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16. Abstract

The Environmental Research Institute of Michigan (ERIM) has recently developed a multiplexed synthetic aperture Side-Looking Airborne Radar (SLAR) that simultaneously images the terrain with X-band (3.2 cm) and L-band (23.0 cm) radar wavelengths. In Brevard County, Florida, ERIM has begun an experimental program directed toward determining the feasibility of using multiplexed SLAR to obtain useful information for the following earth resources purposes: (1) Direct or indirect detection of pools of water under standing vegetation, and specifically under canopies of dense vegetation. (2) Urban and rural land-use planning. (3) Water resources management. (4) Determination of drainage patterns.

In early October, 1973, three test areas in Brevard County were imaged with the multiplexed SLAR. Concurrent with the radar imaging, ground truthing of selected places and features within the test areas was conducted to: (1) Document conditions in the test areas for each of the four earth resources purposes during the radar data gathering. (2) Ground truth any places or features which had unexpected or interesting returns on the radar imagery. (3) Make field measurements of the complex dielectric constant of vegetation using portable microwave equipment.

In late October, 1:24,000 scale black and white aerial photography and 8 - 12.5 micron thermal infrared (IR) imagery of the three test areas was gathered. The thermal IR imagery was gathered within two hours after sunrise.

(Continued)

17. Key Words

Remote Sensing	Urban Land Use
Radar	Rural Land Use
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16. Abstract (Continued)

The radar imagery and ground truth data were interpreted and analyzed by ERIM personnel mainly to determine the feasibility of using multiplexed X- and L-band SLAR for each of the four earth resources purposes. However, because this was the first time that multiplexed SLAR imagery, large-scale aerial photographs, and thermal IR imagery of a region were gathered within such a short time period, comparisons were made as to the information about specific features contained in each type of imagery. Interpretations of the various imagery were done with the unaided eye.

The SLAR imagery, aerial photographs, and thermal IR imagery were examined to determine the qualitative tone and texture of many rural land-use features imaged during the experiment. Also, in many instances the various types of imagery were examined to determine with what other feature(s) a particular feature could be confused. Very few attempts were made to evaluate the appearance of a given feature on the radar imagery relative to the radar look direction, incidence angle, etc., or to determine what radar-return parameters contributed to the radar return from a given feature.

The results of the experiment are as follows: (1) Neither X- nor L-band SLAR at moderate and low depression angles can directly or indirectly detect pools of water under standing vegetation, and particularly under canopies of dense vegetation. (2) Many of the urban and rural land-use categories present in the test areas can be identified (or at least discriminated) and mapped on the multiplexed SLAR imagery. Land cover, instead of land use, is generally what is identified on the SLAR imagery at the coarser levels of classification. (3) Water resources management can be done using multiplexed SLAR. In particular, marsh regions can be readily identified and mapped, open water bodies can be identified, and aquatic vegetation such as water hyacinths, water lilies, and reeds can be differentiated and mapped. (4) Drainage patterns can be determined on both the X- and L-band imagery, but are better determined on the X-band imagery.

Significantly more information was obtained from the multiplexed SLAR imagery for urban and rural land-use planning and water resources management than could have been obtained using the imagery of either wavelength alone. Drainage patterns can be determined using the imagery of just one radar wavelength.

FOREWORD

The research described in this final report was performed by the Environmental Research Institute of Michigan (ERIM). The work was supported by the John F. Kennedy Space Center, NASA. The inclusive dates for this reporting period are June 1, 1973 through April 30, 1974. The Kennedy Space Center Technical Manager for this experiment was Edward J. Hecker. The Co-Principal Investigators were Robert A. Rendleman and Ben Drake. ERIM's number for this report is 104000-1-F.

Many scientists and technicians from ERIM have contributed to this experiment. The authors are especially indebted to the ERIM technicians who gathered and processed the radar imagery. John Hutton and Frank Brake from the Brevard Mosquito Control District helped with the ground truthing, as did Joe Brooks from Melbourne Beach, Florida. Their help is gratefully acknowledged.

Section 5 was written by Charles Liskow, Section 11.3 by Leonard Bryan, Sections 11.4, 12, and 13 by Robert Shuchman and Ben Drake, and Section 14 by Richard Larson. The remainder of the report was written by Ben Drake.

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THE APPLICATION OF AIRBORNE IMAGING RADARS (L- AND X-BAND) TO EARTH RESOURCES PROBLEMS

1

PURPOSE OF THE EXPERIMENT

The Earth Resources Office of the John F. Kennedy Space Center, NASA (KSC) determined that there was a need for assessing the applicability of airborne imaging radars in obtaining useful information for certain earth resources applications. Accordingly, the Environmental Research Institute of Michigan (ERIM) was authorized to undertake an experimental program directed toward determining the feasibility of utilizing its multiplexed synthetic-aperture X- and L-band Side-Looking Airborne Radar (SLAR) to obtain useful data for the following specific earth resources purposes:

(a) Detection of pools of water under standing vegetation. The pools could be detected either directly or by indirect means.

(b) Land-use planning. For the purposes of this report, land use is loosely divided into urban, rural, and environmental. Areas of urban land use are areas of intensive use where much of the land is covered by structures. Rural land use is concerned with non-urban areas. Environmental land use is concerned with specific environmental problems — such as a species habitat.

(c) Water resources management. Mapping water bodies and the vegetation in them.

(d) Determination of drainage patterns.

2
BACKGROUND

Extensive work is being done to investigate ways in which photographic, multispectral scanning, and thermal infrared imagery may be applied to the solution of earth resources problems. Previous experimental work by ERIM and other research organizations with airborne imaging radars capable of imaging with only one radar wavelength at a time has shown that, for certain earth resources problems, SLAR can obtain information not otherwise obtainable, and for other such problems where alternative means may be available, can produce imagery on a more cost-effective basis. The various remote sensors have imaging capabilities that complement and supplement each other in terms of the data that can be gathered concerning a specific earth resources problem or feature. Certain remote sensors, however, are better suited for specific purposes.

ERIM has recently developed a multiplexed synthetic aperture SLAR that simultaneously images the terrain with X-band (3.2 cm) and L-band (23.0 cm) radar wavelengths. The transmitted radar beam is chosen before the imaging flight to be either horizontally or vertically polarized. Both like- and cross-polarized energy is reflected back to the transmitting antenna for each wavelength, thus four channels of radar imagery are simultaneously recorded.

Previously, with a SLAR capable of transmitting only a single-wavelength at any one time, it was necessary to image a region on successive passes when multiple wavelength imagery was desired. This constraint causes problems not only in image gathering but also in interpretation, particularly if a significant length of time intervenes between the imaging passes. In comparison, multiplexed SLAR imagery has several inherent advantages: for all the multiplexed wavelengths there are identical imaging parameters (radar look direction, depression angles, etc.), the same imaged swath, the same motion errors, and the same terrain conditions (surface texture, slope orientations, vegetation, etc.). Hence, for the different wavelength imagery gathered by the multiplexed SLAR, image registration problems are simplified, which in turn means that the multiplexed SLAR imagery is easier to machine-process.

Previous radar imagery gathered by ERIM had demonstrated the usefulness of SLAR for determining drainage patterns, for water resources management and, to an unknown extent, for land-use planning. However, the usefulness of remote sensing techniques, especially SLAR, in detecting pools of water under standing vegetation and particularly under canopies of dense vegetation had not been thoroughly explored.

ERIM prepared its multiplexed X- and L-band SLAR to gather data appropriate to the four earth resources purposes listed above. Based on the knowledge presently available from standard sources, the radar was configured and thoroughly checked to maximize the probability of successfully collecting data in Brevard County, Florida.

Concurrent with the data-gathering flight, ERIM would conduct ground truthing to document conditions in the imaged areas. In addition, to aid in later data analysis, field measurements of the complex dielectric constant of vegetation were to be made by ERIM personnel with ERIM's portable microwave equipment at as many locations in the imaged areas as practicable. Interpretation and analysis of the radar imagery and ground truth data would be done by ERIM personnel.

3

PROPOSED TEST AREAS AND SITES

Five test areas in Brevard County were selected to be imaged by the multiplexed SLAR. Within these test areas, only a few specific test sites were chosen—particularly the cities of Titusville and Melbourne, and certain areas with pools of water under dense canopies of vegetation. Table 1 enumerates the test areas, their locations, and the specific earth resources problem(s) for which they were selected.

The test areas are shown in Figure 1. Only three of the test areas were imaged during the experiment. The topography of the three test areas imaged is relatively flat, the maximum relief amounting to only several tens of feet.

Because of the possible intermittent malfunction of the multiplexed radar system, several geographically separate general test sites for each problem were chosen within the test areas; this maximized the chance that at least some of the test sites for a particular problem would be imaged. The test areas and sites were jointly chosen by KSC and Brevard County personnel, and by ERIM personnel familiar not only with aircraft and radar operating characteristics but also with the implications of the proposed flight geometry on the experiment's outcome. The test areas are long and linear to minimize aircraft turns, while their width corresponds to the width of the radar imagery gathered.

TABLE 1. DESCRIPTION OF PROPOSED TEST AREAS IN BREVARD COUNTY, FLORIDA

Test Area	Location	Earth Resources Problem(s)
1	Western side of Merritt Island	Primarily detection of pools of water under standing vegetation. Secondarily, rural land use and water resources management.
2	Western shore of the Indian River	Primarily urban land use (particularly the cities of Titusville and Melbourne) and rural land use. Secondarily, water resources management and detection of pools of water under standing vegetation.
3	Upper part of the St. Johns River	Primarily water resources management and determination of drainage patterns. Secondarily, rural land use.
4	Canaveral Peninsula	Environmental land use (ocean beach erosion)
5	Immediately northeast of part of Test Area 3	Environmental land use (Dusky Seaside Sparrow habitat)

NOTE: A small part of Test Area 2 overlaps the western part of Test Area 1.

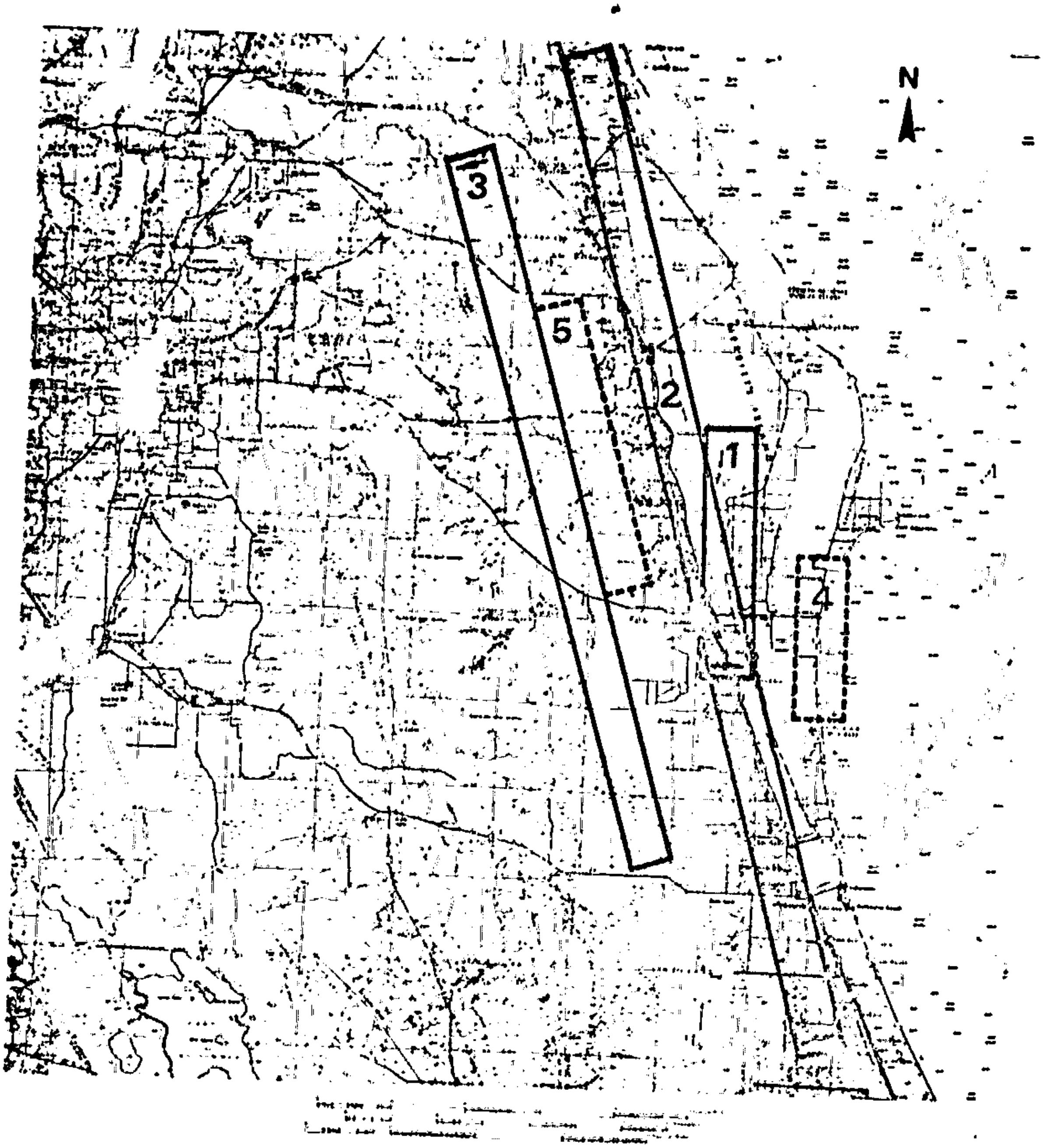

FIGURE 1. PROPOSED TEST AREAS IN BREVARD COUNTY, FLORIDA. Areas actually imaged by radar are bounded by solid lines; those not imaged are bounded by dashed lines. Radar look direction is indicated by the arrow.

4

RADAR DATA GATHERING AND PROCESSING

During August and September, 1973, ERIM prepared the multiplexed SLAR system for the data-gathering mission in Florida. This preparation involved both ground and flight tests of the system in the Ann Arbor, Michigan area. An LTN-51 inertial navigation system was leased from Litton Systems, Inc., Woodland Hills, California, and installed in the ERIM SLAR airplane. The inertial navigation system not only navigates the airplane during imaging missions, but also controls certain units of the radar system.

During the final stages of preparation for the Florida mission, two problems occurred that delayed going to Florida until early October. Determining the feasibility of using multiplexed SLAR to detect pools of water under standing vegetation was one of the purposes of the experiment. Brevard County had experienced a prolonged period of low rainfall in the summer of 1973, and the pools to be imaged as test sites had pretty well dried up by mid-September. Although the test pools filled up in the latter part of September, bad weather conditions along the transit route and over the Florida test areas caused additional delay. The SLAR airplane flew to Florida on October 5.

Two SLAR imaging flights of the Brevard County test areas were originally considered, with the second flight used to cover gaps in the coverage of the first flight and to increase the data base to the limit to which additional flight time was available. However, only a single imaging flight of approximately 3.5 hours was planned to cover possible contingencies such as weather, aircraft, or electronic delays.

A radar data-gathering flight was made during the mid-morning of October 7 to image Test Areas 1, 2, and 3; two attempts were made to image Test Area 1. The characteristics of this imaging flight are given in Table 2. Ground truthing was also started the same day.

A fast, survey optical data processing of the signal films was done at ERIM on October 7 to generate X- and L-band output films. The output films were examined by ERIM personnel who determined that the quality of the radar imagery obtained was acceptable for the experiment's purposes. However, while Test Areas 2 and 3 were imaged essentially as planned, only a small portion of the western part of Test Area 1 had been imaged. Photographic prints of the radar imagery of Test Areas 2 and 3 arrived in Florida on October 9 and were used during the ground truthing.

It was decided to image Test Areas 4 and 5 and to re-image Test Area 1 during another data-gathering flight. Bad weather conditions and a malfunction of the LTN-51 inertial navigation system that necessitated returning the system to the manufacturer delayed this second imaging flight until late in the morning of October 12. Because of adverse weather, this second data-gathering flight unfortunately had to be terminated after imaging only Test Area 1. The characteristics of this imaging flight are given in Table 2.

TABLE 2. CHARACTERISTICS OF MULTIPLEXED SLAR IMAGING FLIGHTS, BREVARD COUNTY, FLORIDA (1973)

Test Area	Date Imaged	Pass No.	Altitude of Airplane Above Mean Sea Level (ft)	Slant Range Distance to Near Edge of Imagery (ft)	Depression Angles		Length of Imaged Area (miles)	Slant Range Swath Width (ft)	Flight Direction, True Azimuth	Radar Look Direction, True Azimuth	Transmitting and Receiving Polarizations, Each Wavelength
					Near Range	Far Range					
1	Oct. 7, 1973	1	6500	13,200	30°	12°	16	18,000	356°	86°	*HH, HV
1	Oct. 7, 1973	4	9500	24,300	23°	13°	16	18,000	356°	86°	HH, HV
2	Oct. 7, 1973	2	8500	17,300	29°	14°	71	18,000	341°	71°	HH, HV
3	Oct. 7, 1973	3	9500	24,300	23°	13°	50.5	18,000	164°	254°	HH, HV
1	Oct. 12, 1973	1	6500	13,200	30°	12°	16	18,000	356°	86°	HH, HV

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*H : horizontal polarization
V : vertical polarization
The first letter represents the transmitting polarization, the second letter indicates the receiving polarization.

A fast, survey optical data processing and quality examination of the radar imagery of Test Area 1 were done at ERIM on October 12. Test Area 1 had been imaged as planned, but the quality of the imagery generally was poor. Photographic prints of the radar imagery arrived in Florida on October 14 and were used during the ground truthing.

A decision was made in Florida on October 12 by the Co-Principal Investigators with the concurrence of the KSC Technical Manager, not to have another radar data-gathering flight and to send the SLAR airplane back to Michigan. This meant that Test Area 1 would not be imaged again and that Test Areas 4 and 5 would not be imaged at all.

Test Areas 4 and 5, though interesting, had the lowest priorities of all the test areas and unfortunately could not be imaged during this experiment. Test Area 4 was selected for its environmental land use, specifically looking at erosion and deposition along ocean beaches. In addition, an attempt was to be made using the multiplexed SLAR to do a coarse analysis of the size and distribution of beach sediments. Test Area 5 was also selected for its environmental land use, specifically to determine the habitat of the endangered Dusky Seaside Sparrow. The radar imagery would have been analyzed not only to map the habitat preferred by the species, but also to determine the distribution of salt pans and marl regions within the test area.

