WAVELENGTH, POLARIZATION, AND INCIDENT ANGLE AS VARIABLES IN SETTLEMENT DETECTION WITH SATELLITE SAR IMAGERY

Floyd M. Henderson
GIS Remote Sensing Laboratory
Department of Geography and Planning
State University of New York at Albany
Albany New York 12222 USA

Klaus Herrig
Department of Geography
Julius-Maximillians Universitaet Wuerzburg
Am Hubland
97074 Wuerzburg
Germany

Commission VII, Working Group 9

KEY WORDS: SAR, Human Settlement, Accuracy, Polarization, Wavelength, Multispectral

ABSTRACT

Knowledge of the current distribution, growth, and population of human settlements is of vital importance not only for census estimates but also for proper resource management. This study is part of a larger project to examine the use of multispectral SAR, merged SAR, and merged SAR and MSS sensor systems for settlement, urban growth, and population-related data collection. The purpose of this paper is to report the influence of wavelength, polarization, and incient angle as variables in settlement visibility. SIR-C SAR imagery of an area southwest of Munich, Germany was acquired at two incident angles, three wavelengths, and four polarizations. In addition three multispectral SAR composite scenes were examined. Findings indicate that visibility improved with wavelength regardless of incident angle. The preferred polarization varied but like-polarized imagery was the poorest. Multispectral composites produced the highest accuracy. Overall, accuracies for the 17 data sets ranged from 17 to over 96 per cent.

INTRODUCTION

Knowledge of the current distribution, growth, and population of human settlements is of vital importance not only for census estimates but also for proper resource management. Census data are often out-of-date, lacking, and at times inaccurate using current field and sampling procedures. This situation is particularly true for developing nations of the world where populations are growing the fastest, existing data collection techniques are the least advanced, and where the extent, frequency, and impacts of migration (especially rural to urban) the most evident. However, the fact that developed nations are seeking new, faster, more frequent, and better methods of acquiring population data is evidence that a demand also exists here. The need for current information on population and human settlement exists at all levels of acquisition.

Information on the patterns of settlement growth at local, regional, national, and global scales is also needed. For example, in what specific geographic areas are settlements being established, growing, or declining? Which settlements are expanding and what existing land cover and land use are being converted to urban activity? Answers to such questions are essential in assessing the current distribution of renewable and non-renewable resources and for proper planning for the future.

Remote sensing systems are being explored to supply such information. The advantages and characteristics of radar imagery compared to other remote sensing systems are well known to the geoscience remote sensing community. The recent increased availability of SAR data, especially operational satellite systems, has been accompanied by a rise in the interest in SAR as a remote sensing system and its potential geoscience applications. This study is part of a larger project to examine the use of multi-spectral SAR, merged SAR, and merged SAR and MSS sensor systems for settlement, urban growth, and population-related data collection. Visibility and detection of settlements are the first steps in delimiting built-up areas for population and growth estimates and algorithm development. The purpose of this paper is to report on the influence of wavelength, polarization, and incident angle as variables in settlement visibility.

BACKGROUND

Work to date has shown that wavelength (Bryan, 1975; Haack, 1984; Henderson and Anuta, 1980), incident angle (Brisco et.al, 1983; Henderson, 1995; Hussin, 1995; Kessler, 1986), and polarization (Haack, 1984; Henderson and Mogilski, 1987; Lewis, 1968) all influence detection of human settlement. The role of environment has also been explored (Forster, 1985; Henderson and Anuta, 1980; Lo, 1986; Trevett, 1986). A review of these system and environmental variables and a review of radar research in these areas can be found in Henderson and Xia (in press); and Xia and Henderson (1995). One of the problems to date has been the unavailability of SAR data sets that permit an analysis of more than a single variable. Most SAR systems acquire data at a single wavelength, polarization, and incident angle. This study provides the opportunity to study these variables simultaneously in a single study area.

STUDY AREA

The study area, approximately 20 by 25 km, is located southwest of Munich, Germany. The glacial and fluvial-glacial landscape is part of the Ammer Loissach Huegelland. The undulating hills reach heights of 750m with a main gradient from south to north. Land cover consists primarily of mixed hardwood and conifer forests, wetlands, and meadows and pastures. The area is popular with tourists and as a commuting suburb to Munich. As a result the area population has increased dramatically over the last thirty years. Village populations range from a high of about 10,000 to small groups of only two or three buildings.

DATA

The study area was imaged by SIR-C SAR on ascending passes on April 11, 1994 and April 18, 1994. The former pass was acquired with an incident angle at image center of 28 degrees; the latter with an incident angle of 57.7 degrees. The data were resampled to produce a 12.5m resolution ground range projection and hard copy images at a scale of 1:110,000 generated for interpretation. The entire data set consisted of 17 scenes. The April 11 data set (small incident angle) consisted of: (1) X-VV; (2) C-VV; (3) C-HH; (4) C-HV; (5) L-VV; (6) L-HH; and (7) L-HV. The April 18 data set (large incident angle) consisted of: (1) X-VV; (2) C-VV; (3) C-HV; (4) L-VV; (5) L-HV; (6) C-total power; and (7) L-total power. In addition, three multispectral color composite SAR scenes were produced: (1) X-VV/C-HV/L-VV; and (2) X-VV/L-HV/C-tp from the large incident angle data and (3) X-VV/C-HH/L-HV from the small incident angle data.

