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N78-14546

NECESSITY TO ADAPT LAND USE AND LAND COVER CLASSIFICATION SYSTEMS TO READILY ACCEPT RADAR DATA

Ben Drake

Remote Sensing Laboratory
Department of Physics and Geophysical Sciences
Old Dominion University
Norfolk, Virginia 23508

ABSTRACT

A hierarchial, four level, standardized system for classifying land use/land cover primarily from remote-sensor data (USGS system) has been proposed for national acceptance by Anderson et al. (1976). The USGS system clearly has been developed for non-microwave imaging sensors such as camera systems and line scanners. Studies have shown that the classification system is compatible with aircraft and spacecraft photography and line-scanner imagery obtained at various altitudes.

The USGS system commonly is not compatible with the land use/land cover classifications at different levels that can be made from radar imagery, and particularly from synthetic-aperture radar (SAR) imagery. The lack of compatibility exists because of the special capabilities of radar, particularly SAR, for data gathering that are not duplicated by the imaging optical sensors. The use of radar imagery for classifying land use/land cover at different levels is discussed, and a possible revision of the USGS system to more readily accept land use/land cover classifications from radar imagery is proposed.

1. INTRODUCTION

Many different land-use classification systems currently are in use in the United States. Some of the classification systems are constructed for specific disciplines such as urban planning, agriculture, forestry, etc. A standardized general classification system for many different disciplines is needed.

During the past forty years it has been successfully demonstrated that remotely-sensed data is useful for land-use and land-cover mapping (Anderson et al., 1976). Several land-use classification systems are designed for or amenable to use with remote-sensing techniques. However, remote-sensing data is not compatible with many of the presently-used land-use classification systems for at least two reasons: (1) In many instances remote-sensing data provides information concerning only the land cover and not the land use. The presently-used systems generally differentiate their categories on the basis of land use, not land cover. The terms land use and land cover are not necessarily synonymous. According to Clawson and Stewart (1965), land use refers to "man's activities on land which are directly related to the land." Burley (1961) believes that land cover refers to "the vegetational and artificial constructions covering the land surface." (2) Many of the presently-used systems classify the land use in a very detailed manner, particularly in their higher levels of categorization. While various types of remote-sensing data can provide

detailed land use/land cover information, the data commonly do not provide the very detailed information needed for certain urban land use classification systems, etc.

As Anderson et al. (1976) point out, there are several problems in using any particular system to classify land use/land cover, whether or not the system is specifically designed to accept remote-sensing data. These problems include: (1) Some uses of the land cannot be directly related to the type of land cover. (2) There may be multiple uses occurring on a single parcel of land. The multiple uses may occur simultaneously or alternately. (3) There commonly are vertical arrangements of land uses above or below the actual ground surface. Mineral or petroleum deposits may be extracted underground, electrical transmission lines cross areas of various urban and rural land use, etc. (4) The size of the minimum area that can be classified as to land use or land cover.

Clearly what is needed is a nationally-accepted standardized system for classifying land use/land cover from data obtained primarily by remote-sensing techniques, but reasonably compatible with present classification systems. The land use/land cover classification system of Anderson et al. (1976) is intended to be the needed system, but unfortunately it is not always compatible with radar data. For convenience, the system of Anderson et al. (1976) is hereafter called the USGS system.

2. THE USGS SYSTEM

The USGS system for classifying land use and land cover from remotely-sensed data is discussed by Anderson et al. (1976) in USGS Professional Paper 964. The professional paper is a revision of an earlier classification system described in USGS Circular 671 by Anderson, Hardy, and Roach (1972). Types of land use and land cover identifiable primarily from remote-sensor data are the basis for organizing the USGS system (Anderson et al., 1976). The USGS system is specifically designed to be receptive to data obtained from satellite as well as aircraft remote sensors. It is intended to be a national system, and it is becoming accepted by the federal government and various states as the system to be used for classifying land use/land cover from remote-sensing data. Therefore, it is extremely important that the necessary revisions in the USGS system be made as soon as possible.