To generate final output films of Test Areas 1, 2, and 3, additional optical data processing of the signal films was done at ERIM in October and November 1973. Copies of some of the output films have been given to KSC.

5

QUALITY OF THE RADAR IMAGERY

The multiplexed SLAR used to obtain imagery of Brevard County is designed to image a swath of terrain approximately 3.5 miles wide paralleling the aircraft flight path. Four simultaneous radar images are ultimately produced: like- and cross-polarized images for both X- and L-band wavelengths. The two X-band output images are produced from one signal film obtained from the two-channel X-band data recorder, and the two L-band output images are produced from the signal film obtained from the two-channel L-band data recorder. The four strips of radar imagery are produced on the ground after the data-gathering flight through optical data processing of the signal films recorded in the air. The output imagery consists of four photographic films.

The output films generally are reproduced as photographic enlargements at a scale adjusted to the user's needs. The slant-range scale of the X-band imagery in this report is approximately 1:35,000 in the range or cross-track direction (perpendicular to the aircraft flight path and parallel to the radar look direction) and approximately 1:33,000 in the azimuth or along-track direction (parallel to the aircraft flight path). The slant-range scale of the L-band imagery is approximately 1:36,500 in both the range and azimuth directions. Although restitution of the slant-range imagery generally is not done, optical systems are available that will adjust the orthogonal scales so they are the same at any selected point on the imagery.

Because a slant range display is used, the imagery's ground-range scale in the cross-track direction varies with the sine of the depression angle, producing a continuous change in the cross-track scale. (The ground-range scale is defined as the linear scale in a horizontal plane.) At the near-range edge of the swaths imaged, the depression angle is approximately 30° and here the ground-range scale in the cross-track direction is approximately 13 per cent less than the linear azimuth scale. At the far range edge of the same swaths, the depression angle is approximately 15°; hence the ground-range scale in the cross-track direction is approximately 3 percent less than the azimuth scale for this part of the image.

Although radar layover is inconspicuous in the radar imagery of Brevard County, a brief description of it will be given. Because the radar energy is propagated in a slant range manner, the indicated position on the radar imagery of a terrain feature with appreciable local relief is different from its true horizontal position. This is true for all side-looking airborne radars regardless of whether they have slant range or ground range displays. The upper part of a high feature, such as a mountain, or high tower or building, will be indicated as being at a smaller range from the radar (i.e., closer to the near edge of the imagery) than the lower part of the feature or level terrain that is horizontally displaced the same distance from the aircraft flight path, but farther in slant range. Thus, the high features appear to "lean" toward the near edge of the radar imagery. This effect, called radar layover, is caused by the radar signal intercepting the top of a feature before it intercepts the bottom. It should be noted that the layover in radar imagery is opposite to that observed in aerial photography. Theoretically, radar layover is much more prevalent in the near range than in the far range of the radar imagery.

The brightness of the radar imagery depends upon the intensity of the radar signal. Although some radar antennas have vertical beam shapes designed to produce a constant image brightness over a range of depression angles, the antennas used with the ERIM radar do not have this corrected pattern. Consequently, there is a 6 dB taper of illumination across the image swath for objects with constant echoing areas. The radar energy reflected to the radar from horizontal terrain varies with the depression angle because at the lower angles such terrain intercepts less radar energy per unit area. Radar imagery of flat terrain will exhibit slightly more intensity taper than will radar imagery of targets with a constant reflecting strength. This type of intensity variation is not conspicuous in the radar imagery of the Brevard County test areas.

Intensity bands running across the X-band imagery from near range to far range may be seen at random locations on the radar imagery of all three test areas. These bands are caused by random variations in X-band antenna alignment which allow the antenna gain along the line of sight to the target to vary. Although the L-band beam parallels and is subject to the same alignment variations as the X-band beam, it is much wider and such small misalignments do not produce noticeable signal modulation. This situation has since been corrected, but the necessary work had not been completed when the Brevard County data were recorded.

Some replication of certain terrain features can be seen in the radar imagery. This is particularly apparent where features that image strongly are located in areas that have little or no radar return, such as smooth water or non-vegetated flat terrain. These false images may be seen offset in the azimuth direction from strongly reflecting targets. Generally they are visible on both sides of the real image but locally are visible on one side only. Their presence is caused by modulation of the radar signals by microphonic elements in the airborne radar system. The stable oscillators operating at microwave frequencies are particularly susceptible to this sort of unwanted modulation by mechanical vibration. The entire airborne system is subject to intense vibration at the aircraft engine frequency of about 30 Hz, and microphonic components must be carefully isolated. The false images observed in the radar imagery result from the formation of modulation sidebands on the radar signals before they are recorded on the signal films.

The offset of the false images from the true image is related to the doppler frequency of the echo signal and therefore to the radar wavelength, aircraft velocity, and radar range. The offset, X, can be calculated from a simple expression:

$$X = \frac{f\lambda R}{2V}$$

where f = modulation frequency
λ = radar wavelength
R = radar range
V = aircraft ground speed

Using this expression, one can predict that false images in the L-band imagery will appear displaced about ± 840 ft at near range and about ± 1610 ft at far range. Corresponding displacements in the X-band imagery amount to approximately ± 120 ft and ± 230 ft. In the L-band imagery, for example, some of the bridges over the Indian River have false images to the north and south. In the X-band imagery, some very bright point targets on Merritt Island have duplicate images on both sides.

Resolution of radar imagery in the range direction is determined by the bandwidth of the radar system, including the transmitter, receiver, recorder, data processor, and the photographic process. If the effective signal bandwidth is restricted in any one of these signal-handling steps, the range resolution of the radar will be degraded. The basic range resolution of a radar is in the slant range plane and is essentially independent of actual distance from the radar to the imaged feature.

Azimuth resolution is determined by the synthetic aperture technique, and under ideal conditions also is independent of radar range. However, with the limitations of signal phase stability imposed by real signal generators, aircraft and antenna stability, and the signal distortions introduced by recording and data processing, the azimuth resolution tends to decrease with range.

The resolution of radar imagery in this report is intended to be approximately 30 ft in both the azimuth and range directions. Resolution is defined as the half-power width of the main lobe of diffraction-limited image components. However, even with all phase stabilities maintained with sufficient accuracy and with photographic focus sharply adjusted, some image components will extend beyond the half-power width. In a typical radar scene the variation in intensities between various image components will be extremely large—a 50 dB variation is not uncommon. Of course, if the faint components are properly exposed on the output film, the brightest components will be greatly over-exposed; they will then bloom photographically to several times their half-power width. Examples of these bright image components are easily found in imagery of the three test areas. They look like crosses because their sidelobes extend in both the range and azimuth directions. Many intermediate-strength images also appear over-sized and may possibly merge into adjacent image components.

6
AERIAL PHOTOGRAPHY AND THERMAL INFRARED IMAGERY

6.1 INTRODUCTION

The task of obtaining black and white aerial photography of the test areas in Brevard County that would be imaged during the SLAR flights was subcontracted, by ERIM, to MAPCOtec, INC., Daytona Beach, Florida. In the time interval between the two radar imaging flights, the Co-Principal Investigators and the KSC Technical Manager for the experiment agreed to have MAPCOtec also obtain broad band 8-12.5 micron thermal infrared (IR) imagery of the same test areas they were to photograph.

The aerial photography and thermal IR imagery were to be obtained as soon as possible after the SLAR imaging flights. However, because of special constraints (such as cloud cover, time of day, etc.) placed by ERIM upon the gathering of the aerial photography and thermal IR imagery, poor weather delayed collection of these two types of imagery until near the end of October.

6.2 AERIAL PHOTOGRAPHY

On October 31, excellent black and white aerial photography was obtained of Test Areas 1, 2, and 3. Figure 2 shows by dashed lines, the extent of the aerial photographic coverage. The photography has a scale of almost exactly 1:24,000 and approximately 60 percent end overlap between successive photographs. All the photographs are cloud-free except for scattered fluffy clouds visible on the photographs of the land east of Lake Harney at the northern end of the photographic coverage of Test Area 3, and scattered clouds northeast of Titusville in Test Area 2. The photographs were taken using a Zeiss RMK A 15/23 camera and a Pleogon A lens with a focal length of 153mm. Particulars of the aerial photographic flights are given in Table 3.

6.3 THERMAL IR IMAGERY

On October 27, thermal IR imagery was obtained of Test Areas 1, 2, and 3. Figure 2 shows by solid lines the extent of the thermal IR coverage. Pre-sunrise thermal IR imagery was desired so that there would be a large contrast between the ground temperatures of various features. All the imagery was gathered within approximately two hours after sunrise (6:31 A.M. EDT at KSC). This was soon enough after sunrise so that the ground temperatures had not yet become roughly equilibrated. The thermal IR imagery of the three test areas has several gray tones on it; these range from the darkest and coldest features (shorter vegetation and certain cultural features) to the lightest and warmest features (water bodies). This indicates that there still was a large thermal contrast at ground level. There was a light ground fog in all three test areas. Scattered clouds were present over the test areas, but their base was at 6000 ft. The characteristics of the thermal IR flights are given in Table 4.

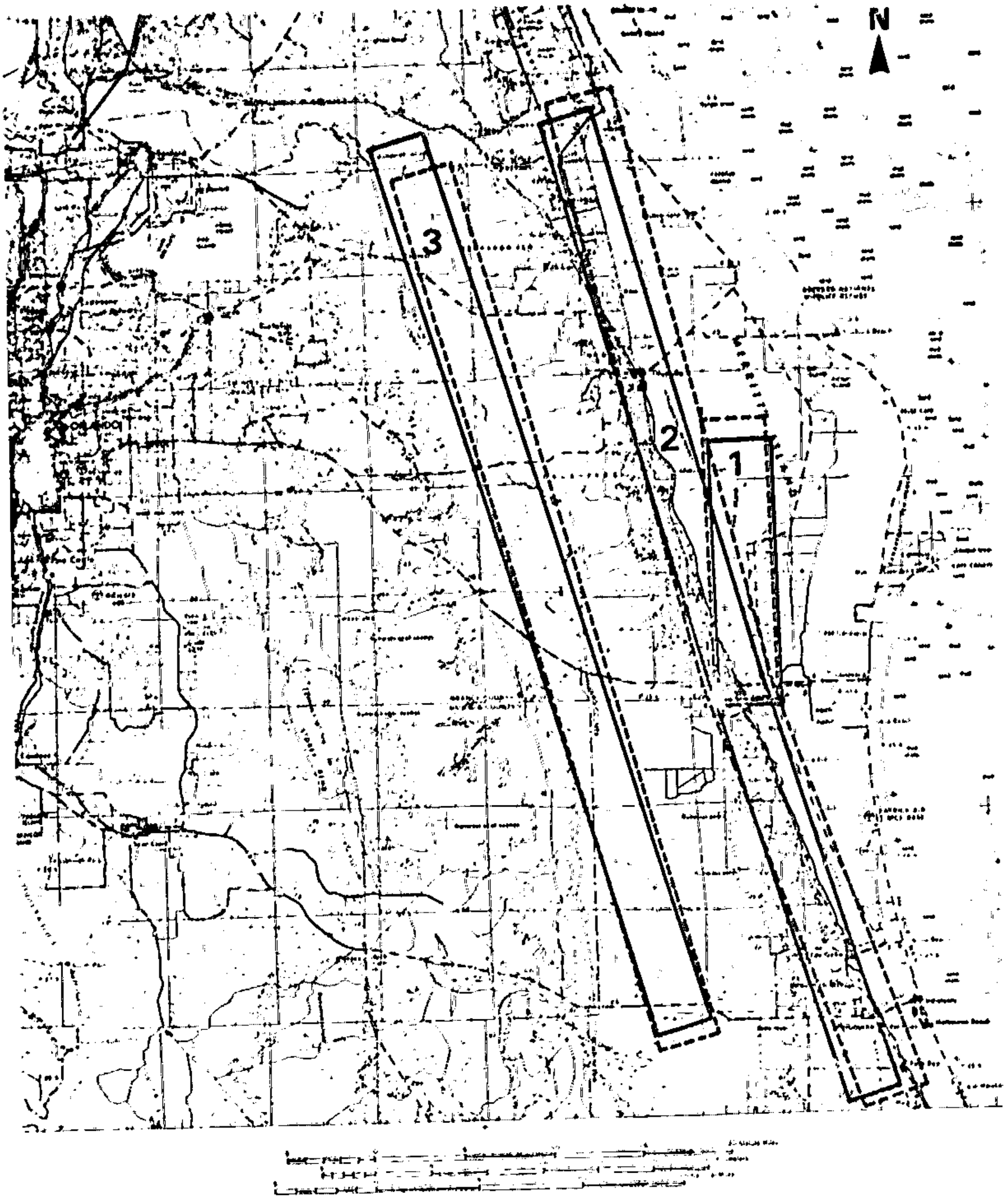


FIGURE 2. AERIAL PHOTOGRAPHY AND THERMAL INFRARED COVERAGE OF TEST AREAS 1, 2 AND 3, BREVARD COUNTY, FLORIDA. Areas covered by aerial photography are indicated by dashed lines, thermal infrared coverage by solid lines.

TABLE 3. CHARACTERISTICS OF AERIAL PHOTOGRAPHIC FLIGHTS, BREVARD COUNTY, FLORIDA (OCTOBER 31, 1973)

Test Area	Time at Start of Flight (EST)	Flight Altitude above mean Sea Level (ft)	Mean Altitude above Ground (ft)	Length of Area Photographed (miles)	Width of Area Photographed (miles)	Flight Direction True Azimuth	Camera Filter	Weather
2	4:03 P.M.	6025	6000	60	3.5	348°	- Blue	Clear
3	4:28 P.M.	6025	6000	51.7	3.5	162°	- Blue	Clear
1	4:40 P.M.	6025	6000	16.3	3.5	359°	- Blue	Clear

TABLE 4. CHARACTERISTICS OF THERMAL IR FLIGHTS, BREVARD COUNTY, FLORIDA (OCTOBER 27, 1973)

Test Area	Time at Start of Flight (EDT)	Flight Altitude above Mean Sea Level (ft)	Mean Altitude above Ground (ft)	Length of Area Imaged (miles)	Width of Area Imaged (miles)	Flight Direction True Azimuth	Weather
2	7:18 A.M.	5625	5600	58.6	3.1	165°	Light Ground Fog
1	7:34 A.M.	5625	5600	15.3	3.1	179°	Light Ground Fog
3	8:02 A.M.	5625	5600	53	3.1	163°	Light Ground Fog

The thermal IR imagery was gathered using a Bendix thermal scanner with a 2.5 milliradian instantaneous field of view. The scanner has a ground resolution of 2.5 ft per 1000 ft of altitude above ground level. Since the flight altitude was 5600 ft above the terrain, the scanner averaged the ground temperatures over a spot 14 ft wide. The scanner employs a mercury-cadmium-telluride detector having a temperature sensitivity of 0.25°C or better.

The thermal IR imagery of all the test areas is distorted. Features are shortened along the length of the imagery but elongated parallel to the width of the imagery. The scale of the thermal IR imagery in this report is approximately 1:28,400 along the length of the imagery and approximately 1:25,600 across the imagery. Aircraft motion errors commonly are visible.

7

GROUND TRUTH PROCEDURES

The three test areas imaged by radar were ground truthed from October 7(the day of the first radar flight) through October 16, 1973. Most of the ground truthing was done by three geoscientists from ERIM, but radar technicians from ERIM ably assisted in the ground truthing during part of the time. John Hutton, a biologist, and Frank Brake from the Brevard Mosquito Control District helped ground truth for two days in Test Areas 1 and 2 for pools of water under standing vegetation. Joe Brooks helped for two days to ground truth Test Area 3.

Objectives of this ground truthing were threefold: (1) Document conditions in the test areas during the radar data gathering for each of the four earth resources purposes. (2) Ground truth any places or features which had unexpected or interesting returns on the radar imagery. (3) Make field measurements of the complex dielectric constant of vegetation using portable microwave equipment.

Most of the ground truthing was done on foot, although a small amount was by observation from a car. Almost all of Test Area 3 was ground truthed from a boat. In most places along the shores of the St. Johns River the boat could not land but it was possible to touch shore and nose into channels away from the main part of the river. Obviously, because of the limited time available for ground truthing and the large areas to be covered, only a relatively small number of places and features could be ground truthed.

The ground truthing was done using the survey processed radar imagery sent to Florida and 1:4800 scale blue-line and black-line enlargements of 1969 black and white aerial photographs of Brevard County. The 1:24,000 scale black and white aerial photographs and thermal IR imagery gathered by MAPCOtec, INC., were not available at the time of the ground truthing. Notes were made directly on the radar imagery and the 1969 photo enlargements as well as in field notebooks. Several hundred color photographs were taken of the places and features observed. Approximate man-hours spent ground truthing for different tasks are as follows:

Detection of pools of water under standing vegetation	75
Urban land use	62
Rural land use	54
Water resource management and determination of drainage patterns	64
Dielectric constant measurements	21
Total man-hours	276

8

RADAR REFLECTOR STUDIES

ERIM and KSC cooperated with Mr. Gene Sivertson of the Shuttle Experiments Office, NASA Langley Research Center (LaRC) in his study of the radar return from experimental radar reflectors. Inflatable type reflectors and 14 rigid, trihedral corner reflectors used to determine relative calibration curves were placed by LaRC personnel on Merritt Island in the northern part of Test Area 1.

The reflectors were successfully imaged during the October 12 imaging mission. ERIM supplied Mr. Sivertson with prints of the like- and cross-polarized X- and L- band imagery showing the radar return from the experimental reflectors.

9
METHODS OF ANALYZING THE IMAGERY

The radar imagery and ground truth data were interpreted and analyzed mainly to determine the feasibility of using multiplexed X- and L-band SLAR for each of the four earth resources purposes. This section discusses how the analysis was done by the Radar Applications Section of ERIM's Radar and Optics Division.

The usefulness of the multiplexed SLAR for the various earth resources purposes was analyzed using photographic prints of the radar imagery, the ground truth field notes and color photographs, the 1:24,000 scale black and white aerial photographs and thermal IR imagery gathered by MAPCOtec, INC., the 1:4800 scale enlargements of the 1969 black and white aerial photographs, and 7.5 minute topographic maps. The regions in Test Areas 2 and 3 that were analyzed in depth are outlined in Figure 3; these regions are numbered the same as the six sets of plates included as Part II of this report.

