Commission VII, Working Group 3

Dr. Floyd M. Henderson
Department of Geography
State University of New York at Albany
Albany, New York 12222
USA

Influence of Radar Azimuth Angle on Small Settlement Detection

The relationship between settlement visibility and radar look direction (azimuth angle) relative to major street orientation and axis of building pattern is examined. Theoretically, when the axis is near parallel or orthogonal to the flightline a higher incidence of detection should be expected as the structures should act as corner reflectors. If this is the case it may be desirable to plan missions with this in mind -- particularly if estimates of size and location of small settlements are requisite. Imagery from different radar systems, environments, and scales is investigated.

Introduction

Population is a concern, either directly or indirectly, to almost all aspects of earth resource management and conservation. The dynamic nature of population is of direct importance to census studies and monitoring migration patterns. Indirectly the location of people is a factor in explaining and planning changing land use patterns, energy consumption, and as a data plane for geo-based information systems to name but a few applications. Population data are of import to the developed as well as the developing nations.

To meet this need many remote sensing systems are being evaluated to determine their role as an aid to population studies. The advantages of radar in areas of the world where cloudy, inclement weather, or low-light conditions prevail are generally recognized. In such cases it may be the only sensor available. Equally as important, however, is an assessment of what, if any, unique contribution can be made by radar compared to other sensor systems.

At present little is known concerning optimum frequencies, look angles, polarizations, etc., for extracting pertinent data. Radar's potential for enhancing object to background contrasts of man-made targets; its potential for adding important textural information for detection and classification of urban areas; and improved accuracy when used in conjunction with other sensors merits attention. The purpose of this work is to examine one aspect of this unknown area: the influence of radar azimuth angle on small settlement detection.

To infer a measure of population a settlement must be visible and its areal extent delimited. Bryan (1974, 1975), Lewis et.al. (1969), and Moore (1969), among others, have examined the urban infrastructure and reported on the detectability of various urban land use categories. Simpson (1969), Nunnally (1969), and Henderson and Anuta (1979), have addressed the broader perspective of settlement detection with radar imagery. Simpson, using K-band imagery of five small study areas in New England, found that only 50 percent of the settlements having

150 to 800 population were detectable. Nunnally commented on the textures and reflections of urban cover types in North Carolina. Henderson and Anuta examined 15 diverse areas in the United States with X- and K-band imagery to determine the effect of environmental modulation, radar system, scale, and range location on settlement visibility.

Although several authors have commented tangentially on the cardinal effect of urban morphology only Bryan (1979) has systematically addressed this phenomena. He found that the appearance of selected urban land cover types (low commercial and residential areas) is influenced by the orientation of streets and buildings relative to the radar azimuth angle. (Azimuth angle is defined as the direction, on a plane tangent to the earth's surface, in which the radar beam is pointed.) Plotting gray level against theta (the angle between radar azimuth and street orientation) he noted that for areas where theta was less than 10°-15°, the radar return was bright, but where theta was greater than this, the return was darker in tone for similar cover types.

Methodology and Study Areas

Admittedly, there are many factors that affect the radar return or backscatter of an entire settlement, but Bryan's observations did raise the question as to whether a relationship might exist between settlement detectability and theta. Small settlements in the U.S. generally contain a commercial/business district clustered along the major road traversing the settlement. It was hypothesized that this strip of building structures might produce a bright return as a function of theta. Theta was therefore computed for settlements of 1,000 or less population and compared with detectability results. Theta, in this case, was defined as those angles less than or equal to 10° off a line perpendicular or parallel to the radar flightline and determined using the major road that traversed the settlement. The 1,000 population size limit was selected for study as it provided an adequate number of samples and, most settlements greater in size contained more than a single major road. Moreover, Henderson and Anuta (1979) had found that 1,000 seemed to be the threshold population requisite for consistent detection.

Ten study areas were selected for examination using SLAR imagery from K- and X-band systems (Figure 1 and Table 1), along with an ascending pass, digitally processed L-band Seasat SAR image of the Harrisburg, Pennsylvania area (scale approximately 1:500,000). Three of the X-band SLAR areas (1, 3, 6) were of sufficient size to be examined individually. The X-band imagery was also grouped according to scale (1:200,000 and 1:400,000) to determine if the effects of radar azimuth might be related to image scale regardless of environment. Owing to the lower overall detection accuracy for the Seasat imagery an additional group of settlements between 1,000 and 10,000 population were included for testing when this system was considered.