The USGS system classifies land use/land cover in four distinct levels of categorization, with Level II being the "basic" level of classification. As the levels of classification increase from Level I through Level IV, the land use/land cover classifications that can be made become more detailed and the areas that can be classified a specific Level III or IV category commonly become smaller; these are desirable features of the classification system. The system is a hierarchical one in that the more detailed higher-level categories (Levels III and IV) are collapsible into the more generalized lower-level categories (Levels I and II).

Uniformity in categorization is intended only at the first and second levels. Land cover is the primary basis for categorization at the first and second levels. Land cover is the primary basis for categorization at the first and second levels, but land use is also a basis for categorization at the second level. The categories of Levels I and II of the USGS system are discussed in Anderson et al. (1976).

The USGS system is intentionally left open-ended so that various governmental agencies can have flexibility in developing more detailed land-use classifications at the third and fourth levels. This allows the agencies to meet their particular needs and at the same time remain compatible with each other and the national system. Land use generally is the primary basis for categorization at Levels III and IV.

The USGS system has been developed on the assumption that different remote sensors will provide data for different levels of classification. However, the USGS system clearly has been developed for non-microwave imaging sensors, such as camera systems and line scanners. For these optical sensors the scale and resolution of the imagery decrease with range, which is altitude above ground. Anderson et al. (1976) state that the USGS system has been developed "...because different sensors will provide data at a range of resolutions dependent upon altitude and scale. In general, the following relations pertain, assuming

a 6-inch focal length camera is used in obtaining aircraft imagery.

Classification Level	Typical Data Characteristics
I	LANDSAT (formerly ERTS) type of data.
II	High-altitude data at 40,000 feet (12,400 m) or above (less than 1:80,000 scale).
III	Medium-altitude data taken between 10,000 and 40,000 ft (3,100 and 12,400 m) (1:20,000 to 1:80,000 scale).
IV	Low-altitude data taken below 10,000 ft (3,100 m) (more than 1:20,000 scale)."

In the above table, Anderson et al. (1976) say that the remotely-sensed data for Level III classification typically will be at 1:20,000 to 1:80,000 scale. Later they state that remotely-sensed Level III data commonly will be obtained at scales of 1:15,000 to 1:40,000. Substantial amounts of supplemental information are needed at Level III and much more supplemental information is used for Level IV classification (Anderson et al., 1976). Manual methods of imagery interpretation were assumed in determining the different categories and levels of the USGS system.

In his discussion of the USGS system, Avery (1977) also indicates that the system has been developed for optical scanners. Avery states that "Each sensor provides a degree of image resolution that is dependent upon flight altitude and effective focal length (or scale). For example, assuming a focal length of 15 cm, the following flight altitudes and image scales would be appropriate when manual (nonautomated) interpretation is anticipated.

Classification level	Sensor platform or altitudes	Approximate range of image scales
I	Earth satellites	1:500,000 to 1:3,000,000
II	9,000 - 12,000 m	1:60,000 to 1:80,000
III	3,000 - 9,000 m	1:20,000 to 1:60,000
IV	1,200 - 3,000 m	1:8,000 to 1:20,000

It should be stressed that the foregoing recommendations are approximate guidelines and not absolutes. With future technological advances, such tabulations will need to be revised." Notice the difference between Avery and Anderson et al. (1976) in the anticipated range of altitudes of the optical sensors in obtaining data for classification at Levels II and III, and particularly Level II.

As the altitude of optical remote sensors increases, the level of land use/land cover classification that can be accomplished drops. It generally is possible to do only Level I and Level II classifications from satellite or high-altitude photography and line-scanner imagery. In contrast, Level IV classification generally is done from low-altitude photography and line-scanner imagery at a scale larger than 1:20,000. Therefore, one should not expect to do both Level I and Level IV classifications from the same small-scale photography or line-scanner imagery, but Levels I through IV classifications could be done from the same large-scale photography or imagery.

It is not surprising that the USGS system has been developed for use with optical sensor data, considering that most remotely-sensed land use/land cover data has been obtained by such sensors. On the other hand, different types and amounts of land use/land cover data are obtained by the various remote sensors because of their different capabilities for data gathering. Thus it is unfortunate that the USGS system has not been developed to take into account the special characteristics of radar imagery for land use/land cover classification.