This was the first time that multiplexed SLAR imagery, aerial photographs, and thermal IR imagery of a region were gathered within such a short time period (25 days). Therefore, although the interpretation of the multiplexed SLAR imagery was the major task, comparisons were made between the radar imagery, 1:24,000 scale aerial photography, and thermal IR imagery as to the information about specific features contained in each type of imagery. The various types of imagery were interpreted with the unaided eye, using primarily tone and texture as identification parameters with shape, pattern, size, and location as secondary identification parameters. The imperfections of the radar imagery were taken into account during the analysis. Because of these imperfections, no quantitative analysis (densitometer measurements, etc.) of the radar imagery was attempted.

The SLAR imagery, aerial photographs, and thermal IR imagery were examined to determine the qualitative tone and texture of many rural land-use features imaged during the experiment. Also, in many instances the various types of imagery were examined to determine with what other feature(s) a particular feature could be confused. Very few attempts were made to evaluate the appearance of a given feature on the radar imagery relative to the radar look direction, incidence angle, etc., or to determine what radar-return parameters contributed to the return from a given feature.

The results of ERIM's analysis of the radar imagery, aerial photography, and thermal IR imagery are necessarily valid only for these particular sets of imagery gathered with the specific imaging parameters, and for the particular terrain conditions. In many instances the conclusions reached from this experiment are generally true; in other instances they probably are not.

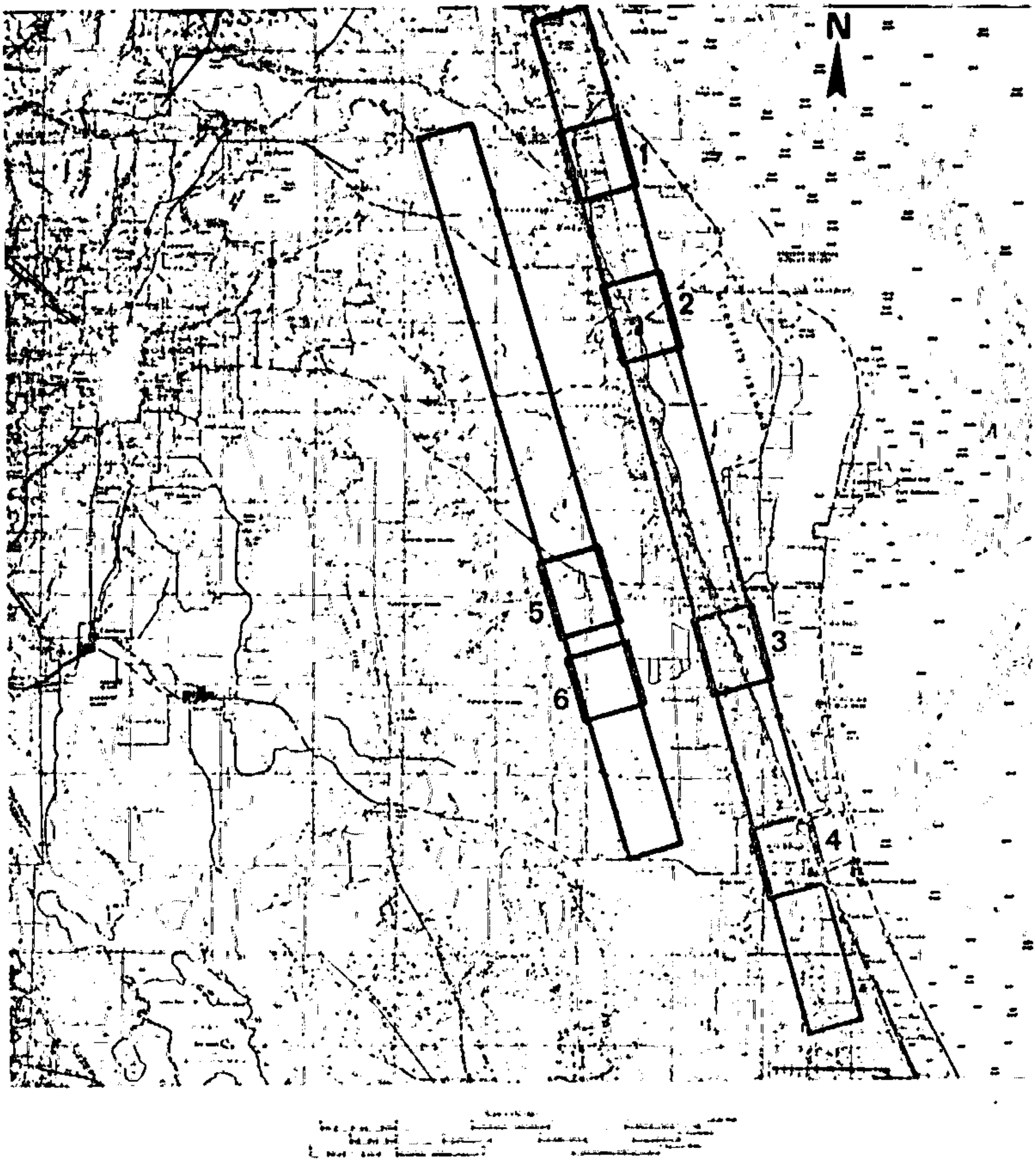


FIGURE 3. REGIONS ANALYZED IN DEPTH. Numbers refer to a series of plates in Part II of this report.

10

FEASIBILITY OF USING MULTIPLEXED SLAR TO DETECT POOLS OF WATER UNDER STANDING VEGETATION

One of the purposes of this experiment was to determine the feasibility of using multiplexed SLAR to detect pools of water under standing vegetation and particularly under canopies of dense vegetation. This was done in the hope that multiplexed SLAR could aid the Brevard Mosquito Control District (BMCD) in looking for temporary pools of water in which the floodwater mosquito larva spends its part of the mosquito life cycle. Alternate wet and dry conditions are needed for the life cycle: the eggs are laid under dry conditions, and the eggs hatch and the larvae mature under wet conditions.

The mosquitoes are controlled by the BMCD primarily for man's benefit, but also to aid livestock and other animals. The pools of mosquito larvae now are found by traverses on foot and by direct observation from a low flying airplane or helicopter. The pools are variable in size; the large ones have been located and the BMCD is looking for smaller pools the size of a "room." The areas of past known pools are checked from time to time to see if they temporarily contain water. The BMCD wanted to know the locations where temporary pools of water could form under higher standing vegetation, particularly canopies of dense vegetation that are hard to penetrate on foot or see down through from the air.

Two of the major mosquito breeding places are pools of water under canopies of dense vegetation and improved cattle pasture (ICP). The pools in the ICP are quite easily seen from the air. However, those under canopies of dense vegetation generally cannot be seen from the air nor can the pool be seen on the ground by looking into the area from its periphery. The canopy levels vary from single to triple and commonly there are several stories of relatively low undergrowth of various heights. Traversing into these canopied areas to find the pools is time-consuming and tedious.

Improved cattle pasture commonly contains temporary pools of water in swales created when the land was cleared. Although these pools can be readily seen from the air, there are several advantages in being able to find them using multiplexed SLAR.

The idea behind this part of the experiment was that the multiplexed SLAR would either directly or indirectly detect the pools of water under standing vegetation. Direct finding of the pools would have meant that the SLAR wavelengths penetrated the covering vegetation to reflect from the water. Indirect finding of the pools would have meant that the SLAR wavelengths did not penetrate the covering vegetation, but that there was a different radar reflection from the vegetation covering the pools of water than from vegetation not covering pools. In fact, the BMCD would have considered that the use of multiplexed SLAR to find new pools of water under standing vegetation was successful if ERIM would just indicate a few regions of vegetation in which there was a high probability of finding a moderate number of temporary pools that the BMCD did not already know about.

Several studies have shown that K-band wavelengths cannot penetrate dense forests and that the diffuse return is from the top of the tree canopy (MacDonald, 1969; Wing, 1971; Moore, 1971). Work by ERIM in Michigan strongly indicated that there was no significant penetration of dense forests by either X- or L-band wavelengths, and that the diffuse returns came from the upper part of the canopy. Thus, it was not anticipated that the pools of water under standing vegetation, particularly under canopies of dense vegetation, would be directly indicated by the SLAR, especially at the moderate and low depression angles that were to be used. However, there was a possibility that the areas of the pools would be indicated indirectly because there are high-energy, light-toned radar returns from vegetation with a higher moisture content, especially lower vegetation (Barr and Miles, 1970).

It was decided to try to find natural pools of water under standing vegetation rather than to look for artificially wetted areas. The BMCD suggested to KSC that the following two regions be imaged during this part of the experiment: (1) In Test Area 1, the western part of Merritt Island between the Barge Canal and the NASA Causeway. (2) The western shore of the Indian River north of Titusville. Because of heavy rain for several days immediately preceding the first radar flight, the pools in these two regions were very full. The water goes into the vegetation soon after it rains (within approximately 24 hours). Thus, the moisture content of the vegetation covering the pools would have been high at the time of the two imaging flights.

The ground truth for this part of the experiment consisted mainly of verifying that pools of water existed in several localities under canopies of dense vegetation at the times of the two radar flights. Two improved cattle pastures that contained scattered pools of water mixed in the low vegetation were examined, as was part of one ICP that was dry except for two obvious open pools of water in it. In all cases, whether the locality was a canopy of vegetation or an ICP, the characteristics of the covering vegetation were noted. Four separate areas containing pools of water under canopies of dense vegetation were ground truthed in the western part of Merritt Island. All four areas are near the western shore of Merritt Island, trend north-south (approximately perpendicular to the radar look direction), are approximately 700 × 250 ft, and the vegetation is extremely dense.

Three separate areas of pools of water under canopies of dense vegetation were ground truthed along the western shore of the Indian River north of Titusville. These areas trend north-south, range in size from 450 × 450 ft to 1900 × 500 (minimum) ft, and the vegetation is extremely dense. Two of these areas are outlined and labeled A and B on Plates 2 A, C, and E.

The dry improved cattle pasture test site along the western shore of the Indian River north of Titusville is part of a larger pasture area trending nearly north-south, and measures

1600 × 1000 ft. It is labeled A on Plates 1 A, C, E, and F. One of the improved cattle pastures that had scattered pools of water mixed in the grass is labeled A on Plates 3 A, C, E, and F. It trends north-south and is 2650 × 1700 ft. The grass in the northern part is shorter and more even in height than the grass in the larger southern part; this is clearly indicated by tonal and textural differences on the L-band imagery and by a tonal difference on the aerial photography. The other ICP that had scattered pools of water mixed in the vegetation is labeled B on Plates 3 A, D, E, and F. Only a small part of the northeastern corner of the very large ICP is visible on the radar imagery. Along with the grass, there is a north-south-trending area of brush several feet high and grass in the northeast corner of the pasture.

The areas of dense vegetation canopies and the dry ICP north of Titusville were suggested to KSC by the BMCD as test sites. All the densely canopied areas as well as the improved cattle pastures were checked either the day of the first radar imaging flight or the day after to determine whether or not pools of water were present. In addition, because of the length of time between the two radar imaging flights, the canopied areas in Test Area 1 were checked again two days after the second imaging flight. Pools of water were found in the canopied areas each time they were checked. The areas of canopies of dense vegetation and the ICP test sites were not checked after the aerial photography and thermal IR flights near the end of October. Because the pools of water seen earlier in the month were so large, it could be assumed that they were still present at the time of the photography and thermal IR flights. The presence of the pools cannot be either confirmed or denied by the thermal IR imagery.

There are no indications that either the X- or L-band wavelengths penetrated the dense canopies and were specularly reflected away from the surface of the pools. Also, on the parallel- and cross-polarized imagery of each wavelength, the returns from the trees above the pools (areas A and B on Plates 2 A and C) were no different than those from trees not standing in water. On neither the aerial photographs (areas A and B on Plate 2E) nor the thermal IR imagery can the pools be seen, and the areas where the pools exist under the canopies do not look different on either type of imagery than dense tree areas where there are no pools.

On neither the X-band parallel- or cross-polarized images does the area of dry ICP (area A on Plate 1A) look any different from the improved cattle pastures where there were scattered pools of water mixed with the low vegetation. This is somewhat surprising in that there were large regions of water-vegetation mix in area A on Plate 3A where it might be expected that the X-band wavelength would either specularly reflect away from the water or give a brighter return from the vegetation in these areas. One large water-vegetation region is to the right of the letter "A" on Plates 3A, C, E, and F. The region is at the confluence of drainage and irregation ditches and is a couple of hundred feet across. The relatively dense vegetation in it sticks out of the water as much as several inches. There are several parts of the region up to several feet across where much more water than vegetation is exposed.

Even more surprising is that the water-vegetation regions in area A cannot be identified on either polarization of the L-band imagery (see Plates 3C and D). Within this ICP the tonal and textural differences that are readily apparent on the L-band imagery are caused by the differences in height and evenness of the low grassy vegetation in the two parts of the field. Thus, it must be surmised that neither the X- nor the L-band wavelength penetrated the vegetation in the water-vegetation regions of this ICP, and that the radar returns are coming from the vegetation.

The water-vegetation regions in area A are either not indicated on the aerial photographs (Plate 3E) or are at best only faintly indicated. One of the regions, however, is indicated on the thermal IR imagery (Plate 3F).

In area B on Plates 3A, D, E, and F there are regions a few tens to a couple of hundred feet across where the grass and the brush-grass mixtures contain abundant standing water. These regions cannot be identified on the X-band parallel- and cross-polarized images or on the L-band parallel-polarized image. There is no definite indication of the water-vegetation regions on the L-band cross-polarized image; the brighter area of return in the northeast corner of the ICP almost certainly is from the brush. There is no indication of the water-vegetation regions on the thermal IR imagery, and only possibly a faint indication of some of the regions on the aerial photography.

The results from this part of the experiment are rather definite. The pools of water under canopies of dense vegetation cannot be detected, either directly or indirectly, by either the X- or L-band SLAR at moderate and low depression angles. It might be possible at very steep depression angles to detect the pools with L-band or longer wavelength SLAR, but it is doubtful. Apparently pools of water in areas of low vegetation such as ICP are not indicated, either directly or indirectly, on either the X-band or L-band imagery. This result might be somewhat suspect because only three improved cattle pastures were used in the experiment. The results of this experiment are considered valid even though only one set of depression angles and one look direction were used for each test area during a particular SLAR imaging flight.

A previous cooperative study by the NASA Johnson Space Center and the New Orleans Mosquito Control District (NOMCD) showed the usefulness of multiband camera imagery in identifying localized sites of mosquito larval incubation in a small 200-acre test site near Lake Pontchartrain, Louisiana (NASA JSC Report MSC-07644, 1973). The photographs were used to map the plants associated with marsh mosquito breeding grounds and were not used to locate pools in which the larvae mature.

Color, color infrared, and multiband sensor and film combinations enhanced by electronic manipulation were used in the NOMCD investigation. The investigation established that there is a strong empirical relationship between several specific plant communities and the breeding grounds of marsh mosquitoes.

It is not known if such methodology is valid over large unknown areas. Work also is currently underway to compare the results of the New Orleans study with data obtained using electronic multispectral scanning techniques and broad observations from the Earth Resources Technology Satellite.

Work done during the course of the present experiment for KSC has shown that multiplexed SLAR has great potential for mapping vegetation communities. Although no ground truthing was done to determine the ability of SLAR to discriminate various vegetative communities within marsh areas, it is distinctly possible that plant communities in marsh areas can be mapped using multiplexed SLAR.

11

FEASIBILITY OF USING MULTIPLEXED SLAR FOR LAND-USE PLANNING

11.1 INTRODUCTION

Many land-use classification systems exist at the present time, and are used by different federal, state, and local governmental agencies. Several of the classification systems have been developed for specific purposes, such as agriculture (Hardy, Belcher, and Phillips, 1971), forestry (National Academy of Sciences, 1970), and urban land use (Nez, 1972). There obviously is need for standardization and acceptance of one or only a few classification systems as the definitive ones.

For many years land-use classification was based on data obtained by ground observation and enumeration, complemented by data obtained from conventional aerial photography. Recent development of other remote-sensing techniques such as multispectral scanning, spacecraft photography, and SLAR has now made it possible to inventory the land use of large areas in a short period of time. Also, data processing techniques allow the storage of large quantities of detailed information that can be used in several ways to meet specific needs. In the future, land-use classification will be accomplished largely by automatic data processing of remote-sensing imagery. Thus, the development and acceptance of a system for classifying land-use information, obtained mainly by remote-sensing techniques but reasonably compatible with existing classification systems, is urgently needed (Anderson, Hardy, and Roach, 1972).

Several problems exist in defining a land-use classification system for use with remote-sensor data: (1) Land-use patterns change and evolve with time. Consequently, no one detailed classification system will be adequate for more than a relatively short period of time. (2) Different types and amounts of land-use information are obtained by the various remote sensors because of their different capabilities for data gathering. (3) What is meant by "land use" is not clearly defined. Clawson and Stewart (1965) define land use as "man's activities on land which are directly related to the land." Burley (1961) describes land cover as "the vegetational and artificial constructions covering the land surface." In some cases remote-sensing techniques can determine the land use, but in many instances only the land cover can be determined. Land cover generally is what is determined from remote sensing imagery at a scale of 1:100,000 or smaller, (4) The classification system must allow for the classification of all parts of the area under study and should also provide a unit of reference for each land use (Anderson, et al., 1972).

Assuming that different sensors will provide information for different levels of classification, Anderson, et al., (1972) anticipate the relations given in Table 5.