Upon completion of interpretation the location of each study area was recorded on USGS topographic maps. For the X-band study areas (1-9) and the Seasat image the straight, linear nature of the flightline permitted calculation of theta for detected and non-detected settlements from the maps. However, the sinuous K-band flightline (Study Area 10) precluded accurate map measurement of theta. This necessitated a modification of procedure. Theta was calculated directly from the K-band imagery but only for the visible settlements. In addition, two other measures were recorded from the K-band data. Since the K-band imagery was recorded in both HH and HV polarization modes a measure of the de-polarized (HV) contribution (i.e. specular return) was obtained by noting the polarization where high returns occurred. In some instances on the K-band imagery no specular return from detected settlements was observed. At other times a specular return was evident but had no one orientation. These instances of non-specular and multi-directional or diffuse return were also tabulated.

For each X-band study area and the Seasat image the data were grouped as follows:

1) Settlements with theta $\leq$ 10° parallel or perpendicular to the flightline versus all others.

2) Settlements with theta $\leq$ 10° perpendicular to the flightline versus all others.

3) Settlements with theta $\leq$ 10° parallel to the flightline versus all others.

This procedure allowed an examination of the overall effect of radar azimuth as well as separate orientations. χ^2 analyses were conducted to test for significance. The null hypothesis was that there was no significant association between detectability and radar azimuth angle. The significance level was set at $\alpha = .05$. As an additional measure, ϕ coefficients were computed from the 2 x 2 contingency tables. The advantage of using both tests is that while χ^2 provides information on the significance of the data, the ϕ coefficients indicates the strength of the association. ϕ can range from -1 to +1.

Results

As can be seen in Table 2, the test results from the X-band SLAR imagery are mixed. For Study Area 1 the overall effect of radar azimuth is significant ($\chi^2 = 11.85$) far beyond the critical value, and there is a strong positive association between settlement orientation and detectability ($\phi = 0.675$). However, the dominant influence is from settlements oriented parallel to the flightline ($\chi^2 = 11.92$). In this case, it is hypothesized that settlements aligned perpendicular to the radar look direction may provide greater continuous surface area that act as corner reflectors, assuring a marked linear high return response. No significant associations were evident in Study Areas 3 and 6.

For all small settlements examined at 1:200,000 (Study Areas 1-4) χ^2 was found significant but the effect of parallel orientation to the flightline was much less pronounced. The strength of association was also more modest. For the areas imaged at 1:400,000 (Study Areas 5-9) a significant relationship was present only for settlements oriented perpendicular to the flightline ($\chi^2 = 3.88$) but the strength of the association was weak. A perplexing problem was why the parallel orientation of settlements was of import at 1:200,000 but disappeared in the 1:400,000 scale imagery only to be replaced, to some degree, by a perpendicular orientation factor.

The effect of radar azimuth was much more pronounced when the

L-band Seasat data were examined. The association was significant (in some cases to .001) for all cases except for larger settlements oriented perpendicular to the flightline ($\chi^2 = 3.00$). (See Table 2.) The ϕ coefficients were positive, but the strength of association varied from $\phi = 0.178$ to $\phi = 0.664$. Too, the parallel orientation to flightline seems again to be the more important factor. Whether this association between azimuth/settlement detection and parallel orientation to flightline will hold for Seasat SAR imagery across diverse environments is not known at present.

Fifty-eight settlements of less than 1,000 population were detected in the K-band imagery of Study Area 10 (Table 3). Of these, 29 evidenced specular return and 29 did not. Other factors such as shape, geometry, texture, spatial location, and pattern were obviously decisive in the detection of these settlements. Of the 29 settlements with specular return, 15 were oriented $\leq 10°$ of perpendicular or parallel to the flightline, two were oriented with $\theta > 10°$, and twelve settlements had no direction or linearity to their specular return.

With regard to polarization parameters, all 29 settlements with a specular component produced a high return in the HH mode but 9 also generated a specular response in HV mode. Of the 15 settlements with $\theta \leq 10°$, 9 had only HH return, but 11 of the 12 settlements with no directional specular component produced only HH return.