3. THE USE OF RADAR IMAGERY FOR LAND USE/LAND COVER CLASSIFICATION

With the proper power supply, the resolution of synthetic-aperture radar (SAR), particularly in the range direction, is essentially independent of range and radar wavelength. SAR commonly is used on aircraft and is the type of

radar to be used on spacecraft. The presently unclassified resolution of radar used in the United States is approximately 1.6 m (range) x 2.2 m (azimuth).

The parameters that most significantly affect the radar return from terrain features include surface roughness, topography (including orientation and slope of surfaces), complex dielectric constant of the feature, object geometry, type and extent of vegetation, and the incidence angle, wavelength, and polarization of the transmitted radar energy. Changes in these parameters can greatly change the return from similar features, even with the same imaging conditions. However, studies done using either single- or dual-polarized radar imagery have shown that the level of land use/land cover classification that can be done from radar imagery is primarily a function of the wavelength, polarization(s), and resolution of the reflected radar energy, and the orientation of the feature (particularly a linear feature) to the radar look direction. Therefore, considering that the resolution of a SAR system remains constant with increasing altitude, the level of land use/land cover classification that can be done from radar imagery is independent of the range from the radar to the terrain.

Furthermore, the level of land use/land cover classification that can be done commonly is independent of the scale of the radar imagery. Levels I through III or IV classifications are possible from the same small- or medium-scale radar imagery. The special imaging capabilities of radar, such as producing high-intensity point returns from individual features, bright linear returns from linear features, areas of no-return, etc., aid in delineating spot locations and areas of certain categories of Levels III and IV on small-scale radar imagery. The presence or absence of bright point or linear returns on radar imagery generally is a function of both the orientation of the feature to the radar look direction and the polarization of the reflected radar energy.

The USGS system has been developed on the assumption that different remote sensors will provide data for different levels of classification. Anderson et al. (1976) state that there is little likelihood that any one sensor or system will produce good land use/land cover data at all altitudes. Both beliefs are wrong as far as SAR is concerned. However, it is true as Anderson et al. (1976) point out, that as the more detailed levels of categorization are used (Levels III and IV), more dependence must be placed on higher resolution remote-sensor data. High-resolution data can be obtained by SAR at all altitudes, but high-resolution data can be obtained by civilian optical remote sensors only at low and medium altitudes.

In discussing the four levels of classification of the USGS system, Anderson et al. (1976) state or imply that generally as the level of classification goes from Level I to Level IV, the altitude of the remote sensor decreases, the scale of the imagery becomes larger, and the resolution of the remote-sensor system markedly improves. This obviously is not necessarily true as far as a SAR system is concerned. Therefore, the USGS system not only needs to be revised to readily accept the land use/land cover classifications at different levels that can be made from radar imagery, but the discussion of the classification criteria needs to be re-written to emphasize: (1) The differences at the different levels of classification in the typical characteristics of the data obtained by imaging optical remote sensors and imaging microwave sensors. (2) That the basis of the USGS system is that in going from Level I to Level IV, the land use/land cover classification that can be done from all types of remote-sensing data just becomes more detailed.

4. POSSIBLE REVISION OF THE USGS SYSTEM

The USGS system and its predecessor system have been tested and found to be compatible with aircraft and spacecraft photography and line-scanner imagery, including thermal infrared imagery (Brown and Holz, 1976), obtained at various altitudes. In fact, the land-use classification system proposed in USGS Circular 671 was revised in order to incorporate the results of extensive testing of that system. However, the USGS system is not necessarily compatible with land use/land cover classifications at different levels that can be made from radar imagery. This lack of compatibility for urban areas has been pointed out by Bryan (1974, 1975). Anderson et al. (1976) anticipate that the USGS system may need modification in the future, particularly for use with automatic data analysis.

A possible revision of the USGS system so that it will readily accept land

use/land cover classifications made from radar data is given in Table 1. Other revisions of the USGS system certainly are possible and are encouraged in order that the best possible revision of the system in terms of radar data can be constructed and tested.

