr. The commercial development along this section generates some of the highest returns on the whole of the HH image (arrow 2, Figure 1). In contrast, the section from Cicero to the Loop has as much commercial development

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[5] Source of ribbon locations was Figure 1, p. xv., Berry (1963).

but the different orientation has resulted in a much lower level of return (arrow 8, Figure 1). The implication is that until a correction can be applied for the cardinal effect no reliable quantitative statements can be made regarding the extent of retail frontages in a given area. In fact, the overall conclusion with respect to the identification of commercial land use is that it is much less reliable than had been anticipated.

c. Residential

Relatively little can be said about residential areas apart from the fact that they can be distinguished from other land uses primarily on the basis of texture. They are areas of low to moderate return with just sufficient internal variation in gray scale values to distinguish them from parks and other open spaces. It would be useful to be able to differentiate areas of high and low residential densities, but this does not appear feasible with the existing imagery. A complicating factor in the Chicago area is the presence of a large number of trees in residential districts; since the K-band does not contain pulses of a long enough wavelength to penetrate tree cover, the determination of housing densities might not be possible with higher resolution. However, this does not rule out the possibility of obtaining such information; possible alternatives are a winter overflight or use of a longer wavelength system.

d. Parks and Other Open Spaces

Since these areas tend to be characterized by a lack of buildings or other structures, they do not produce as much backscatter as surrounding land uses. Mostly they stand out as darker areas on both the HH and HV, although the former usually provides the more reliable information. Two categories of open space in particular may be easily identified:

1. Parks containing lakes - excellent examples are provided by Washington and Jackson Parks near the University of Chicago (arrow 9, Figure 1).

2. Golf courses - the contrast between the rough and the mown fairways is sufficient to produce a distinctive pattern of lighter and darker lines.

Summary

The above discussion has shown that a considerable amount of data relating to patterns of land use within the urban area can be obtained utilizing a K-band side-looking radar. It is evident that different degrees of accuracy are associated with the identification of different components of the urban structure:

i) The linear elements of the transportation network are clearly defined with the HV polarization proving to be more useful than the HH as high returns from adjacent buildings on the latter prevent accurate interpretation.

ii) The gross patterns of industrial, residential, and open space land use are capable of identification although it is not possible to map the local boundaries of different land uses in detail. The main criterion for distinguishing between these land use categories is the variation in image texture. The HH polarization provides the main basis for interpretation.

iii) Attempts to identify commercial land proved to be surprisingly unsuccessful, the cardinal effect introducing considerable problems in the recognition process.

Although the overall results of the experiment are promising a number of steps are necessary before meaningful statements can be made regarding the utility of side-looking radar in urban research. First and foremost, it is necessary to define problems which are significant within the urban planning and research context to which radar techniques are applicable. The radar systems must be evaluated with respect to these specific problems. Second, with respect to K-band radar, comparable imagery for a number of test areas must be obtained in order to derive statements which possess some generality. Third, carefully specified flight patterns which permit the establishment of statistical controls for the cardinal effect must be flown. Finally, similar experiments are necessary using other radar systems. In particular, attention should be focused on designing systems which are appropriate to the data desired in contrast to present procedures of attempting to determine what data can be extracted from one specific system.

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