TABLE 5. CLASSIFICATION LEVELS OF LAND USE

Classification Level	Source of Information
I	Satellite imagery, with very little supplemental information
II	High-altitude and satellite imagery combined with topographic maps
III	Medium-altitude and remote sensing combined with detailed topographic maps and substantial amounts of supplemental information
IV	Low-altitude imagery with most of the information derived from supplemental sources

Level I classifications are made from imagery at a scale smaller than 1:100,000, and mainly smaller than 1:250,000. Thus, only a general classification can be made at this level. Level II units of classification are made from imagery at a scale of approximately 1:100,000, and the complexity of classification is greatly increased over that of Level I. Level II categories cannot all be interpreted with equal reliability. At Level III it is expected that substantial amounts of supplemental information will be used in addition to remotely-sensed information at scales of 1:40,000 to 1:15,000. Anderson, et al., (1972), believe that by using both remotely-sensed and supplemental information, most land uses except those of very complex urban areas or thoroughly heterogeneous mixtures can be adequately located and determined. Classification at Level IV demands much more supplemental information and remotely-sensed data at a much larger scale. Land cover is the basis for classification at Levels I and II, and the activity dimension of land use appears at Levels III and IV (Anderson, et al., 1972). The accuracy in land-use identification and classification that is attainable at each classification level will to a great extent be determined by the capabilities of the various remote sensors.

These four different levels of classification have been developed for imaging sensors which measure angles, such as camera systems and scanners; for these sensors the scale and resolution of the imagery decrease with range, which in this case is altitude above ground. As the altitude of these sensors increases, the level of land-use classification that can be accomplished drops. Most remotely-sensed land-use information has been provided by angle measuring sensors —particularly cameras.

Radar measures distances, and its resolution is essentially independent of range and radar wavelength. Thus, Anderson, et al., (1972), are wrong when they state, "there is little likelihood that any one sensor or system will produce good information at all altitudes." Land-use information obtained by an analysis of SLAR imagery does not readily fit into the classification levels discussed above because of the radar scales and resolution involved. For example, the multiplexed SLAR imagery of the Brevard County test areas was gathered with a slant range cross-track scale of approximately 1:180,000 for both the X- and L-band wavelengths, and an azimuth scale of approximately 1:13,100 for the X-band imagery and approximately 1:32,800 for the

L-band imagery; thus, much of the land-use classification from this SLAR imagery should only be possible at Levels I and II. However, the resolution of the Brevard County SLAR imagery is approximately 30 ft × 30 ft, and this in several cases, as is discussed in later sections, enables land-use classification at Levels III and IV to be done from the multiplexed radar imagery. The present land-use classification systems for use with remote-sensor data should be modified to readily accept the types of land-use information that can be obtained by the special capabilities of SLAR.

11.2 LAND-USE CLASSIFICATION SYSTEM USED

Anderson, et al., (1972), have proposed a land-use classification system designed specifically for use with remote-sensor data (Table 6) that they consider suitable for general use throughout the United States. Their classification system includes only the more generalized first and second levels of categorization, and minimal reliance is placed on supplemental information. The classification system was developed to be compatible with the widely used land-use classification systems currently in use, but as they state, considerable care should be taken in comparing land-use classifications based on remote-sensing data and the definitions proposed by Anderson, et al., with classifications based on data obtained by enumeration and observation and category definitions written for use with those techniques. The land-use categories listed in Table 6 are defined in the Appendix.

The classification system of Anderson, et al., (1972), was developed for use with major research activities in the testing of remote-sensing techniques. The definitional structure they proposed is a first approximation, capable of further refinement and revision on the basis of widespread review and varied use of the system. Thus they fully expect that modification of their classification system may be necessary for its use with automatic data analysis.

We have followed the land-use classification system of Anderson, et al., (Table 6) during this study, even though there are problems in doing so: (1) The system was developed specifically for imaging sensors which measure angles; it was not developed for radar. (2) Some features can be recognized and classified on the SLAR imagery at a finer scale and resolution than allowed for in the classification system. For example, overland railroad track should not be classified as category 1.5, Transportation, Communications, and Utilities, unless six or more tracks are joined to give sufficient width for delineation at a scale of 1:250,000. A water area should not be classified as category 5 (Water) unless, if linear, it is at least 660 ft wide and if extended covers at least 40 acres. The minimum sizes stated by Anderson, et al., for classification into categories have been ignored in this study. (3) The classification system is provisional and has not yet been widely tested. (4) Not enough data is presently available to determine, using the classification system, the accuracy of land-use interpretation on imagery of the various

TABLE 6. LAND-USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA (From Anderson, et al. 1972)

Level I	Level II
1 Urban and Built-up Land	
	.1 Residential
	.2 Commercial and Services
	.3 Industrial
	.4 Extractive
	.5 Transportation, Communications, and Utilities
	.6 Institutional
	.7 Strip and Clustered Settlement
	.8 Mixed
	.9 Open and Other
2 Agricultural Land	
	.1 Cropland and Pasture
	.2 Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas
	.3 Feeding Operations
	.4 Other
3 Rangeland	
	.1 Grass
	.2 Savannas (Palmetto Prairies)
	.3 Chaparral
	.4 Desert Shrub
4 Forest Land	
	.1 Deciduous
	.2 Evergreen (Coniferous and Other)
	.3 Mixed
5 Water	
	.1 Streams and Waterways
	.2 Lakes
	.3 Reservoirs
	.4 Bays and Estuaries
	.5 Other
6 Nonforested Wetland	
	.1 Vegetated
	.2 Bare
7 Barren Land	
	.1 Salt Flats
	.2 Beaches
	.3 Sand Other Than Beaches
	.4 Bare Exposed Rock
	.5 Other
8 Tundra	
	.1 Tundra
9 Permanent Snow and Icefields	
	.1 Permanent Snow and Icefields

Level I land-use categories are indicated in this report by integers such as 1. Level II categories are indicated by decimal suffixes such as .1. Thus, a number such as 2.1 gives both the Levels I and II classifications.

sensors. (5) Not all of the categories of the system are represented in the test areas, and some land uses are present in the test areas that are not provided for in the classification system.

Although we generally are actually classifying land cover, we have followed Anderson, et al., (1972), and discussed the various types of land use at Levels I and II. However, agricultural land use and some types of urban land use in many instances were clearly indicated on the three types of imagery.

11.3 COMPARISON OF URBAN LAND-USE CLASSIFICATION FROM SLAR IMAGERY AND AERIAL PHOTOGRAPHY

Although a considerable amount of work has been done using SLAR imagery for earth resources problems (Bryan, 1973), few of these efforts have concentrated on the interpretation of SLAR imagery of urban and built-up areas. This section of the report discusses methodologies which have been used in interpreting multiplexed SLAR imagery of two urban areas in Florida.

Land-use maps based upon the visual interpretation of the multiplexed SLAR imagery were prepared of parts of two urban areas within Brevard County, namely the Titusville and Melbourne metropolitan regions, each of which has a population less than 50,000. These land-use maps then were compared with similar land-use maps based upon the visual interpretation of the 1:24,000 scale black and white aerial photography in order to determine the accuracies of the urban land-use identifications made from the SLAR imagery. It is assumed that the land-use identifications made from the aerial photographs are correct; this assumption is considered valid because of the generalized classification system used and the large scale of the aerial photography. All Level II categories of Urban and Built-up Land except 1.4, Extractive, and 1.8, Mixed, are represented on the land-use maps made from the radar imagery. Category 1.8, Mixed, is used only for cities of more than 50,000 population, and thus is not applicable in this study. Plates 2 A-D are the multiplexed radar images, 2E the aerial photographs, and 2F the radar-derived urban land-use map of the Titusville region. Plates 4 A-D are the multiplexed radar images, 4E the aerial photography, and 4F the radar-derived urban land-use map of the Melbourne region. The radar-derived urban land-use maps were drawn to the scales of the respective X-band, parallel-polarized images, but can be overlaid on the other radar images and the aerial photography with a close correspondence of scales. Railroad lines are indicated by dashed lines on the two radar-derived land-use overlays, but highways and roads, and canals in the Melbourne region, are not indicated.

Two individuals interpreted urban land use at 200 points randomly selected in each of the two urban areas. One individual worked with only the radar imagery, and the other used only the aerial photographs. Working independently, each individual interpreted the land use in a 0.125-in.-diameter circle centered on each random point; this corresponds to a ground diameter of approximately 250 ft and a circular ground area of approximately 49,000 sq ft.

All four multiplexed SLAR images of the particular urban area were examined while interpreting the land use at the locations of the points. The radar-derived urban land-use maps were then drawn based on the land use determined at the 200 points in each urban area.

Table 7 summarizes the interpretations of land use made from both the SLAR imagery and aerial photographs at the locations of the 200 random points in the Melbourne area. Table 8 does the same for the Titusville area, and Table 9 shows the combined interpretations of land use in both the Melbourne and Titusville areas. The diagonal extending from the upper left to the lower right in each table gives, for each land-use category, the number of points at which that interpretation of land use was made on the SLAR imagery and on the aerial photographs, although the same interpretation was not necessarily made at a particular point. Assuming that the interpretations of land use from the aerial photographs are correct, the diagonals also give the number of times that a particular land use was correctly identified on the SLAR imagery.

Residential areas are the predominant type of urban land use in the areas studied. Locally, there are misinterpretations on the SLAR imagery of non-residential areas as residential areas, and vice versa. Residential areas in the Titusville and Melbourne areas can be confused with the following Urban and Built-up Land categories: 1.2, Commercial and Services; 1.7, Strip and Clustered Settlement; and 1.9, Open and Other; and also with rural categories 3, Rangeland, and 4, Forest Land. The confusion with Commercial and Services areas of towns occurs especially with residential areas that are close to commercial areas and also with those which apparently are the older parts of town and have experienced some mixing, over both time and space, with commercial areas. Area C on Plates 2A, C, and E, and areas A, B, and C on Plates 4A, C, and E are representative parts of single-family housing areas that were correctly classified on the SLAR images as residential areas. These four areas may be easily confused with commercial areas because they contain numerous buildings, some of which are Commercial and Services units; however, the concentrations of large buildings indicative of central business districts generally are not present.

A second type of residential development that can be confused with commercial areas is the trailer park. Examples of trailer parks are area D on Plates 2A, C, and E, and area D on Plates 4A, C, and E. Trailer parks are areas in which the residential units are closely spaced, generally a uniform distance apart. The trailers may have a constant alignment or they may be oriented in different directions. The radar return from individual trailers is strongly dependent upon the orientation of the trailer to the radar look direction. The strong radar returns from house trailers, particularly at L-band, appear to result from a combination of several factors: the trailers are metal; the trailers with rounded sides present a smooth surface, part of which commonly is oriented perpendicular to the radar look direction; and there are many dihedral reflectors formed between the sides of the trailer and the ground. Consequently, trailer parks commonly appear on radar imagery as a series of closely spaced, very bright points with areas of low or no

TABLE 7. INTERPRETATION OF URBAN LAND USE AT 200 RANDOM LOCATIONS IN THE MELBOURNE AREA

Interpretation from Aerial Photography	Interpretation from Multiplexed SLAR Imagery												
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2	3&4	5	6.1	Totals
1.1	101	6	1	0	0	0	1	0	0	6	0	1	116
1.2	2	5	0	0	0	1	4	1	1	0	0	0	14
1.3	0	0	0	0	0	0	0	0	0	0	0	0	0
1.4	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	1	0	0	0	16	0	0	0	0	0	0	0	17
1.6	1	0	0	0	0	9	2	1	0	0	0	0	13
1.7	0	0	1	0	0	0	0	0	0	3	0	0	4
1.9	5	1	0	0	0	1	0	14	1	3	0	0	25
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3&4	0	0	0	0	0	0	0	0	0	6	0	0	6
5	0	0	0	0	0	0	0	0	0	0	4	0	4
6.1	0	0	0	0	0	0	0	0	0	0	0	1	1
Totals	110	12	2	0	16	11	7	16	2	18	4	2	200

Common Number of SLAR and Aerial Photography Interpretations (i.e., the diagonal elements) = 156

TABLE 8. INTERPRETATION OF URBAN LAND USE AT 200 RANDOM LOCATIONS IN THE TITUSVILLE AREA

Interpretation from Multiplexed SLAR Imagery

Interpretation from Aerial Photography	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2	3&4	6.1	Totals
1.1	50	5	2	0	1	0	5	5	1	9	0	78
1.2	1	6	0	0	0	2	1	1	0	0	0	11
1.3	0	0	1	0	0	1	2	0	0	0	0	4
1.4	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	5	0	0	2	0	0	0	7
1.6	1	1	0	0	0	4	0	0	0	0	0	6
1.7	0	0	0	0	0	0	4	0	0	0	0	4
1.9	23	2	0	0	0	3	1	11	11	31	0	82
2	0	0	0	0	0	0	0	0	0	0	0	0
3&4	0	0	0	0	0	0	0	0	0	0	0	0
6.1	0	0	0	0	0	0	0	5	0	3	0	8
Totals	75	14	3	0	6	10	13	24	12	43	0	200

Common Number of SLAR and Aerial Photography Interpretations (i.e., the diagonal elements) = 81

TABLE 9. INTERPRETATION OF URBAN LAND USE AT 400 RANDOM LOCATIONS IN THE MELBOURNE AND TITUSVILLE AREAS

Interpretation from Multiplexed SLAR Imagery

Interpretation from Aerial Photography	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2	3&4	5	6.1	Totals
1.1	151	11	3	0	1	0	6	5	1	15	0	1	194
1.2	3	11	0	0	0	3	5	2	1	0	0	0	4
1.3	0	0	1	0	0	1	2	0	0	0	0	0	4
1.4	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	1	0	0	0	21	0	0	2	0	0	0	0	24
1.6	2	1	0	0	0	13	2	1	0	0	0	0	19
1.7	0	0	1	0	0	0	4	0	0	3	0	0	8
1.9	28	3	0	0	0	4	1	25	12	34	0	0	107
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3&4	0	0	0	0	0	0	0	0	0	6	0	0	6
5	0	0	0	0	0	0	0	0	0	0	4	0	4
6.1	0	0	0	0	0	0	0	5	0	3	0	1	9
Totals	185	26	5	0	22	21	20	40	14	61	4	2	400

Common Number of SLAR and Aerial Photography Interpretations (i.e., the diagonal elements) = 237

return between the points, at least in some directions. In this respect trailer parks appear quite similar on radar imagery to many commercial areas, especially strip developments composed of small units.

On the radar imagery, one of the major differences in appearance between trailer parks and strip developments is the amount of open space between the structures and the servicing highway(s). The open spaces in commercial areas generally are smooth, flat parking lots, and consequently have very low, if any, radar return when there are no cars on them. These large open spaces normally are not found in trailer parks. However, if the trailers are set back a considerable distance from the street(s) and the intervening area is occupied by sidewalks and mowed grass, it could be difficult to distinguish the trailer park from a commercial area on SLAR imagery. The variations with wavelength and polarization in the radar return from trailer parks can be seen by examining area D on Plates 4A-D.

Residential areas of single-family houses also can be confused with categories 1.9, Open and Other; 3, Rangeland; and 4, Forest Land. However, where there are not a great number of trees in the residential areas, there generally is little confusion. On both the X-band and L-band imagery, the streets in such residential areas generally are imaged in patterns of specular no returns and the brighter returns from the inter-street areas are from both cultural and vegetation features. Many of the houses commonly appear as point returns that generally are randomly distributed. An example of this type of residential area is area E on Plates 4A, C, and E.

Area F on Plates 4A, C, and E is part of a single-family residential area that contains more trees. Consequently, there is more shadowing of the streets and houses by the trees. The street patterns in this area are less easily discerned on all four radar images, but are more difficult to see on L-band imagery than on the X-band imagery. However, the scattered point returns from this area would help identify it as a residential area. As the trees in single-family residential areas increase (both in terms of height and density), they increasingly overhang and shadow the streets; thus there is a decreasing definition of street pattern, particularly on the L-band imagery (area E on Plates 2A, C, and E). Concurrently, there generally is a decrease in the number and intensity of point returns as the radar return, particularly at L-band, increasingly comes from the trees. It is these heavily wooded single-family residential areas that generally are confused with categories 1.9, Open and Other; 3, Rangeland; and 4, Forest Land. These areas are best identified as residential areas by examining the radar imagery of all wavelengths and polarizations.

Shopping centers generally are easily identified on the SLAR imagery. Basically, a shopping center is a large, flat, smooth parking lot associated with a number of buildings. There are no radar returns from the parking lot surfaces, but there are returns, commonly prominent ones, from the buildings. Area G on Plates 4A, C, and E is a small shopping center of three buildings around a large mall or grass area and parking lot. Area H on Plates 4A, C, and E is a shopping center where most of the buildings are in a single row and set back a considerable distance from the street to the south. There is a line of bright point returns on both the X- and L-band imagery from a row of cars parked on the south side of the row of buildings, and point returns from the other buildings in the shopping center. Area F on Plates 2A, C, and E is a large shopping center consisting of a large building surrounded by a parking lot. The cause of the bright returns at the east end of the building is not known, but they probably are from structures on the roof. Generally, these shopping centers are easier to identify on the X-band imagery. There often is a pattern on the SLAR imagery of evenly spaced point returns from the parking lots; the returns are coming from structures in the parking lots, and almost certainly from light poles. The point returns from the parking lots are brighter and more easily seen on the L-band imagery than on the X-band imagery, and are brighter on the parallel-polarized imagery of both wavelengths.

Strip and Clustered Settlements are difficult to identify on the SLAR imagery; parts of them are often misidentified as residential or various commercial areas. According to the definition of this category (see 1.7 in Appendix), the settlements can be a combination of residential, commercial, industrial, institutional, and occasionally other land uses along a transportation route. They generally appear on the radar imagery as a linear cluster of bright point returns along a highway, railroad track, etc. Area G on Plates 2A, C, and E is one of these settlements; it has been identified as such primarily by the linear cluster of bright point returns on the parallel-polarized images of both wavelengths, particularly the L-band imagery. If the X- and/or L-band cross-polarized images were the only ones used to identify this large Strip and Clustered Settlement, it probably would have been classified as residential and commercial areas. Area I on Plates 4A, C, and E is another Strip and Clustered Settlement.

Category 1.9, Open and Other, was confused during this study on both the SLAR imagery and aerial photography with Level I classifications 3, Rangeland, and 4, Forest Land. This confusion is partly from the general descriptions of the classifications (see Appendix), and partly because the descriptions were interpreted somewhat differently by the two people doing the analysis of the imagery. Although the interpretation of land use at each of the random locations was to have been made solely on the basis of the radar returns from the area within the 0.125 inch diameter circle, the interpreter often based his interpretation also upon the location of the point and the spatial arrangement of the immediate area around the point. Area H on Plates 2A, C, and E is an area that is covered by trees and rangeland vegetation, but is free of cultural structures. A small pond in the area is visible on both the radar imagery and the aerial photography. One interpreter classified the area as category 1.9, Open and Other, in the context that it was a park in an urban area; the other interpreter classified it as an area which, though undeveloped, was not necessarily specifically zoned for recreational purposes. It was finally decided not to classify the area as Urban and Built-up Land. Examples of areas classified by both observers as Open and Other are areas I and J on Plates 2A, C, and E.