Revision of the USGS system is done only at Levels I and II, with most of the revision involving the present Level II categories of Urban or Built-up Land. New as well as revised Levels I and II categories are suggested to accommodate the types of land use/land cover data that can be obtained from radar imagery, and these categories are briefly described. Levels III and IV categories are still to be determined locally. However, at these levels the detail seen on radar imagery may be greater than that seen on imagery obtained by optical remote sensors.

Many of the features of the suggested new and revised categories may "look" different on radar imagery, and in some instances may not be detected or identified, depending upon the orientation of the feature to the radar look direction and the wavelength and polarization of the radar imagery being interpreted (see Lewis, 1968; Lewis, MacDonald, and Simonett, 1969). The features that may "look" different or may not be detected or identified on radar imagery include railroads, power transmission lines, and microwave transmission towers.

1. Urban or Built-up Land

The description of this category is the same as that given by Anderson et al. (1976) except that transportation, power, and communications facilities are taken out of this category and made into separate Level I categories. Brown and Holz (1976) have suggested doing something similar after a study of thermal infrared imagery.

11. Residential

Essentially the same description for this category as that of Anderson et al. (1976). However, housing areas on military bases or at colleges and universities, living quarters for laborers near a work base, or lodging for employees of agricultural field operations or resorts may be readily discernable on radar imagery. If so, these areas should not be placed within the Industrial, Agricultural, or Commercial and Services categories.

13. Industrial

Electric-power generating stations, and oil refineries and tank farms are taken out of this category as defined by Anderson et al. (1976) and put into new Level II categories.

2. Transportation

The transportation routes and facilities must be mappable on the imagery as separate features distinct from other land uses. Level II categories include Highways, Railroads, Airports, and Ports and Marinas.

21. Highways

Following Anderson et al. (1976), the highways include rights-of-way, interchanges, highway bridges, and service and terminal facilities. In urban regions, highways generally consist of more than two lanes.

22. Railroads

Rail facilities include stations, parking lots, roundhouses, repair and switching yards, and related areas, as well as overland track and spur connections, and railroad bridges.

23. Airports

All airports regardless of their size, use, and runway materials are included in this category. Airport facilities include the runways, intervening land, terminals, service buildings, navigation aids, fuel storage, parking lots, and a limited buffer zone (Anderson et al., 1976).

TABLE 1. Possible revision of the USGS system to readily accept land use/land cover classifications made from radar data.

Level I		Level II	
1	Urban or Built-up Land	11	Residential.
		12	Commercial and Services.
		13	Industrial.
		14	Industrial and Commercial Complexes.
		15	Mixed Urban or Built-up Land.
		16	Other Urban or Built-up Land.
2	Transportation	21	Highways.
		22	Railroads.
		23	Airports.
		24	Ports and Marinas.
3	Utilities	31	Electric Power Generation.
		32	Refineries.
		33	Other Utilities.
		34	Utility Transmission Networks.
4	Communications	41	Microwave and Media Transmission Areas.
		42	Communication Transmission Networks.
5	Agricultural Land	51	Cropland and Pasture.
		52	Orchards, Groves, and Vineyards.
		53	Nurseries and Ornamental Horticultural Areas.
		54	Confined Feeding Operations.
		55	Other Agricultural Land.
6	Rangeland	61	Herbaceous Rangeland.
		62	Shrub and Brush Rangeland.
		63	Mixed Rangeland.
7	Forest Land	71	Deciduous Forest Land.
		72	Evergreen Forest Land.
		73	Mixed Forest Land.
8	Water	81	Streams and Canals.
		82	Lakes.
		83	Reservoirs.
		84	Bays and Estuaries.
9	Wetland	91	Forested Wetland.
		92	Nonforested Wetland.
10	Barren Land	10-1	Dry Salt Flats.
		10-2	Beaches.
		10-3	Sandy Areas other than Beaches.
		10-4	Bare Exposed Rock.
		10-5	Strip Mines, Quarries, and Gravel Pits.
		10-6	Transitional Areas.
		10-7	Mixed Barren Land.
11	Tundra	11-1	Shrub and Brush Tundra.
		11-2	Herbaceous Tundra.
		11-3	Bare Ground Tundra.
		11-4	Wet Tundra.
		11-5	Mixed Tundra.
12	Perennial Snow or Ice	12-1	Perennial Snowfields.
		12-2	Glaciers.