Conclusions and Observations

The following relationships between radar azimuth and settlement detection were observed as a result of this study.

- For X-band SAR imagery (HH polarization) of different environments radar azimuth did significantly influence settlement detectability at a scale of 1:200,000. Settlements with $\theta \leq 10°$ were more readily detected.

- For X-band SAR imagery (HH polarization) at a scale of 1:400,000 radar azimuth was a significant factor only when specular return was oriented perpendicular to the flightline. The strength of association was also less than with the 1:200,000/imagery.

- For the digitally processed L-band Seasat SAR scene (HH polarization) at a scale of 1:500,000 the statistical relationship between radar azimuth and settlement detection was stronger and more consistent than that obtained over the SLAR study areas. No single orientation of settlements was evident.

- For the K-band SLAR imagery (scale 1:225,000) radar azimuth was not always a factor in settlement detection. Half of the detected settlements had no specular return but were identified by other image clues. For those settlements with specular return, it always occurred in the HH mode as expected, but almost a third of these settlements also evidenced specular return in the HV polarization.

It is accepted that the orientation of a structure or group of structures will affect radar backscatter. From this study it appears that, on a broader scale, the detectability of small settlements (i.e., less than

1,000 population) is also influenced by radar azimuth. That is, if the entire settlement morphology/geometry is such that the street and building pattern is oriented within 10° parallel or perpendicular to the flightline more of its surface area will be susceptible to specular return, thus increasing the probability of identification. Such orientation may prove very important for settlements where extensive urban vegetation (i.e. tree cover) is present. Although not considered in this study it certainly merits attention.

Given the sample size employed and the variables inherent in the data, the results of this study should not be viewed as conclusive but pointing to the direction of further work. The variations observed among study areas, scales of imagery, and system wavelengths call for additional research to document the precise relationship between radar system parameters such as wavelength, scale, resolution, polarization, radar azimuth, and incidence angle, and settlement visibility -- and by inference the utility and role of radar imagery for population studies.

Figure 1.

Location of Study Areas

(See Table 1 for Descriptions)