Golf courses are a type of urban Open and Other land use that is quite easily identified on all the radar imagery, but especially on the X-band imagery. Area J on Plates 4A, C, and E is a golf course where the narrow fairways and roughs commonly are bordered by single rows of trees. The fairways are more even in height than the roughs and consequently, they commonly have a darker tone and smoother texture on the X-band imagery than the roughs. No distinction can be made between the fairways and the roughs in their radar returns on theL-band imagery. There is a strong return on both the X- and L-band imagery from the near-range side of the tree belts that are at a high angle to the radar look direction.

Surprisingly, institutional areas were not confused with commercial and residential areas as often as one might expect. Institutions such as hospitals, schools, etc., commonly are large structures in an open setting (as are many commercial establishments); the grass and asphalt areas adjacent to or surrounding the institutional buildings are analogous to the parking lots in shopping centers. However, the conglomerations of land cover in the institutional areas and their regional settings in many instances allow these areas to be readily identified on the SLAR imagery.

In the parts of the Titusville and Melbourne areas that were studied, the schools generally are either in or near commercial zones but separated from the commercial buildings by a "buffer" of residential areas (area K on Plates 2A, C, and E), or they are within or at the periphery of the residential areas (areas K and L on Plates 4A, C, and E). The open areas around the institutional buildings have a dark to moderate tone and a relatively smooth texture on the X-band imagery of both polarizations. This indicates that the open areas consist of short vegetation, probably grass, that is quite even in height. The return at X-band wavelength is greater than that from a flat, smooth parking lot. The open areas have a dark tone and smooth texture on the L-band imagery of both polarizations; this return is the same as that from the parking lots. The grassy areas are not sufficiently rough to give an appreciable backscatter at L-band wavelength.

11.4 RURAL LAND USE

11.4.1 INTRODUCTION

For the purposes of this report, rural land use ha been defined as land use outside the urban areas. In this study, rural land use is concerned with Level I categories 2 (Agricultural Land) through 6 (Nonforested Wetland), but not all Level II categories of these Level I classifications are present in the test areas. Water resources and nonforested wetland are discussed in Sections 12 and 13.

The purpose of this experiment was to determine the feasibility of using multiplexed SLAR, among other purposes, for rural land-use planning. Accordingly, large areas of rural land use generally have not been mapped and discriminated on the SLAR imagery, the aerial photographs, of the thermal IR imagery. Instead, numerous examples of a particular rural land-use category or feature have been examined on all the types of imagery. Specific objectives of this part of the study are to:

(1) Determine with what other rural land-use categories or features a particular rural category or feature could be confused on the various types of imagery, and how to discriminate them.

(2) Determine at what level(s) rural land use in the test areas can be classified on the multiplexed radar imagery.

(3) Determine whether the major differences in appearance on the multiplexed SLAR images of the various vegetation types in the test areas are primarily wavelength or polarization differences.

The same two persons visually interpreted the rural land use on the three types of imagery. The four multiplexed SLAR images were interpreted first, and then the aerial photographs and thermal IR imagery were interpreted to determine the validity of the SLAR interpretation. Initially the two men worked independently, but later, using all three types of imagery, agreed upon a common interpretation of the rural land use in the area under discussion. In most instances their interpretations were very similar. It was determined which rural land-use categories and features could be confused on the three types of imagery and how to discriminate them. The categories and features are discriminated primarily on the basis of tone and texture, but pattern, location, shape, and even size, commonly aided in the discrimination.

A series of plates numbered 1, 2, 3, 5, and 6 in Part II of this report show identified examples of the various rural Levels I and II land-use categories present in the test areas. Plates A-D of each numbered set are the multiplexed SLAR images, E is the aerial photography, and F is the thermal IR imagery. The rural land-use categories indicated on the plates commonly include small areas of other rural categories that are not labeled. A notation such as 3/4 on the plates indicates that two major land-use categories are present in the area; the number of the dominant land-use category is to the left of the slash.

Several different types of vegetation, both on land and in the water, can be differentiated and mapped on the multiplexed radar imagery by the relative heights, densities, surface roughnesses, etc., of the vegetation. The vegetation type is not directly sensed by the SLAR.

Multiplexed SLAR is a good indicator of the relative heights of vegetation. Using both the X- and L-band imagery, the relative heights of vegetation differing only 18 to 24 inches in height ca be discerned.

11.4.2 IMPROVED CATTLE PASTURE

Improved cattle pasture (ICP) is an area from which most of the native vegetation has been removed by man, the land made essentially level, and then re-sodded with "grass." Trees commonly are left standing in the ICP, both as isolated trees and in small scattered stands. Some of the improved cattle pastures have been cropped to improve their acceptability to the cattle. The recently cropped ICP is shorter and more even in height than the ICP that has not been cropped. In area A on Plates 3A, C, E, and F, the grass in the cropped northern part of the field is approximately 18-24 inches shorter and more even in height than the grass in the southern part; this is clearly indicated by tonal and textural differences on the L-band imagery but not on the X-band imagery (Plates 3A and C).

Drainage and irrigation ditches generally are present in the ICP. They trend in various directions, but mainly occur in two intersecting sets paralleling the boundaries of the pasture. The ditches are of various sizes and depths, and several different spacings between ditches commonly are present.

Thirty-one different ICP regions containing one or more pastures were analyzed during the course of this study. The ICP regions were identified using the SLAR imagery, 1:24,000 scale aerial photographs, the thermal IR imagery, and available ground truth. Most of the improved cattle pastures studied are in Test Areas 2 and 3, and are indicated by the number 2.1 on the plates of the various imagery. Those improved cattle pastures that did not contain large amounts of standing water were mainly studied, because the tones of an ICP on the aerial photographs and thermal IR imagery, but not on the radar imagery, are quite variable when the ICP contains large amounts of standing water.

ICP can be confused with Rangeland and Nonforested Wetland on both the X- and L-band imagery. Locally ICP can be confused with citrus groves on the radar imagery, but the row patterns in the groves, if visible on the imagery, will enable the ICP and citrus groves to be differentiated.

Some ICP can be confused with Rangeland and Nonforested Wetland on the aerial photographs, and, on the thermal IR imagery, ICP can be confused with Rangeland and locally with citrus groves. The linear boundaries and geographic locations of most improved cattle pastures help to identify them on all three types of imagery.

11.3.3 CITRUS GROVES

Citrus groves are extensively present in Test Areas 1 and 2 on both sides of the Indian River. We were not able to differentiate between orange and grapefruit groves on the various types of imagery and thus the general term citrus groves is used in this report. Citrus groves are labeled 2.2 on the plates of the various imagery.

The trees in the groves are planted in one or more row directions. Rows running in various directions generally are quite visible on the aerial photography, and locally the rows are visible in a few groves on the thermal IR imagery. In many groves the rows approximately paralleling the azimuth direction can be seen on the 30 × 30 ft resolution X-band imagery, and locally the rows approximately paralleling the range direction also can be seen on the X-band imagery. It generally takes a several-power magnification to see the rows on the X-band imagery. Where the rows can be seen on any of the types of imagery, they positively identify the area as citrus groves.

On the aerial photographs citrus groves can be differentiated from all other types of vegetation, and four stages of growth can be distinguished using tone, texture, and row direction(s) and spacing. We called the four growth stages young, intermediate, mature, and wild; these may or may not be correctly identified.

Using tone, texture, and the criterion of whether or not the rows are visible, we believe that there is great potential for distinguishing the same four growth stages on the radar imagery. To do so it will be necessary to use the parallel- and cross-polarized imagery of both the X- andL-band wavelengths.

Citrus groves can be confused with Nonforested Wetland on the X-band imagery, but not on L-band imagery. Groves locally can be confused with Forest Land on the L-band imagery, but generally not on X-band imagery. Infrequently, groves can be confused with Rangeland on both the X- and L-band imagery.

Groves can be confused with Rangeland and Forest Land on the thermal IR imagery. The linear boundaries and geographic locations of the citrus groves help to identify them on the different types of imagery.

11.4.4 RANGELAND

Several different types of Rangeland can be differentiated on the multiplexed SLAR imagery. Multiplexed SLAR is the single best sensor of the three to differentiate and map Level II categories of Rangeland. General Rangeland is labeled 3 on the plates of the various imagery.

Various types of "grasses" and low brush of various heights are present in all three test areas. Several areas of grasses and brush immediately adjacent to the palmetto regions on Plates 3A-F can be discriminated on the multiplexed radar imagery (Plates 3A-D): one of the larger grass-brush areas is labeled 3.1.

Two areas of Palmetto Prairies were ground truthed. The palmettos in these areas are generally 3 to 5 ft high, quite even in height, and so closely spaced that they are touching. The palmetto regions of one of the ground truthed areas are labeled 3.2 on Plates 3A, C, E, and F.

Scattered southern pine trees are present in the labeled palmetto regions. These Palmetto Prairies are quite readily mapped on the X- and L-band imagery, but are difficult to distinguish from other types of vegetation on the aerial photographs and thermal IR imagery. The moderate texture of these areas on the X- and L-band imagery indicates the evenness in height of the palmettos. Several small areas of shorter grassy vegetation and brush are visible within the palmetto regions on all three types of imagery (Plates 3A-F).

Unimproved cattle pasture is used for cattle grazing. It usually consists of native vegetation several feet high, commonly is located near rivers, and when flooded becomes a type of marshland. Areas interpreted as unimproved cattle pasture are labeled A on Plates 5A, C, E, and F, and Plates 6A, C, E, and F. On the three types of imagery, unimproved cattle pasture is extremely difficult to distinguish from other types of vegetation.

Rangeland can be confused with Forest Land on the L-band imagery. Rangeland can be confused with Nonforested Wetland on both the X- and L-band imagery, but especially on the X-band imagery when little open water is visible in the Nonforested Wetland.

On the aerial photography, Rangeland locally can be confused with Forest Land when the trees are essentially uniform in height and so dense that the crowns touch. Rangeland can be easily confused with Nonforested Wetland, expecially when there is much vegetation in the nonforested Wetland.

11.4.5 FOREST LAND

Forest Land is labeled 4 on the plates of the various imagery. It is extremely difficult to determine on the radar imagery whether tree areas are Deciduous, Evergreen, or Mixed. Evergreen areas labeled 4.2 on Plates 3A, C, E, and F were identified by ground truthing. It was not possible to identify the tree type (oak, palm, pine, etc.) except on the basis of the geometric considerations of the tree stands. Linear belts of Australian pines generally can be identified on the radar imagery, especially when they are oriented at a high angle to the radar look direction.

Qualitative estimates of the densities of tree areas can be made from the radar imagery (particularly the L-band imagery) as well as from the aerial photographs. In the areas numbered 4.2 on Plates 3A, C, E, and F, the pine trees are so dense that their crowns touch and it is not possible for either the X- or L-band wavelength to penetrate the crowns. The area labeled 3.2/4.2 on Plates 3A, C, E, and F is an area of pine trees mixed with palmettos. In this area the tree crowns do not touch and it was possible for the X- and L-band wavelengths to reflect from the palmettos as well as from the tree crowns. On the L-band imagery, note the difference in the brightness of these two different types of areas.

12

FEASIBILITY OF USING MULTIPLEXED SLAR FOR WATER RESOURCES MANAGEMENT

12.1 INTRODUCTION

Water resources encompass the Level I categories 5, Water, and 6, Nonforested Wetlands. However, many features pertinent to water resources, such as islands, shorelines, floating vegetation, and diking systems do not readily fit into the two Level I categories mentioned above. For this reason, water resources are discussed under various subheadings.

12.2 OPEN WATER AREAS

Open water areas are standing or flowing water bodies without an appreciable amount of either standing or floating vegetation.

Boundaries of open water areas can be seen quite well on the radar imagery and are clearly delineated except where the vegetation around the water body is very low and uniform in height. Boundaries of open water areas can be clearly delineated on the aerial photographs except locally where the open water area abuts against a marsh or is in a marsh. The boundaries of open water areas generally can be determined on the thermal IR imagery, but locally cannot be placed as accurately as on the radar imagery and aerial photographs.

Open water areas that are nonlinear can be identified as water areas on the 30 × 30 ft resolution SLAR imagery down to at least 125 ft across in size. On the aerial photographs nonlinear open water areas can be correctly identified down to 60 ft across, and on the thermal IR imagery they can be correctly identified down to a size of 125 ft across.

Linear open water areas (primarily drainage and irrigation ditches or river channels) can be identified as water areas on the 30 × 30 ft resolution radar imagery, especially on the X-band imagery, down to 10-20 ft in width. Linear open water areas also can be correctly identified on the aerial photographs and thermal IR imagery down to 10-20 ft wide. Examples of major drainage and irrigation ditches are labeled C on Plates 6A, C, E, and F. It appears that linear open water areas are better identified on the radar imagery when they closely parallel the look direction. Narrow linear bodies of water can be confused with roads on the radar imagery, but not on the aerial photographs or thermal IR imagery. "Very" small nonlinear and "very" narrow linear open water areas can be seen and identified better on the X-band imagery than on the L-band imagery, and sometimes are not even discernable on the L-band imagery.

The aerial extent of open water bodies can be determined and surface areas can be calculated using the radar imagery even though locally there is distortion in the shape of the water body, especially in the near range of the imagery. The radar imagery and early-morning

Islands as small as 40 × 70 ft can be clearly seen on the 30 × 30 ft resolution radar imagery and on the aerial photographs, but not on the thermal IR imagery. Islands smaller than 150 × 75 ft cannot be seen on the thermal IR imagery.

Islands cannot be positively differentiated on the radar imagery from masses of floating vegetation, but generally can be differentiated on the aerial photographs.

12.4 SHORELINES

Radar, particularly at X-band and shorter wavelengths, generally is an excellent indicator of the water-land boundary. The boundary between water and low vegetation that is even in height cannot be located on the L-band imagery, but can be seen on X-band imagery. Therefore, the location of the water-land boundary should be checked on both the X- and L-band imagery. The water-land boundary generally can be determined on the aerial photographs, but locally there are ambiguities as to its location, especially when there is shallow water directly offshore, that do not exist on the radar imagery. Therefore, radar is a better sensor to use to determine the water-land boundary, particularly where shallow water is involved.

The water-land boundary commonly cannot be accurately placed on the thermal IR imagery regardless of the height of the vegetation at the water's edge, unless there is a large thermal contrast between the water and land—such as where dense growths of trees and some types of rangeland directly border the water body.

Radar imagery is well suited for determining how much of low-lying islands and shorelines is above water at different flood stages.

12.5 NAVIGATION AIDS, POWER POLES, AND DOCKS IN THE INDIAN RIVER

Navigation aids (buoys, fixed signs, etc.) can be seen as point target returns on both the X- and L-band radar imagery, but cannot be seen on the thermal IR imagery and only infrequently, if at all, on the aerial photographs. The navigation aids have brighter returns on the L-band imagery than on the X-band imagery. The percentage of navigation aids seen on the radar imagery is not known, but many of the aids can be seen.

Transmission line poles, both metallic and wooden, in water bodies can be clearly seen on both the X- and L-band imagery as separate distinct point targets. They generally cannot be seen on the aerial photographs except for an infrequent pole or two or their shadows. The poles are not visible on the thermal IR imagery.

Docks for pleasure boats on both sides of the Indian River can be seen on the X-band parallel-polarized imagery, but generally not on the X-band cross-polarized imagery. Some docks are visible on the L-band parallel-polarized imagery, but are not as well defined as on the X-band parallel-polarized imagery. Generally, the docks are not visible on the L-band cross-polarized imagery or on the thermal IR imagery. The aerial photography clearly defines each pleasure dock.

12.6 DIKING SYSTEMS

Diking systems and accompanying ditches are used for flood control as well as irrigation purposes. The dikes consist of a linear pile of earth material standing several feet above the terrain with ditches, commonly full of water on one or both sides. Often vegetation and an access road are on top of the several feet to few tens of feet wide dikes.

Typical dikes are labeled D on Plates 1A, C, E, and F; L on Plates 2A, C, E, and F; and B on Plates 5A, C, E, and F. Dikes also are visible in the marsh in the upper right corner of Plates 3A, C, E, and F. Dikes give a moderately strong return on both the X- and L-band radar imagery when their orientation is essentially perpendicular to the radar look direction, and a moderate return when oriented essentially parallel to the look direction. Those essentially perpendicular to the look direction present a steep sloping surface that the radar beam reflects from back to the antenna. However, most of the radar return comes from the vegetation growing along the banks and top of the dikes; therefore, the more vegetation and the more uneven in height the vegetation on the bank, the stronger the radar return. Quite commonly, the ditch (with or without water) alongside the dike is visible on the radar imagery. The dikes and ditches can be seen and traced very well on the aerial photographs and generally very well on the thermal IR imagery.

12.7 AQUATIC VEGETATION

The water hyacinths generally stand 1 to 3 ft above the water. They commonly float in the water and migrate along the St. Johns River due to the action of wind and water currents. However, large patches of them also are stationary. The hyacinths generally are clearly defined on the radar imagery, and areas of them are labeled C on Plates 5A and C, and B on Plate 6A and C. The hyacinths generally are well indicated on both the aerial photographs and the thermal IR imagery (C on Plates 5E and F, and B on Plates 6E and F). Hyacinths are a hazard to boat navigation, as well as choking current flow. Therefore, monitoring of their growth and migration is of importance.

The water lilies that were ground truthed have 5 inch diameter pads and extend up to 3 inches out of the water. The pads of the water lilies are faintly indicated on both the X- and L-band imagery (D on Plates 5A and C). These pads are not seen on the thermal IR imagery (D on Plate 5F) and only faintly seen on the aerial photography (D on Plate 5E).

An arc of reeds standing up to 5 ft out of the water is labeled E on Plates 5A, C, and E. Individual reeds are spaced a few to several inches apart, but commonly touch each other when the wind blows. A clump of water hyacinths (C on Plates 5A and C) was lodged against the reeds at the time of the radar flight, but had been blown away at the time of the aerial photography and thermal IR flights. The reeds are clearly visible on all the multiplexed SLAR images, only faintly visible on the aerial photography, and not visible at all on the thermal IR imagery (E on Plate 5F).