24. Ports and Marinas

Port areas include the docks, shipyards, drydocks, locks, and waterway control structures (Anderson et al., 1976). Marinas include docks and supporting service facilities.

3. Utilities

Areas used for the processing, treatment, or generation of water, gas, oil, or electricity are included in this category, as well as the long-distance networks used to transport the products of the processing, treatment, or generation. Level II categories include Electric Power Generation, Refineries, Other Utilities, and Utility Transmission Networks.

31. Electric Power Generation

These are the areas and facilities used for generating electric power and include hydroelectric, nuclear, and fossil fuel power plants. Electric power generation facilities utilizing wind and solar energy will also be included in this category.

32. Refineries

Includes all the facilities actively involved in refining petroleum, as well as the facilities at the refinery used in delivering the petroleum and tank farms used to store the refined products.

33. Other Utilities

These are the utilities not involved in generating electric power or refining petroleum. Includes water treatment facilities, telephone facilities, etc.

34. Utility Transmission Networks

Includes all overland and underground facilities used to transport petroleum, electric power, telephone conversations, water, etc. from the areas of processing, treatment, or generation to where the petroleum, electric power, etc., is used by consumers. Pumping stations, electric substations, and other similar facilities used along the route and at the terminus of the route are included in this category. Although Utility Transmission Networks generally go through areas of other land use/land cover, they commonly constitute the dominant use of the land, particularly when the network occurs above ground.

4. Communications

Includes facilities (buildings, antennas, etc.) used to transmit airwave communications and the transmission networks used to carry the communications long distances. Level II categories include Microwave and Media Transmission Areas and Communication Transmission Networks.

41. Microwave and Media Transmission Areas

These are the areas from which the airwave communications originate. Generally, the radar, radio, or television antennas are the most identifiable features of these areas.

42. Communication Transmission Networks

Includes all facilities used to carry the communications long distances overland. The networks consist primarily of relay stations and associated antennas.

5. Agricultural Land

The Level II category of the USGS system, 22. Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas, is broken down into two Level II categories, 52. Orchards, Groves, and Vineyards, and 53. Nurseries and Ornamen-

tal Horticultural Areas, in this proposed revision of the USGS system. The descriptions of the features of the new Level II categories 52 and 53 are the same as those given by Anderson et al. (1976).

5. SUMMARY

Limited studies have shown that accurate land use/land cover classification at different levels can be done from single-wavelength, either single-or dual-polarized radar imagery (Lewis, 1968; Lewis, MacDonald, and Simonnett, 1969; Henderson, 1977) and from multispectral radar imagery (Bryan, 1975) by untrained individuals who had little or no previous experience either interpreting radar imagery or with the area(s) being interpreted. These studies, although certainly not definitive, show that there are no large-scale interpreter limitations on the land use/land cover classification of radar imagery. There is an extremely good chance that when radar imagery, particularly multispectral radar imagery, is routinely available from space shuttle and satellites in the 1980's and beyond, that, because of three reasons, we may not be able to effectively use the imagery for land use/land cover classifications: (1) We will not have acquired enough signature data indicating what certain land use and land cover categories should look like on radar imagery of different wavelengths and polarizations. (2) We will not have trained enough human interpreters and will not know how to accurately computer classify the data. (3) The land use/land cover classification system(s) for use with remote sensor data will not readily accept the types of land use/land cover data that can be obtained by radar.

There certainly is no need to develop a new land use/land cover classification system especially for radar data. Basically, what is needed is to revise the descriptions of the characteristics of the various levels of land use/land cover classification to point out that the levels differ in terms of detail of classification and not necessarily in differences in scale or resolution of the imagery or range of the sensor from the terrain. The revision of the USGS system to readily accept data obtained from radar imagery should be done now while the classification system is still in its formative stages.

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