METHODOLOGY

Each scene was visually interpreted and all sites thought to be settlements were delimited. SAR scenes were selected for interpretation in a random order. The images were interpreted over a three week period with the color composites analyzed last to minimize any learning curve bias. The results were compared with 1:50,000 topographic maps of the study area to determine accuracy and errors. Fifty-three settlements in the study area comprised the data base. Settlements listing no population in the census reports were excluded from the study as being too small.

RESULTS

Wavelength: The best results from the single wavelength scenes were obtained with the L-band imagery. The poorest results were from the X-band imagery, with the C-band accuracies falling in between. This was true for both incident angles.

Polarization: For the large incident angle data the C-tp image was the most accurate of the C-band data, followed by the HV and the VV images. A slight reverse in this ranking was evident for the L-band data. Here, the HV image was the best, followed by the L-tp and the VV images. At the small incident angle the best C-band image was the HV, followed by the HH and VV; the rankings were identical for the L-band data. For all single image data sets the best polarization was the L-HV image.

Incident Angle: The poorest accuracy was produced consistently by the small incident angle images. Steep incident angle imagery was not conducive to settlement detection. When imagery with the same wavelength and polarization but different incident angles was compared (5 cases), the large incident angle was significantly superior in every case.

Color Composite: There were three multispectral SAR data sets generated as color composite images. The small incident angle image was comprised of X-VV/C-HV/L-VV data, and the two large incident angle images were combinations of X-VV/L-HV/Ctp and X-VV/L-HV/C-HH. Each of the color composite images evidenced a synergetic effect, compared to the individual images. The accuracy of the multispectral SAR image ranged from 11 per cent to 64 per cent better than the individual bands that comprised the composite. The two large incident angle color composites were the most accurate images of all 17 SAR image data sets.

Table 1 lists the respective images, their accuracy, and number of commission errors. As can be seen, the detection ranged from a high of 96.2 per cent for the X-VV/C-HV/L-VV LIA (Large Incident Angle) composite to a low of 17.0 per cent for the X-VV SIA (Small Incident Angle) image. The L-HV LIA image produced the third highest accuracy (83.0%), and the L-tp image was tied with the SIA color composite (81.1%) for fourth best.

The worst image was the X-band, VV polarized image acquired at the small incident angle. The greatest number of commission errors (7) was found in that image, the X-band VV polarized LIA image, and the C-band VV polarized LIA image. It is apparent that VV polarized imagery is of minimum use for settlement detection, at least for this environment.

L-band imagery, alone or as a component of a color composite, consistently produced the highest accuracy. A basic principle of SAR imagery is that the angle over which an anomolously large backscatter is observed will increase as wavelength increases (Raney, in press). In other words, the cardinal effect is enhanced for longer wavelength systems. This would mean that for buildings in a row, the number that will be equal to or less than 10 degrees from perpendicular to the incident wave (and the extent of high signal return) will increase as wavelength increases. For very small villages this increased backscatter at longer wavelengths would produce a larger, distinct, bright return on the image than that generated by shorter wavelength systems. That alone may not be enough to explain the superiority of the L-band wavelength in settlement visibility. However, on the L-band (longer wavelength) images more of the surrounding grass and meadow surface terrain will appear smooth (dark) than on the shorter wavelength C- or X-band images due to the surface roughness criterion. For the latter images the differences in response and contrast between settlement structures and grasses would be less, producing a more homogeneous appearing landscape. The L-band image would generate a high backscatter response from a larger area of the settlement against a surrounding area of low return. The only other areas with responses similar to settlements would be some forested and wetland areas, and they would be distinguishable from settlements by different shape and texture. The results of this study support those observations.

The fact that the best single image was HV L-band supports earlier work (Bryan, 1975; Haack, 1984; Henderson and Mogilski, 1987; and Lewis, 1968) that cross-polarized imagery provides more separation of human settlement structures versus vegetation due to the role of volume scatter. The accuracy of the total power images, unavailable to the earlier researchers, suggests that they may produce equal or better results than cross-polarized imagery. Further investigation of total power images merits attention.

The superiority of large incident angle images also supports earlier work in similar terrain (Henderson, 1995; Kessler, 1986). Whether better accuracy would be attained with a slightly smaller incident angle than that used here (57.7 degrees) remains to be addressed.

Each of the color composite images produced higher accuracy than any of the separate component images. Although some settlements were visible on only one or two of the individual images, many settlements on the color composite were not detected on any of the single band component images. Similar to many other remote sensing applications, the "multi-" aspect of multispectral SAR imagery is very important in settlement detection and delimitation of the built-up area. Each wavelength may be sensitive to select backscatter components in urban/settlement areas. Identification of these factors is the subject of current research. The color composites also enhance settlement visibility by providing improved contrast and color differences the interpreter uses to separate human settlement (bright white returns) from natural elements of vegetation, soils, and water (colors and black).