In this instance, the water hyacinths, water lilies, and reeds can be differentiated only on the multiplexed SLAR imagery. It is important to note that it is necessary to use both polarizations of both the X- and L-band imagery for the differentiation.

12.8 MARSH REGIONS

Marshes are part of category 6.1, Vegetated Nonforested Wetland, and in the test areas are located on flat terrain. Marshes are considered to be perennial areas that contain appreciable amounts of both water and vegetation (predominantly reeds). Individual marshes can be relatively hard to definitely identify using any one of three sensors individually because the marshes vary so greatly in terms of the vegetation/water ratio. The great majority of all marshes can be identified on the multiplexed SLAR imagery.

There is a strong diffuse return from marsh areas on the X-band imagery because the X-band wavelength is not able to penetrate the marsh vegetation and the return is from the top of the vegetation. There apparently are differences in the return from some marshes between the X-band parallel- and cross-polarized imagery. On the L-band imagery of both polarizations, the return is mainly a specular no-return with a faint mottled or speckled overprint. The L-band wavelength apparently penetrates the marsh reeds standing up to 5 ft out of the water, and the "return" mainly is a specular reflection off the water away from the radar antenna. The speckled overprint apparently is the small part of the L-band energy that is reflected back from the marsh reeds. The amount of speckled overprint seems to indicate the relative amount of reeds in the marsh, but might be a function of the height and/or density of the vegetation. The darker the return on the imagery of both wavelengths, the greater the amount of open water relative to the vegetation.

Marsh areas can be confused with certain types of Rangeland and Agricultural Land on the L-band imagery. On the X-band imagery, the return from marshes is nearly the same as that from Rangeland and Agricultural Lands.

Various marshes are pointed out on the radar imagery, aerial photography, and thermal IR imagery (Plates 1, 2, 3, 5, and 6A, C, E, and F). The marshes are indicated by the number 6.1.

Because of the relatively warmer water in them, the marsh areas are light-toned on the early-morning thermal IR imagery; however, it commonly is difficult to determine their boundaries (Plates 5 and 6F). Marsh areas can be located and identified and their areal extents and boundaries determined with a high degree of confidence using a combination of multiplexed SLAR and thermal IR imagery.

Some of the marsh regions can be identified on the aerial photography, particularly when there is a darker tone in the marsh region indicating the presence of a large amount of water. In other instances, the presence of the marsh is only hinted at on the aerial photographs. The marshes can be confused on the aerial photographs with Rangeland. The geographic location of most marshes aids in their identification on the aerial photographs, as it also does on the other types of imagery.

13

FEASIBILITY OF USING MULTIPLEXED SLAR FOR DETERMINING DRAINAGE PATTERNS

Much work has been done, particularly at K-band wavelengths, to demonstrate the great usefulness of SLAR for drainage basin analysis (McCoy, 1968, 1969, 1971, 1973), and it was not the intention of this experiment to duplicate this work. McCoy and others showed how SLAR can be used to determine individual stream type and regional drainage patterns, stream orders, stream density, average length ratio, etc.

Generally, the drainage patterns in the Florida test areas can be delineated as well on the SLAR imagery as on the aerial photography. The stream patterns can be seen on the thermal IR imagery also, but locally cannot be delineated and traced as well. X-band imagery is better than L-band imagery for tracing the stream patterns.

Braided streams can be seen as well on the radar imagery as on the aerial photography, but on the thermal IR imagery, the braided streams, especially the narrower ones, are not clearly distinguished unless there is a strong thermal contrast between the stream channel and the bordering land.

The channels that are choked with aquatic vegetation can be identified quite readily on the aerial photography, thermal IR imagery, and the X-band imagery (F on Plates 5A, E, and F). Locally, on the L-band imagery, it is difficult to distinguish the vegetation-choked channels from other vegetation features.

The stream channels can be quite readily traced through marsh areas on the aerial photography and the X-band imagery, but cannot be traced nearly as well on the L-band imagery and the thermal IR imagery. The lack of a strong thermal contrast between the stream and the marsh area commonly hinders tracing the stream path on the thermal IR imagery.

In general, either X-band or shorter wavelength SLAR or aerial photographs should be used for drainage basin analysis. L-band radar imagery and thermal IR imagery add supplemental information, but should not be the primary data sources for drainage basin analysis.

14

ANALYSIS OF THE COMPLEX DIELECTRIC CONSTANT MEASUREMENTS OF MARSH VEGETATION

14.1 INTRODUCTION

In addition to visual interpretation techniques as described in previous sections, considerable information can be obtained from radar imagery (as well as from imagery provided by other sensors) by using statistical techniques to analyze sections of the imagery or by using deterministic measures. Statistical methods are recognition schemes based on statistical analysis of the radar return from a given area. When a statistically determined set of parameters has been "learned," say from a given test site, other such sites on the imagery are recognized when the statistical analysis produces the identical or nearly identical result. Usually such statistical analyses are accomplished with the aid of a digital computer (Malila, 1973). Statistical recognition schemes are most successful when multi-channel (multispectral) measured data are available—such as from the multiplexed radar system or multispectral scanning systems.

Use of deterministic techniques requires both multi-channel data and a defined model of the area of interest. For example, a particular class of terrain types may have a roughness scale such that a scattering model would predict that the ratios of backscattered power for the two particular wavelengths should fall within certain limits. In addition, the model may specify the expected range of the ratio of the depolarized signals, based on requirements that the value of the dielectric constant for the particular type of area should be within certain limits. When the returned radar signals satisfy the requirements of the particular model, the scattering area should then be defined, within certain limits, by the model —if the model is accurate. Clearly, the verification of a deterministic model will require considerable empirical data. By supplementing the ground truth for this experiment with measurements of the dielectric constant, the information should then be available to begin to provide some insight into the realization of the deterministic approach and thus help define the additional work necessary before this technique can be applied.

14.2 SITES OF THE MEASUREMENTS

Based on the study and comparison of the X- and L-band radar images, two test sites were selected where dielectric constant measurements would be made. There is considerable contrast between the X- and L-band parallel-polarization images of the two areas. A wavelength dependency in the scattering properties of each area is thus indicated. A comparison of the parallel- and cross-polarized radar imagery of each wavelength showed some depolarization at L-band and perhaps greater depolarization at X-band. One of the test sites is labelled D on Plates 6A, C, E, and F.

14.3 MEASUREMENTS

Ground observations of the following types were made at each of the two test sites: (1) photographic, consisting of color photographs of the sites; (2) electrical, consisting of dielectric constant measurements at frequencies of 100 MHz and 9.3 GHz; and (3) physical measurements of dimensions and general observations. Equipment was available to make dielectric constant measurements at 1.2 GHz, but the equipment was damaged in transit and field repairs could not be made.

Only qualitative measurements have been deduced from the radar imagery. A comparison of the X- and L-band parallel-polarized imagery from the two test sites show that there is "considerably less" signal return from the areas at L-band than there is at X-band. Time and funds precluded any quantitative measurements, but clearly these measurements should be made after a calibration of the radar is realized.

Both test sites consist of tall "grass" extending out of the water (see sketch, Figure 4). The grass-type vegetation is homogeneous throughout the areas of interest. Heights average about 4 ft, the diameter of the "stalks" is approximately 4 in., and the diameter of the individual stems is approximately 0.4 in. Dielectric constant measurements were made of Sections A and B for each sample gathered. The surface density of the stalks is about 8 per square yard. Water completely extends throughout the two test sites. The grass canopy covers from 50 to 65 percent of the water looking straight down.

The dielectric constant measurements are summarized in Table 10.

14.4 DETERMINISTIC MODEL

An example of a deterministic model that may have application to the situation being considered is that derived from Peake (1959) as modified by Crispin and Siegel (1968). This model is used in an attempt to show correlation between conclusions based on the radar imagery and results based on a descriptive model of the area. Calculations have been made using the measured values of dielectric constant and measured physical parameters to describe the marsh grass areas. The model used (Peake's) is depicted in Figure 5. Table 11 gives the associated radar parameters calculated using the measured dielectric constant and physical dimensions from the two test sites.

Clearly, additional data from ground measurements are required and also, using the radar data, quantitative measurements of the signal returns are required to verify a model for recognition applications.

Consideration of the calculated values given in Table 11 shows an expected difference in σ_o of about 8 dB, with the value for 9.3 GHz being larger, as expected. Since the water surface under the grass is smooth, most of the L-band radiation is scattered in the forward

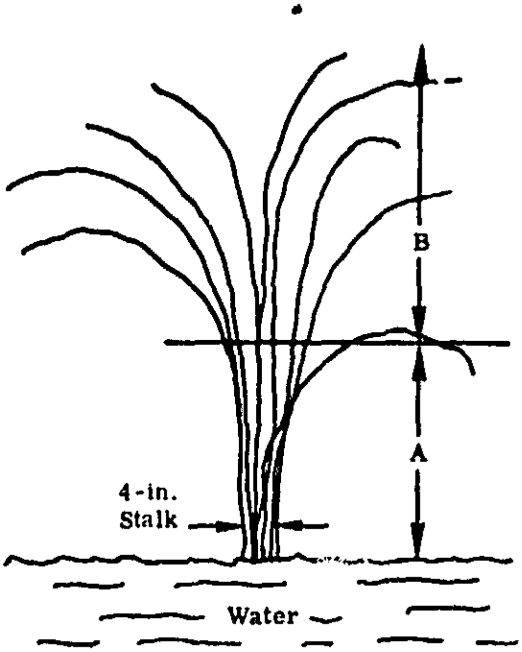
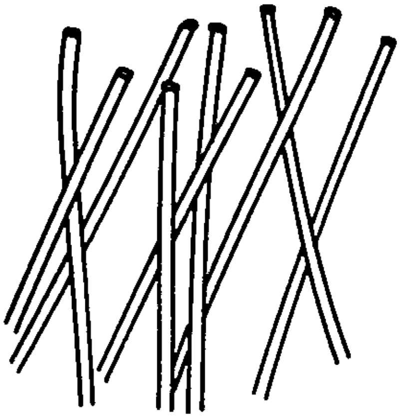


FIGURE 4. SKETCH OF GRASS PROFILE SHOWING APPROXIMATE SECTIONS WHERE DIELECTRIC CONSTANT MEASUREMENTS WERE MADE

TABLE 10. SUMMARY OF DIELECTRIC CONSTANT MEASUREMENTS OF MARSH VEGETATION

Section of Grass	Relative Dielectric Constant ε		Loss Tangent (tan δ) at 9.3 GHz
	1:00 MHz	9.3 GHz	
A	4.5 3.0 4.1	20.0	>0.33
B	2.6 1.92 3.2 2.6	12	>0.1



Random Thin Cylinders

FIGURE 5. THEORETICAL MODEL OF MARSH GRASS USED IN CALCULATING RADAR BACKSCATTER CROSS-SECTION

TABLE 11. CALCULATED VALUES FOR RADAR BACKSCATTER CROSS-SECTION

Cross-Section of Thin Cylinder* (σ_{cyl})		Total Backscatter Predicted by Model (σ_o)	
9.3 GHz	1.2 GHz	9.3 GHz	1.2 GHz
0.2 m^2	0.8 m^2	0.064	0.008

*d = 0.4 in.
ℓ = 4 ft

spectral direction. There will be some multiple scattering not accounted for by the model. This will result in increased backscattering power, particularly at 9.3 GHz, which should increase the difference in signal returns at the two operating wavelengths. Calculations were also made using the large dimension, 4 in., for the stalk of the grass as the cylinder diameter (after Ruck et al., 1970). Similar ratios between the values for σ_o and X-band and L-band were obtained. Clearly, results would be different if the surface were ground instead of water.

Qualitatively, the model's description of the backscatter is in agreement with that observed from the radar imagery. For this particular situation, similar areas observed on the imagery can, with reasonable confidence, be said to be identical to the two test sites.

One approach to radar imagery interpretation is through the use of deterministic models to describe a particular area or "target" characteristic. The model must define the relative values of the sensor parameters (wavelengths, polarizations). The imagery is then analyzed for the particular parameter ratios or relative values. Additional ground measurements in coincidence with multiplexed SLAR flights should be made. A variety of test sites should be considered based on criteria of differences in structure of areas of interest. This part of the experiment attempted, in a limited way, to demonstrate the feasibility of this approach. With a limited amount of effort, the present measurement technique used to obtain dielectric constant values at X- and L-bands could be modified. This would permit the dielectric constant measurements to be obtained more easily, and, through a computer program, data reduction could be rapid.

15

PRINCIPAL CONCLUSIONS

These conclusions refer specifically to this experiment, though in many cases they also are more generally valid. They are grouped to correspond to various sections of the discussion, rather than being listed in order of importance.

15.1 GENERAL CONCLUSIONS

A. Significantly more information for urban and rural land-use planning and for water resources management was obtained from the multiplexed X- and L-band SLAR imagery than could have been obtained from the imagery of either wavelength alone.

B. Once the radar imagery has been gathered, it can be processed and returned to field personnel within a short enough period of time so that timely ground truthing can be done for many short-lived phenomena.

C. On the multiplexed SLAR imagery the major differences in appearance of an urban or rural land-use category or feature or a water resources feature are primarily wavelength differences, not polarization differences. However, the use of all four radar images sometimes is necessary to positively differentiate between certain features.

D. Radar interpretation should be performed at the finest resolution available.

E. Multiplexed SLAR, large-scale black and white aerial photography, and thermal IR imagery each provide certain types of information concerning a specific earth resources problem or feature, and complement and supplement one another. They should be used concurrently for an earth resources experiment.

15.2 DETECTION OF POOLS OF WATER UNDER STANDING VEGETATION

A. Neither X- nor L-band SLAR at moderate and low depression angles can directly or indirectly detect pools of water under canopies of dense vegetation. The pools also cannot be detected, either directly or indirectly, on either the aerial photographs or the thermal IR imagery.

B. Apparently neither X- nor L-band SLAR at moderate and low depression angles can directly or indirectly detect pools of water in areas of low vegetation where the relatively dense vegetation is intimately mixed with the water and projects up to several inches above the water. It may or may not be possible to see these pools on the aerial photographs and thermal IR imagery.

15.3 LAND-USE PLANNING

A. General

(1) Following the classification system of Anderson, et al. (1972), many of the Levels I and II urban and rural land-use categories present in the test areas can be identified (or at least differentiated) and mapped on the multiplexed SLAR imagery. The accuracy of identification of land use, both urban and rural, is better at Level I than at Level II. Also, the accuracy of identification greatly increases as the resolution of the SLAR imagery increases. Land cover, instead of land use, generally is what is identified on the SLAR imagery at Levels I and II.

(2) Some Level III, and possibly even Level IV, land-use identification—particularly of Agricultural Land, but also to some extent of Rangeland and Urban and Built-up Land—can be done on the 30 ft × 30 ft resolution SLAR imagery.

(3) Higher levels of land-use classification can be accomplished using multiplexed SLAR imagery than can be accomplished using single-wavelength SLAR imagery.

(4) The level of land-use classification that can be done using radar imagery is independent of the distance of the radar from the imaged terrain. The level of land-use classification that can be done using imagery gathered by angle-measuring sensors decreases as the distance of the sensor from the terrain increases.

(5) The major land-use classification systems for use with remote-sensor data have been developed for imaging sensors which measure angles; these systems are not always directly applicable for the interpretation of SLAR imagery. The present classification systems should be modified to readily accept the types of land-use information that can be obtained by SLAR.

(6) Both urban and rural land use can be determined better on either the multiplexed SLAR imagery or the aerial photography than on the early-morning thermal IR imagery.

B. Urban

(1) Radar imagery is much better for identifying general areal land use than for identifying land use at particular points.

(2) Large-scale aerial photography allows finer detailed and more accurate identification of urban land use than can be done from the 30 ft × 30 ft-resolution multiplexed SLAR imagery.

(3) Locally, residential areas were confused on the radar imagery with non-residential areas. Residential areas without a great number of trees in them were confused with Commercial areas and Strip and Clustered Settlements. Residential areas of single-family houses that are not heavily wooded can be identified on the basis of the patterns of specular no-returns from the streets and the brighter returns from the inter-street areas, including scattered point target returns from the houses.

(4) Urban areas that are heavily wooded and/or covered by lower vegetation, such as Residential areas of single-family houses and Open and Other areas, can be confused among themselves on the radar imagery as well as with Rangeland and Forest Land.

(5) Commercial areas locally were confused on the radar imagery with Strip and Clustered Settlements.

(6) Institutional areas were not confused on the radar imagery with Commercial areas and Residential areas as often as might be expected. However, it is extremely difficult to identify the type of institution (school, hospital, etc.).

(7) Strip and Clustered Settlements are difficult to identify on the radar imagery; parts of them are commonly misidentified as residential or various commercial areas.

C. Rural

(1) Levels I and II land use can be identified as well and often better on the multiplexed radar imagery as on the large-scale aerial photography.

(2) Several different types of vegetation, both on land and in the water, can be differentiated and mapped on the multiplexed radar imagery by the relative heights, densities, surface roughnesses, etc., of the vegetation. The vegetation type per se is not sensed by the multiplexed SLAR. At this time, not enough signature analysis has been done to definitely identify the type of vegetation community, except for tree areas, without ground truthing.

(3) Multiplexed SLAR is a good indicator of the relative heights of vegetation. Using both the X- and L-band imagery, the relative heights of vegetation differing only 18 to 24 inches in height can be discerned. The multiplexed SLAR is a much better indicator of the relative heights of vegetation than either the aerial photography or thermal IR imagery.

(4) Improved cattle pasture (ICP) can be confused with Rangeland and Nonforested Wetland on both the X- and L-band imagery. ICP locally can be confused with

citrus groves on the radar imagery, but the row patterns in the groves, if visible on the imagery, will enable the ICP and citrus groves to be differentiated.

Some ICP can be confused with Rangeland and Nonforested Wetland on the aerial photographs. ICP can be confused with Rangeland and locally with citrus groves on the thermal IR imagery. The linear boundaries and geographic locations of most improved cattle pastures help to identify them on all three types of imagery.

(5) Citrus groves can be differentiated from all the other types of vegetation on the aerial photographs, and four stages of growth can be distinguished.