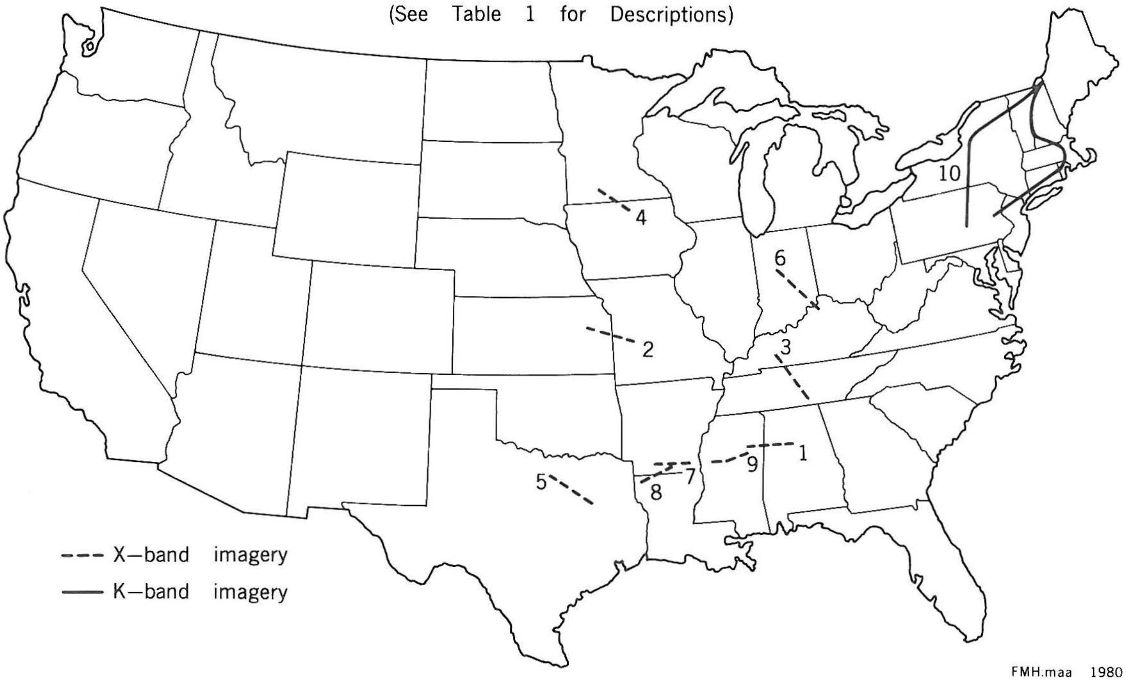

TABLE 1: STUDY AREA IMAGERY CHARACTERISTICS

Study Area	Imagery Type	Nominal Scale	Approximate Resolution	Polarization
1,2,3,4	SAC-102 X-band	1:200,000	6-9 meters	HH
5,6,7,8,9	SAC-102 X-band	1:400,000	6-9 meters	HH
Seasat SAR	L-band	1:500,000	25 meters	HH
10	AN-APQ-97 K-band	1:225,000	15 meters	HH/HV

TABLE 2: EFFECT OF RADAR AZIMUTH ON SETTLEMENT DETECTION

Study Area	$\leq 10°$ (⊥, ||) vs. all others		$\leq 10°$ (⊥) vs. all others		$\leq 10°$ (||) vs. all others	
	χ^2	ϕ	χ^2	ϕ	χ^2	ϕ
1	11.85	.675	0.39	.123	11.92	.677
3	3.11	.220	0.42	.081	0.05	.028
6	2.21	.125	1.50	.103	2.86	.142
1:200,000 (1,2,3,4)	9.82	.279	1.60	.113	4.13	.181
1:400,000 (5,6,7,8,9)	2.24	.110	3.88	.145	0.93	.071
Seasat pop. < 1,000	13.56	.323	4.12	.178	7.06	.233
Seasat pop. 1,000- < 10,000	14.11	.664	3.00	.306	4.89	.391

⊥ = θ perpendicular to flightline   critical value = 3.84

|| = θ parallel to flightline

TABLE 3: RELATIONSHIP OF RADAR AZIMUTH, POLARIZATION, AND SPECULAR RETURN FOR SETTLEMENTS IN STUDY AREA 10 (K-Band Imagery)

	Polarization of Observed Specular Return			
Radar Azimuth	HH	No Specular Return	HH and HV	Totals
≤ 10° 1 or 11	9	--	6	15
> 10° 1 or 11	--	--	2	2
no direction observed	11	29	1	41
TOTALS	20	29	9	58

Sample Size = 58 settlements

BIBLIOGRAPHY

Bryan, M. L. (1974), "Extraction of Urban Land Cover Data from Multiplexed Synthetic Aperture Radar Imagery," *Proceedings of the 9th Symposium of Remote Sensing of Environment*, University of Michigan, Ann Arbor, pp. 271-288.

_____ (1975), "Interpretation of an Urban Scene Using Multi-Channel Radar Imagery," *Remote Sensing of Environment* 4 (1), pp. 207-319.

_____ (1979), "The Effect of Radar Azimuth Angle on Cultural Data," *Photogrammetric Engineering and Remote Sensing* 45 (8), pp. 1097-1107.

Henderson, F. M. and M. A. Anuta (1979), "Settlement Detection with Radar Imagery," *Joint Proceedings of the ASP-ACSM 1979 Fall Technical Meeting* , American Society of Photogrammetry, Falls Church, Virginia, pp. 89-105.

Lewis, A. J., H. C. McDonald, and D. S. Simonett (1969), "Detection of Linear Cultural Features with Multipolarized Radar Imagery," *Proceedings of the 6th International Symposium on Remote Sensing of Environment*, University of Michigan, Ann Arbor, pp. 879-895.

Moore, E. G. (1969), *Side-Looking Radar in Urban Research: A Case Study*, USGS Interagency Report, NASA-138, Washington, D.C., 24 pp. (NTIS #N68-16108).

Nunnally, N. R. (1969), "Integrated Landscape Analysis with Radar Imagery," *Remote Sensing of Environment*, 1 (1), pp. 1-6.

Simpson, R. B. (1969), "APQ-97 Imagery of New England: A Geographic Evaluation," *Proceedings of the 6th International Symposium on Remote Sensing of Environment*, University of Michigan, Ann Arbor, pp. 909-925.