SUMMARY

A small area of a European northern boreal environment served as the basis of this study. For such an environment it has been shown that L-band imagery is superior to X- or C-band imagery for settlement detection. Cross-polarized imagery is the most accurate but total power images may be equal or better. More comparison of and work with total power images are requisite. Large incident angle images are quite superior to small incident angle images. Use of multispectral SAR composites is the most accurate of all images, but the exact combination of component images that will produce the maximum accuracy remains to be determined. Future work will report on population size, population estimate, and settlement infrastructure variables.

BIBLIOGRAPHY

M.L. Bryan: "Interpretation of an Urban Scene Using Multi-Channel Radar Imagery", Remote Sensing of Environment, 4(1), 1975, pp.49-66.

B. Brisco, F.T. Ulaby, M.C. Dobson: "Spaceborne SAR Data for Landcover Classification and Change Detection", Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, San Francisco, 1983, pp.1.1-1.8.

B.C. Forster: "An Examination of Some Problems and Solutions in Monitoring Urban Areas from Satellite Platforms", Int. J. of Remote Sensing, 6(1), 1985, pp.139-151.

B.N. Haack: "L- and X-Band Like- and Cross-Polarized Synthetic Aperture Radar for Investigating Urban Environments", Photo. Engineering and Remote Sensing, 50(3), 1984, pp.331-340.

F.M. Henderson: "An Analysis of Settlement Characterization in Central Europe Using SIR-B Radar Imagery", Remote Sensing of Environment, 1995, in press.

______ and M.A. Anuta: "Effects of Radar Systems Parameters, Population, and Environmental Modulation on Settlement Visibility", Int J. of Remote Sensing, 1(2), 1980, pp.137-151.

______ and K.A. Mogilski: "Urban Land Use Separability as a Function of Radar Polarization", Int. J. of Remote Sensing, 8(3), 1987, pp.441-448.

______ and Z. Xia: "Radar Application in Urban Analysis, Settlement Detection and Population Estimation", Chapter 15 in Principles and Applications of Imaging Radar, F.M. Henderson and A.J. Lewis (Eds.), Vol II, Manual of Remote Sensing, 3rd Ed., American Society of Photogrammetric Engineering and Remote Sensing, Bethesda, MD., in press.

Y.A. Hussin: "Effect of Polarization and Incidence Angle on Radar Return from Urban Features Using L-Band Aircraft Radar Data", presented at Quantitative Remote Sensing for Science and Applications--IGARSS'95, Firenze, Italy, July 10-14, 1995.

R. Kessler: Radarbildinterpretation fuer Forstliche Anwendung und Landnutzungsinventur, Doctoral Dissertation, Albert Ludwigs Universitaet, Freiburg i Br., Germany, 1986, 183pp.

A.J. Lewis: Evaluation of Multiple-Polarized Radar Imagery for the Detection of Selected Cultural Features, NASA Technical Letter 130, 1968, reprinted in The Surveillant Science, R. Holz, (Ed.), Houghton Mifflin, Boston, 1973, pp.297-313.

C.P. Lo: "Human Settlement Analysis Using Shuttle Imaging Radar-A Data: An Evaluation", in Remote Sensing for Resources Development and Environmental Management, M.C. Damen, et.al., (Eds.), Proceedings of the Symposium on Remote Sensing for Resource Development and Environmental Management, Enschede, Netherlands, 1986, pp.841-845.

K. Raney: "Radar Fundamentals: Technical Perspective", Chapter 2 in Principles and Applications of Imaging Radar, F.M. Henderson and A.J. Lewis (Eds.), Vol. II, Manual of Remote Sensing, 3rd ed., American Society of Photogrammetry and Remote Sensing, Bethesda, Md., in press.

J.W. Trevett: Imaging Radar for Resource Surveys, Chapman and Hall, New york, 1986, 313pp.

Z. Xia and F.M. Henderson: "Understanding the Relationships Between Radar Response Patterns and the Bio- and Geophysical Parameters of Urban Features", presented at International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications, Toulouse, France, Oct. 9-13, 1995.

Image	XCL/LIA	XLCtp/LIA	L/HV/LIA	L\TP\LIA	XLC/LIA	Ctp/LIA	L/HV/SIA	L/VV/LIA	C/HV/LIA	C/VV/LIA	C/HV/SIA	C/HH/SIA	L/HH/SIA	L/VV/SIA	X/VV/LIA	C/VV/SIA	X/VV/SIA
Accuracy	96.2	94.3	83.0	81.1	81.1	77.4	69.8	66.0	64.2	60.4	52.8	49.0	47.2	43.4	35.8	30.2	17.0
Errors	1	1	3	1	2	3	5	3	1	7	1	2	5	4	7	3	7

Table 1: Detection Accuracy of SAR Images and Color Composites: Wavelength/Polarization/Incident Angle (LIA=Large Incident Angle; SIA=Small Incident Angle)