Citrus groves can be confused with Nonforested Wetland on the X-band imagery, but not on the L-band imagery. Groves locally can be confused with Forest Land on the L-band imagery, but generally not on the X-band imagery. Infrequently, groves can be confused with Rangeland on both the X- and L-band imagery. There is great potential for distinguishing the four growth stages of the groves on the multiplexed radar imagery.

On the thermal IR imagery, groves can be confused with Rangeland and Forest Land.

The linear boundaries and geographic locations of the citrus groves help to identify them on the different types of imagery.

(6) Rangeland can be confused with Forest Land on the L-band imagery. Rangeland can be confused with Nonforested Wetland on both the X- and L-band imagery, but especially on the X-band imagery when little open water is visible in the Nonforested Wetland. In most instances Palmetto Prairies can be distinguished from Grass on the radar imagery. Of the three sensing methods, multiplexed SLAR is the single best sensor to differentiate and map the distributions of Level II categories of Rangeland.

Rangeland locally can be confused with Forest Land on the aerial photography, and can be easily confused with Nonforested Wetland, especially where there is much vegetation in the Nonforested Wetland.

(7) It is extremely difficult to determine on the radar imagery whether tree areas are Deciduous, Evergreen, or Mixed. It was not possible to identify the tree type (oak, palm, pine, etc.) except on the basis of geometric considerations (belts of Australian pines).

Qualitative estimates of the densities of tree areas can be made from the radar imagery, particularly the L-band imagery, as well as from the aerial photographs.

X- and L-band radar wavelengths will not significantly penetrate dense areas of trees. The diffuse return at each wavelength comes from the upper part of the tree canopy.

15.4 WATER RESOURCES MANAGEMENT

A. Open Water Areas

(1) In general, water bodies of all shapes, trends, and larger than a "minimum" size can be seen equally well on the X-band imagery, aerial photographs, and thermal IR imagery. Open water areas can be confused with non-water areas on all three types of imagery.

(2) Radar imagery and early-morning thermal IR imagery yield no information about the relative depth of water, bottom features, or sediment content of water, but aerial photographs can. Thermal plumes are visible on the thermal IR imagery but not on the radar imagery or aerial photographs.

B. Islands

(1) On both the radar imagery and the thermal IR imagery, only the parts of islands above water are visible. On the aerial photographs, both the parts of islands above water and those covered by shallow water are visible.

(2) Islands cannot be positively differentiated on the radar imagery from masses of floating vegetation, but generally can be differentiated on the aerial photographs.

C. Shorelines

(1) Radar, particularly at X-band, is an excellent indicator of the water-land boundary. The water-land boundary generally can be determined on the aerial photographs, but locally there are ambiguities that do not exist on the radar imagery. Often the water-land boundary cannot be accurately placed on the thermal IR imagery.

(2) Radar imagery is well suited for determining how much of low-lying islands and shorelines is above water at different flood stages of a river or lake.

D. Navigation Aids, Power Poles, and Docks

(1) Navigation aids and power poles in water bodies can be seen on both the X- and L-band imagery, but cannot be seen on the thermal IR imagery. They can be seen only infrequently on the aerial photographs.

(2) Docks can be seen on some of the radar images. The docks are clearly visible on the aerial photographs.

E. Diking Systems

(1) Dikes, and commonly the accompanying drainage ditches, can be seen on both the X- and L-band imagery, regardless of their orientation to the radar look direction. The dikes and drainage ditches can be seen and traced very well on the aerial photographs, and generally very well on the thermal IR imagery.

F. Aquatic Vegetation

(1) Water hyacinths, water lilies, and small patches of reeds are visible on both the X- and L-band imagery. The hyacinths generally are visible on both the aerial photographs and thermal IR imagery. The water lilies and reeds are not visible on the thermal IR imagery and are only faintly indicated on the aerial photographs.

The three types of water vegetation can be differentiated only on the multiplexed radar imagery.

G. Nonforested Wetland (Marshes)

(1) Because they vary so greatly in terms of their vegetation/water ratio, individual marshes can be relatively hard to definitely identify using any one of the three sensors individually.

The great majority of the marsh areas can be identified on the multiplexed SLAR imagery. Using both the multiplexed SLAR and thermal IR imagery, virtually all the marsh areas can be identified and their areal extent and boundaries determined. Some of the marsh regions can be identified on the aerial photographs, particularly when there is a large amount of water in the marsh. The geographic location of most marshes aids in their identification on all the types of imagery.

(2) There is no significant penetration of marsh vegetation at X-band wavelength. The L-band wavelength apparently penetrates marsh reeds standing up to 5 feet out of the water. The amount of the small L-band return from the marsh seems to indicate the relative amount of reeds in the marsh, but might be a function of the height and/or density of the vegetation. The darker the return on the imagery of both wavelengths, the greater the amount of open water relative to the vegetation.

15.5 DETERMINATION OF DRAINAGE PATTERNS

A. Drainage patterns, including both different orders of streams as well as different types of drainage patterns, can be readily seen on both the X- and L-band imagery, but are better determined on the X-band imagery. Only single-wavelength SLAR is needed to provide information about drainage patterns.

B. Generally, the drainage patterns, including braided ones, can be delineated as well on the SLAR imagery as on the aerial photographs. Locally, the drainage patterns cannot be delineated and traced as well on the thermal IR imagery.

C. Channels that are choked with floating vegetation can be identified quite readily on the aerial photography, thermal IR imagery, and the X-band imagery. Locally, on the L-band imagery, it is difficult to distinguish the vegetation-choked channels from other vegetation features.

D. The stream channels can be quite readily traced through marsh areas on the aerial photography and the X-band imagery, but cannot be traced nearly as well on the L-band imagery and the thermal IR imagery.

E. In general, either X-band or shorter wavelength SLAR or aerial photographs are the preferred sensor to use for drainage basin analysis. L-band radar imagery and thermal IR imagery add supplemental information, but should not be the primary data sources for drainage basin analysis.

16

RECOMMENDATIONS FOR FUTURE WORK

The recommendations include those for the continued analysis of the Brevard County imagery already acquired, as well as long-term recommendations, most of which require additional radar imaging. Items in the following enumeration are not necessarily listed in order of importance.

16.1 CONTINUED ANALYSIS OF BREVARD COUNTY IMAGERY ALREADY ACQUIRED

A. Short-Term Applications

(1) Make land-use maps of the three Brevard County test areas at the most detailed level(s) of classification possible. The maps should be made using data from the multiplexed SLAR imagery, the large-scale aerial photography, the thermal IR imagery, and 7.5 minute topographic maps. The maps should show both urban and rural land use, and water resources such as locations and areal extent of marshes, floating vegetation, etc.

(2) Prepare a basic environmental geologic map and several special-use environmental maps of Test Area 2 showing the different environmental and resource units. These maps would be very similar to those of the Environmental Geologic Atlas of the Texas Coastal Zone (Texas Bureau of Economic Geology, 1972). The maps would be drawn using data from the multiplexed SLAR imagery, the 1:24,000 scale aerial photography, the thermal IR imagery, 7.5 minute topographic maps, and other available imagery such as from ERTS, color and color infrared film, etc., and supplemented, where appropriate, by detailed field studies and compilation of data from diverse sources.

(3) Using both the aerial photographs and the radar imagery, determine the distribution of the four growth stages of the citrus groves.

(4) Map, if possible, the distribution of unimproved cattle pasture, using all three types of imagery.

(5) Using all the three types of imagery, attempt to classify Forest Land into the Level II categories Deciduous, Evergreen, and Mixed. Further attempts should be made to determine the predominant type(s) of trees (palm, oak, pine, etc.) in individual tree stands.

(6) Inventory the natural and man-made open water areas in all three test areas.

(7) Map the various stream channels and up-date the most recent topographic maps. Channels that are persistently choked with vegetation should be noted.

B. Basic Research

(1) Determine for each wavelength how the transmitting and receiving polarizations, the orientation of the feature to the radar look direction, the depression angles used, the incidence angles, etc., influence the recognition of specific features on the radar imagery.

(2) Determine what radar-return parameters contribute to the radar return from a given feature.

(3) Continue to qualitatively determine on all three types of imagery the signatures of the various categories and features present in the test areas.

(4) Determine, if possible, how to distinguish on each of the three types of imagery between the Levels I and II categories that can be confused with each other.

(5) Determine the accuracy of recognition under different terrain conditions on the various types of imagery of at least the Levels I and II categories present in the test areas. Also determine the minimum size(s) of the various categories and features that can be accurately recognized on the three types of imagery.

(6) Determine what specific information about various categories and features can be obtained from the three types of imagery.

(7) Begin quantitative analysis, where feasible, of the radar imagery.

(8) Compare the land-use maps of the test areas made from the three types of remote-sensing imagery against the land-use maps of those areas compiled from "conventional" sources. This will help determine the validity of making land-use maps from primarily remote-sensing imagery.

(9) Determine the maximum vegetation/water ratio that will allow a marsh to be identified on the multiplexed radar imagery.

(10) Determine the ease and accuracy with which specific features on the radar imagery can be identified by inexperienced interpreters.

16.2 LONG-TERM RECOMMENDATIONS

A. Periodically radar image the marshes in the test areas in order to determine how the marshes are growing, being enchroached upon, or being drained.

B. Monitor ocean beach erosion and deposition by periodically imaging proposed Test Area 4 with the multiplexed SLAR. A coarse analysis of the size and distribution of beach sediments could also be done.

C. Radar image proposed Test Area 5 to help determine the habitat preferred by the Dusky Seaside Sparrow, and the distribution of salt pans and marl regions.

D. Radar image the St. Johns River at different water levels.

E. When radar imaging a region, transmit vertically as well as horizontally (now only possible on successive passes), and use different depression angles and look directions.

F. Modify existing systems for classifying land-use information obtained mainly by remote-sensing techniques, or develop new land-use/land-cover classification systems at different levels that will readily accept the kinds of information provided by the special capabilities of SLAR.

G. Determine how multiplexed SLAR can be used to identify urban land use for communities of various sizes, populations, and densities.

H. Determine now multiplexed SLAR can be used to map Rangeland vegetation communities during their various growth stages.

I. Determine the range of differences in relative heights of different vegetation communities that can be determined on the multiplexed SLAR imagery. Particular attention should be paid to determining the minimum differences in relative heights that can be detected.

J. Inventory marsh regions in Florida and the southeastern United States.

K. Begin automatic data processing of good quality radar imagery. Special optical data processing techniques should be developed, particularly for use with the signal film.

L. Establish an agricultural test site in the southeastern United States to begin to determine how multiplexed SLAR can be used to identify various crops during their growth stages, including those crops indigenous to the southeastern United States. Work also should continue with the agricultural test site established in southeastern Michigan in order to determine the preferred transmitting polarization(s), depression angles, and look direction(s) that should be used.

M. Determine how multiplexed SLAR imagery can be used for geologic mapping, particularly in the Appalachian Mountains. Special attention should be paid to the use of the SLAR imagery for structural, textural, and lithologic analysis. (The ERIM radar airplane crosses the Appalachian Mountains while in transit to most areas in the southeastern United States.)

N. Calibrate the multiplexed radar.

O. One or more wavelengths should be added to the present multiplexed radar system. Probably at least one of these wavelengths should be shorter than X-band.

Appendix*

DEFINITIONS OF LEVELS I AND II LAND-USE CATEGORIES

DEFINITIONS

In the definitions presented here, an attempt has been made to include sufficient detail to provide a general understanding of what is included in each category at Levels I and II. Many of the uses described in detail will not be visible on spacecraft and high-altitude imagery. However, the detail will aid in the interpretation process, and the additional information will be useful to those who have large-scale aerial photographs and other supplemental information available.

1 - URBAN AND BUILT-UP LAND

Urban and Built-up Land comprises areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, villages, strip developments along highways, transportation, power, and communications facilities, and such isolated units as mills, mines, and quarries, shopping centers, and institutions.

As development progresses, small blocks of land of less intensive or nonconforming use may be isolated in the midst of built-up areas and will generally be included in the 1-category. Agricultural, forest, or water areas on the fringe of Urban and Built-up areas will not be included except where they are part of low-density urban development. The Urban and Built-up Land category takes precedence over others when the criteria for more than one category are met. Thus, residential areas that have sufficient tree cover to meet Forest Land criteria will be placed in the Residential category.

The Level II categories of Urban and Built up Land are: Residential; Commercial and Services; Industrial; Extractive; Transportation, Communications, and Utilities; Institutions; Strip and Clustered Settlements; Mixed; and Open and Other.

1.1 - RESIDENTIAL

Residential land uses range from high density, represented by the multiple-unit structures of urban cores, to low density, where houses are on lots of more than an acre, on the periphery of urban expansion. Linear residential developments along transportation routes extending outward from urban areas should be included as residential appendages to urban centers, but care must be taken to distinguish them from commercial strips in the same locality. The residential strips generally have a uniform size and spacing of structures, linear driveways, and lawn areas; the commercial strips are more likely to have buildings of different sizes and spacing, large driveways, and parking areas. Residential development along shorelines is also linear and sometimes extends back only one residential parcel from the shoreline to the first road.

Areas of sparse residential land use will be included under another category. In some places, the boundary will be clear where new housing developments abut against intensively used agricultural areas, but the boundary may be vague and difficult to discern when residential development is sporadic, or occurs in small isolated units over an extended period of time in areas of mixed or less intensive uses. A careful evaluation of density and the overall relation of the area to the total urban complex must be made.

Residential sections may also be included in other use categories where they are integral parts of the other use. Housing on military bases, at colleges and universities, living quarters for laborers near a work base, or lodging for employees of agricultural field operations or resorts are often difficult to identify and may be placed within the institutional, industrial, agricultural, or commercial categories.

1.2 - COMMERCIAL AND SERVICES

Commercial areas are those used predominantly for the sale of products and services. They are often abutted by residential, agricultural, or other contrasting uses which help define them. The principal components of the Commercial-use category are urban central business districts; shopping centers, usually in

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*Excerpted from "A Land-Use Classification System for Use With Remote-Sensor Data," by James R. Anderson, Ernest E. Hardy and John T. Roach, Geological Survey Circular 671, 1972.

suburban and outlying areas; commercial strip developments along major highways and access routes to cities; and resorts. The main buildings, secondary structures, and areas supporting the basic use are all included—office buildings, warehouses, driveways, sheds, parking lots, landscaped areas, and waste-disposal areas.

Commercial areas may include some noncommercial uses too small to be separated out. Central business districts often include some institutions, such as churches and schools, and commercial strip developments may include some residential units. These are not separated out unless they exceed one-third the total commercial area. Recreational areas are not segregated as such at Level II but may cause some problems in identification. Recreational facilities that form an integral part of an institution should be included in the Institutional category. A self-contained sports area, on the other hand, such as a stadium for professional events, is Commercial. There is usually a major visible difference in the form of parking facilities, arrangements for traffic flow, and the general association of buildings and facilities. Near a resort, the intensively developed recreational areas would be included in the Commercial category, but extensive golf courses and riding areas would be included in another category, the Open and Other, if in an urban setting. Public and private golf courses, ski and toboggan areas, and other recreational facilities are also classed as Open land.

1.3 - INDUSTRIAL

Industrial areas include a wide array of uses from light manufacturing and industrial parks to heavy manufacturing plants. Identification of light industries—those focused on design, assembly, finishing, and packaging of products—can often be based on the type of building, parking, and shipping arrangements. Light industrial areas may be, but are not necessarily, directly in contact with urban areas; many are now found at airports or in relatively open country. Heavy industries use raw materials such as iron ore, lumber, or coal. Included are steel mills, pulp or lumber mills, electric power generating stations, oil refineries and tank farms, chemical plants and brick-making plants. Stock piles of raw materials, major power sources, and waste product disposal areas are usually visible, along with transportation facilities capable of handling heavy materials.

1.4 - EXTRACTIVE

Extractive Land encompasses both surface and subsurface mining operations, such as sand and gravel pits, stone quarries, oil and gas wells, and metallic and nonmetallic mines. In size, these activities range from the unmistakable giant strip or pit mines covering vast areas to the unidentifiable gas wells less than a foot square. Surface structures and equipment may range from a minimum of a loading device and trucks to extended areas with access roads, processing facilities, stockpiles, equipment sheds, and numerous vehicles. Spoil material and slag heaps are usually found within a short trucking distance of the major mine areas and may be the key indicator of underground mining operations. Uniform identification of all these diverse extractive uses is extremely difficult from remote sensor data alone.

Industrial complexes where the extracted material is refined, packaged, or further processed are included in the Industrial category even if the plant is adjacent to the mine. Areas of future reserves are included in the appropriate present-use category, Agricultural or Forest Land, regardless of the expected future use. Unused pits or quarries that have been flooded are placed in the Water category if the water body is larger than 40 acres. Areas of tailings, abandoned pits and quarries, and strip-mined areas may remain barren for decades unless steps are taken to hasten the establishment of vegetation. Until vegetative cover is established, such parcels remain in the Extractive category.

1.5 - TRANSPORTATION, COMMUNICATIONS, AND UTILITIES

Major transportation routes and areas greatly influence other land uses, and many land-use boundaries are outlined by them. The types and extent of transportation facilities in a locality determine the degree of access and affect both the present and potential use of the area.

Highways and railways are characterized by areas of activity connected in linear patterns. The highways include areas used for interchanges, limited access right-of-way, and service and terminal facilities. Rail facilities include stations, parking lots, roundhouses, repair and switching yards, and related areas, but overland track is not included unless six or more tracks are joined to give sufficient width for delineation at a scale of 1:250,000. Spur connections from an active line are included in the appropriate Industrial or Extractive category.

Airports, seaports, and major lakeports are isolated areas of high utilization, usually with no well defined intervening connections, although some water ports are connected by canals. Airport facilities include the runways, intervening land, terminals, service buildings, navigation aids, fuel storage, parking lots, and a limited buffer zone. The perimeter fence around airports usually makes a very sharp boundary that is visible on high-altitude imagery. Small airports, such as those on rotatable farm land, heliports, and land associated with seaplane bases are not included. Port areas include the docks, shipyards, drydocks, locks, and watercourse-control structures.

Communications and utilities areas involved in transport of water, gas, oil, electricity, and areas used for airwave communications are also included in this category. Pumping stations, electric substations, and areas used for radio, radar, or television antennas are the major types. Small facilities, or those associated with an industrial, commercial, or extractive land use, are included within the larger category with which they are associated. Long-distance gas, oil, electric, telephone, water, or other transmission facilities rarely constitute the dominant use of land over which they pass. If these uses are dominant and meet the minimum width criteria, they may be identified as transportation uses.

1.6 - INSTITUTIONAL

Education, religious, health, correctional, and military facilities are the main components of this subcategory. All buildings, grounds, and parking lots that compose the facility are included within the institutional unit, but areas not specifically related to the purpose of the institution should be placed in the appropriate category. Auxiliary land uses, particularly residential, commercial and services, and other supporting land uses on a military base would be included in the Institutional subcategory, but agricultural areas not specifically associated with correctional, educational, or religious institutions are placed in the appropriate agricultural category. Small institutional units, as, for example, many churches and some secondary and elementary schools, will not meet the minimum area requirements and will be included within another category, usually Residential or Commercial. Historic forts may be confused with correctional institutions because of the similarity of buildings, but the historical sites have larger parking areas and often smaller landscaped or grass areas.

1.7 - STRIP AND CLUSTERED SETTLEMENT

The Strip and Clustered Settlement category includes developments along transportation routes and the smaller cities, towns, and built-up areas where separate land uses may not be distinguishable. Residential, commercial, industrial, institutional, and occasionally other land uses may be included. Farmsteads intermixed with strip or cluster settlements will be included within the built-up land, but other agricultural land uses should be excluded.

1.8 - MIXED

This category is used for a mixture of second-level urban uses in larger cities (more than 50,000 inhabitants) where no one use predominates. In any category, as much as one-third intermixture of another use is allowed without changing the basic classification, but where the intermixture is greater, where several uses, though each is less than one-third, are included, or where individual second-level units may be too small to be separated although the aggregate of such uses may be large, the Mixed category is used.

1.9 - OPEN AND OTHER (URBAN)

Open land consists of golf courses, some parks, ski areas, cemeteries, and undeveloped land within an urban setting. Open land may be in very intensive use but a use that does not require structures. Other land includes the small blocks of less intensive or nonconforming uses that become isolated.

2 - AGRICULTURAL LAND

Agricultural Land may be broadly defined as land used primarily for production of farm commodities. On high-altitude imagery, the chief indications of agricultural activity will be symmetrical patterns made on the landscape by use of mechanized equipment. However, pasture and other lands where such equipment is used infrequently may not show as well-defined shapes as other areas.

Symmetrical patterns are also characteristic of Urban and Built-up Lands because of street layout and development by blocks. Distinguishing between Agricultural and Urban and Built-up Lands should ordinarily be possible on the basis of urban activity indicators and the associated concentration of population. The number of building complexes is smaller and the density of the road and highway network is much lower in Agricultural Lands than in Urban and Built-up Land. Some urban land uses, such as parks and large cemeteries, however, may be mistaken for Agricultural Land, especially when they occur on the periphery of the urban areas.

The interface of Agricultural Land with other categories of land use may sometimes be a transition zone in which there is an intermixture of land uses at first and second levels of categorization. Where farming activities are limited by wetness, the exact boundary may also be difficult to locate, and Agricultural Land may grade into swamp Forest Land, Nonforested Wetland, or Water.

The Level II categories of Agricultural Land are: Cropland and Pasture; Orchards, Groves, Vineyards, Bush Fruits, and Horticultural Areas; Feeding Operations; and Other.

2.1 - CROPLAND AND PASTURE

The several components of Cropland and Pasture now used for agricultural statistics include: Cropland harvested; cultivated summer fallow and idle cropland; land on which crop failure occurs; cropland in soil improvement grasses and legumes, cropland used only for pasture or pasture in rotation with crops; pasture on land more or less permanently used for that purpose. From imagery alone, it is generally not possible to make a distinction between Cropland and Pasture with a high degree of accuracy and uniformity, let alone a distinction among the various components of Cropland. Moreover, some of the categories listed represent the condition of the land at the end of the growing season, and will not apply exactly to imagery taken at other times of the year. They will, however, be a guide to identification of Cropland and Pasture.

Certain factors vary throughout the United States and this variability must also be recognized; field size depends on topography, soil types, sizes of farms, kinds of crops and pastures, capital investment, labor availability and other conditions. Irrigated land in the Western States is easily recognized in contrast to Rangeland, but in the Eastern States, irrigation by use of overhead sprinklers cannot always be detected from imagery unless distinctive circular patterns are created. Drainage or water control on land used for cropland and pasture may also create a recognizable pattern that may aid in identification of the land use. In areas of quick-growing crops a field may appear to be in nonagricultural use unless the temporary nature of the inactivity is recognized.

2.2 - ORCHARDS, GROVES, VINEYARDS, BUSH-FRUIT, AND HORTICULTURAL AREAS

Orchards, groves, vineyards, and bush-fruit areas produce the various fruit, nut, and berry crops. Horticultural areas include nurseries, floricultural areas, and seed-and-sod areas used perennially for that purpose. Many of these areas may be included in another category, generally Cropland and Pasture, when identification is made by use of satellite or high-altitude imagery alone. Identification may be aided by recognition of the combination of soil qualities and climatological factors needed for these operations: water bodies in close proximity to moderate the effects of short duration temperature fluctuations; site selection for air drainage on sloping land, deep, well-drained soils on slopes moderate enough to permit use of machinery. Isolated orchards of a few acres do not constitute commercial orchards large enough to identify on high-altitude imagery, and remnants of the few acres of fruit trees on the family farm are usually not recognizable and are therefore not included.

2.3 - FEEDING OPERATIONS

Feeding Operations are large, specialized, livestock-production enterprises, chiefly beef cattle feedlots and large poultry farms, but also including large hog and fur-bearing animal farms. These operations have large animal populations restricted to relatively small areas. The result is a concentration of waste material that is an environmental concern. The waste-disposal problems justify a separate subcategory for these relatively small areas. Feeding Operations have a built-up appearance, chiefly composed of buildings, much fencing, access paths, and waste-disposal areas. Some are located near an urban area to take advantage of transportation facilities and proximity to processing plants.

Feeding operations in conjunction with another farm enterprise are not included. Also excluded are shipping corrals and other temporary holding facilities. Game farms and zoos do not meet the animal-population densities to be placed in this subcategory.

2.4 - OTHER AGRICULTURAL LAND

Inactive agricultural land is an important component of this subcategory. Such land has no physical indication of present agricultural use and no natural cover, such as brush, which would curtail its ready use for agriculture. Farmsteads, including holding areas for livestock, farm lanes and roads, ditches and canals, small farm ponds, and similar uses are generally quite small and often unrecognizable from high-altitude imagery so that these uses will generally be included with adjacent agricultural uses.

3 - RANGELAND

Rangeland may be defined as land where the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs, where natural herbivory was an important influence in its precivilization state, and that is more suitable for management by ecological rather than agronomic principles. Some rangelands have been or may be seeded to introduced or domesticated plant species. Most of the rangelands in the United States are in the Western Range, the area to the west of an irregular north-south line that cuts through the Dakotas, Nebraska, Kansas, Oklahoma, and Texas. Rangelands are also found in the Southeastern States and Alaska.

The Level II categories of Rangeland are: Grass, Savannas (Palmetto Prairies), Chaparral, and Desert Shrub.

3.1 - GRASS

This subcategory encompasses the tall grass (or true prairie), short grass, bunch grass or palouse grass, and desert grass regions. These grass regions generally represent a sequence of declining amounts of available moisture. Most of the tall grass region has been plowed for agriculture. The bulk of the remaining tall grass range is now in North Dakota, Nebraska, southern Kansas and Oklahoma, and the Texas Coastal Plain. Short grass rangeland occurs in a strip about 300 miles wide from the Texas Panhandle northward to the Dakotas where it widens to cover the western half of the Dakotas, the eastern three-fourths of Montana, and the eastern third of Wyoming.

3.2 - SAVANNAS (PALMETTO PRAIRIES)

The Palmetto Prairies in south-central Florida, north, west, and southwest of Lake

Okeechobee consist mainly of dense medium tall grasses with scattered palms and shrubs. Many areas are now in improved pasture.

3.3 - CHAPARRAL

This category includes California chaparral, the scrub oak or shinnery, and the mountain brush types.

3.4 - DESERT SHRUB

Vegetation in this zone includes the creosote bush, sagebrush, greasewood, and other desert shrubs. Bottom lands and moister flats are often characterized by dense stands of mesquite, and where alkali is high, desert saltbrush dominates wide areas.

4 - FOREST LAND

Forest lands are lands that are at least 10 percent stocked by trees capable of producing timber or other wood products that exert an influence on the climate or water regime. Forest land can generally be identified rather easily from high-altitude imagery, although the boundary between it and other classes of land may be difficult to delineate precisely.

Lands from which trees have been removed to less than 10 percent stocking but which have not been developed for other use are also included. For example, lands on which there is forest rotation, involving clear-cutting and block planting, are part of Forest Land. On such lands, when trees reach marketable size, which for pulpwood in the Southeastern United States may occur in two to three decades, there will be large areas that have little or no visible forest growth. The pattern can sometimes be identified by the presence of cutting operations in the midst of a large expanse of forest. Unless there is evidence of other use, such areas of little or no forest growth should be included in the Forest Land category. Lands that meet the requirements for Forest Land and also for a higher use category should be placed in the higher category.

At Level II, Forest Land will be divided into three categories: Deciduous, Evergreen, and Mixed. To differentiate the three, sequential imagery, or at least imagery during the period when deciduous trees are bare, will be necessary.

4.1 - DECIDUOUS FOREST LAND

Deciduous Forest Land includes all forested areas in which the trees are predominantly those from which the leaves fall at the end of the growing period. In most parts of the United States, these would be the hardwoods, such as oak, maple, beech, ash, hickory, and aspen, and the "soft hardwoods" such as sweet gum, tupelo, cottonwood, and yellow poplar. Tropical hardwoods such as mahogany and ebony are not included as they are broad-leaved evergreens and hence are included in the Evergreen Forest Land category.

4.2 - EVERGREEN FOREST LAND

Evergreen Forest Land includes all forested areas in which the trees are predominantly those which remain green throughout the year. Both coniferous and tropical broad-leaved evergreens are included in this category. In most areas, the coniferous evergreens predominate, but the mangrove swamps of Florida and some of the forests of Hawaii are notable exceptions. The coniferous evergreens are commonly referred to or classified as softwoods. They include such eastern species as the longleaf, slash, shortleaf, loblolly, and other southern yellow pines; spruce and balsam fir; white and red pines; jack pine; hemlock; and cypress; and such western species as Douglas-fir, ponderosa pine, redwood, Sitka spruce, Engelmann spruce, lodgepole pine, red cedar, larch, hemlock, and white pine.

4.3 - MIXED FOREST LAND

Mixed Forest Land includes all forested areas where both evergreen and deciduous trees are growing and neither predominates.

5 - WATER

The Water category includes all areas within the land mass of the United States that are predominantly or persistently water covered, provided that, if linear, they are at least 1/8 mile (660 feet or 200 meters) wide and if extended cover at least 1/8 square mile or 40 acres. Water bodies smaller than these minimums are included within the land-use unit in which they are located. Sewage-treatment or water-supply facilities are a basic part of the urban pattern and should be included in the 1-Urban category even where the unit is large enough to be separately identified. Water bodies that are vegetated are placed in the 6-Wetland category, or in Forest Land if swamp forests exist.

There are five Level II categories: Streams and Waterways, Lakes, Reservoirs, Bays and Estuaries, and Other.

5.1 - STREAMS AND WATERWAYS

This subcategory includes rivers, creeks, canals, and other linear bodies that meet the minimum width requirement of 1/8 mile. Occasional constrictions of streams to less than 1/8 mile may be included to preserve continuity. Streams flowing through deltas will be classified as water as long as width minimums are met, but where there are many distributaries and individual streams are less than 1/8 mile wide, they will be included in the appropriate land use. Where the water course is interrupted by a control structure, the impounded area, if it exceeds 40 acres, will be placed in the Reservoirs subcategory.

The boundary between streams and lakes, reservoirs, or the ocean is the straight line across the mouth of the stream unless the mouth is more than 1 mile wide. In that case the rule given under 5.4 for bays and estuaries is followed.

5.2 - LAKES

Lakes are bodies of water more than 40 acres in areal extent, but excluding reservoirs. Islands within lakes that are too small to delineate will be included in the water area. The delineation of a lake will be based on the areal extent of water at the time the imagery is taken.

5.3 - RESERVOIRS

Reservoirs are artificial impoundments of water greater than 40 acres in areal extent, whether for irrigation, flood control, municipal water supplies, or hydroelectric power generation. Dams, levees, other water-control structures, or the excavation itself will usually be evident to aid in the identification.

5.4 - BAYS AND ESTUARIES

Bays and estuaries are inlets or arms of the sea that extend into the land and as such are properly classified in this system only when they are included within the land mass of the United States. In order that this land mass area be commensurate with the area of the United States used in compiling census statistics, the convention used by the Bureau of the Census in setting the outer limits of the United States will be followed. Where bays and estuaries are between 1 and 10 nautical miles in width, the outer limit of the United States will be the straight line connecting the headlands except where the indentation of the embayment is so shallow that the water area would be less than the area of a semicircle drawn with this straight line as the diameter. In that event the coastline itself would form the outer limit of the United States. Embayments less than one nautical mile in width are classed as 5.1 Streams and Waterways. Embayments or portions of embayments more than 10 nautical miles wide are not considered as included within the land mas .

5.5 - OTHER

Other water areas include large farm ponds that may not be identifiable as reservoirs, other water features not mentioned in the preceding categories, or combinations of water features that cannot be clearly defined.

6 - NONFORESTED WETLAND

Nonforested Wetlands consist of seasonally flooded basins and flats, meadows, marshes, and bogs. Wetlands are usually relatively level areas. Uniform identification is difficult because the wetland areas change as the result of such factors as long-term drought, high rainfall, seasonal fluctuations in precipitation, and diurnal tides. The observations must be correlated with tide and weather information to obtain consistent results.

Open saline- and fresh-water areas, sounds, and bays are included under 5-Water. Wetland areas with a 10 percent forest crown cover, or where recent clear-cutting has occurred, are placed in 4-Forest Land.

Nonforested Wetland may be either Vegetated or Bare.

6.1 - VEGETATED NONFORESTED WETLAND

Vegetated Nonforested Wetland includes areas where the forest crown cover is less than 10 percent or the vegetation is nonwoody. Cattails, tules, and grasses such as Indian rice grass and saw grass occur in fresh-water marshes, and salt-tolerant grasses such as Spartina occur in the salt marshes.

6.2 - BARE NONFORESTED WETLAND

Tidal flats are the main component.

7 - BARREN LAND

Barren land is land of limited ability to support life and little or no vegetation. In general, it appears to be an area of oily soil, sand, and rocks. Vegetation, if present, is more widely spaced and scrubby than that in the Desert Shrub subcategory of Rangeland except when unusual conditions, such as a heavy rainfall, occasionally result in growth of a short-lived more impressive plant cover.

Land may be temporarily barren owing to man's activities, but such land is usually included in another land-use category. Agricultural land may be temporarily without vegetation because of tillage practices. Sites for urban development may be stripped of cover before construction begins. Areas of extractive and industrial land have waste and tailings dumps, and exhausted sources of material supply are often evident.

Level II categories of Barren Land are: Salt Flats, Beaches, Sand Other Than Beaches, Bare Exposed Rock, and Other.

7.1 - SALT FLATS

Salt flats are the flat-floored bottoms of interior desert basins. For a short time after a cloudburst, they may be covered by a sheet of water, or playa lake. On vertical air photographs they appear as white scars in the desert because the soil, flatness, and color cause a diffused reflectancy much higher than the albedo of other desert features.

7.2 - BEACHES

Beaches are the smooth sloping accumulations of sand and gravel along shorelines. The surface is stable inland, but the shoreward part is subject to erosion by wind and water, and material is deposited in protected areas. The Beach category is not used if there is vegetative cover or another land use.

7.3 - SAND OTHER THAN BEACHES

Sand Other Than Beaches is composed primarily of dunes, accumulations of sand of aeolian origin. Dunes are most commonly found in deserts although they also occur on shore and strand lines, coastal plains, river flood plains, deltas, and in periglacial environments. They are of various shapes, the crescentic being the most elementary, and range in size from diameters of a few to several thousand meters and in height from one to several hundred meters. Isolated crescent-shaped dunes migrate freely, but longitudinal dunes tend to remain nearly fixed in position.

7.4 - BARE EXPOSED ROCK

The Bare Exposed Rock category includes areas of bedrock exposure, desert pavement, scarps, talus, slides, volcanic material, and other accumulations of rock without vegetative cover.

7.5 - OTHER

This subcategory is used for a mixture of Barren Land features or when a Barren Land subcategory cannot be positively identified.

8 - TUNDRA

Tundras are cold treeless lands, primarily in Alaska, with a vegetative cover of moss and lichen, grasses, and shrubs. The tundra zone can be divided into three subzones on the basis of vegetative cover: an arctic subzone characterized by an interrupted cover of sparse moss and lichen sedges: a typical tundra subzone characterized by various types of moss and lichen sedges and rare shrubs in river valleys; and a shrub tundra subzone, characterized by birch and willow shrubs together with mosses, sedges, and grasses. Mountain tundra, along the mountain tops, extends well to the south and is enriched by alpine flora.

The interfaces of Tundra to Permanent Snow and Icefields and to Water are fairly easily determined if the imagery is taken in late summer. Between Forest Land with a light crown cover and Tundra, the boundary tends to be transitional over a wide area and is also uneven, as changes in growing conditions bring about protuberances of brushland into Tundra areas. Distinguishing between Tundra and Nonforested Wetland is difficult where there is a hummocky landscape with intervening areas of standing water. Flooded portions may vary in size owing to seasonal changes in depth of frost, amount of precipitation, and evapotranspiration potential. The ratio of flooded land to vegetation is the basis for decision. The Barren Land-Tundra interface occurs where one or more of the vegetative growing factors are deficient. The boundary will be difficult to establish.

9 - PERMANENT SNOW AND ICEFIELDS

Permanent Snow and Icefields are those that survive summer ablation. Snow, firn, icepacks, icecaps, and glaciers are included and the underlying mass may be either land or water. An average frontal position over a period of a few years would be the most desirable border, but an expedient delineation can be made through observations at the time of maximum retreat, probably during August in the northern hemisphere. The abutting land would most probably be classed as Water, Barren Land, Tundra, or Nonforested Wetland.

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