K-Band Radar in Vegetation Mapping

Discrimination studies of pine, fir, and hardwood forests, juniper woodland, sagebrush, chaparral, grassland, etc.

Analysis Techniques

Vegetation analysis method with radar

In an earlier paper (Morain and Simonett, 1966) we noted that a number of methods help in the discrimination of plant communities on radar imagery. These methods include analysis of: (1) differences in average gray scale values between communities, (2) textural differences, (3) edge effects, particularly those which arise from different means of gradation from one plant community to another, (4) probability density functions per unit area, (5) analysis of spatial arrange-

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1967 under the title "An Evaluation of K-Band Radar in Vegetation Mapping: Image Discrimination Studies at Horsely Mountain, Oregon." The study was supported by the National Aeronautics and Space Administration under Contract NSR-17-004-003 and NASA Grant NSG-298.
ABSTRACT: Methods for the interpretation of vegetation from radar imagery have been investigated through use of an image discrimination, enhancement, combination and sampling system (ID ECS) developed at the Center for Research in Engineering Science at the University of Kansas. HH and HV polarization K-band imagery of Horsefly Mountain, Oregon has been analyzed using several electronic techniques aimed at improving our ability to discriminate distributional patterns of vegetation. These techniques include the use of tri-color image combinations, the generation of probability-density functions to quantify variations in gray-scale level between types; and the employment of a data space sensor to help distinguish between vegetation types.

photographic color methods involving multiple projectors and color filters.

We also noted that although the above are concerned with single images, it was also possible to obtain simultaneously recorded radar imagery which would give the full polarization matrix and/or a number of frequencies. Data of this type is potentially suitable for a number of additional types of analysis including polychromatic-display techniques.

It is with the polychromatic-display techniques that the present paper is primarily concerned, for the study deals mostly with the various color combinations possible with $HH$ and $HV$ polarization K-band imagery of a vegetated area at Horsefly Mountain, Oregon. With this color combined imagery various forms of level slicing, and data-space sampling are employed.

ELECTRONIC IMAGE DISCRIMINATION

Equipment capable of performing the necessary image discrimination, enhancement, combination and sampling (for which we use the acronym IDECS) has been assembled at the Center for Research in Engineering Science at the University of Kansas. The system, illustrated in Figures 1 and 2 is described more fully in Simonett, (1966) and only a brief outline of the operation of the system is given here.

The first operation in the IDECS data-handling system is the scanning of up to three images in a three-channel flying-spot scanner (FSS). The electrical analogs of the images placed on the faces of the FSS are fed singly or collectively to the matrixing unit and the outputs of the matrix are presented to the three (red, blue and green) electron guns of the cathode ray tube in a color television unit (CTV). Combinations of images can thus be reproduced in various colors to aid their interpretation. The CTV is synchronized with the FSS by synchronizing their rasters (see Figure 2). An alternative tricolor oscilloscope (TCO) may also take the outputs from the matrix or directly from the $A$, $B$ and $C$ channels of the FSS. This device has very high color fidelity, but poorer resolution than the CTV. It may however be used for scanning images and handling radar scatterometer data.

The output of either the red, blue or green channels from the matrix unit or the $A$, $B$, $D$. S. SIMONETT

D. S. SIMONETT

K-BAND RADAR IN VEGETATION MAPPING 731
and C channels of the FSS may also be fed into a pulse height analyzer to produce probability density functions and other statistical manipulations. The three channels of the FSS may also be sampled with a data space sensor (DSS), including a number of Schmitt Triggers used in concert; and the outputs from these devices in turn may be fed to the CTV to selectively enhance the data sampled by the DSS or the Schmitt Triggers. Finally, a differentiation unit is included which enables one or more images to be differentiated and presented in different colors to the CTV.

Using the IDECS system we have studied the degree to which it is possible to extract selectively various levels of information on natural vegetation employing HH and HV K-band images of Horsefly Mountain, Oregon. The Horsefly Mountain site was chosen because the radar imagery displays notable differences in texture between and within different plant communities, and wide variations in the gray scale response occur on the two polarization images. In addition detailed field studies on vegetation in this area and its relation to the radar image has recently been concluded by the senior author (Morain, 1967).

**BACKGROUND OF THE HORSEFLY MOUNTAIN SITE**

**PATTERNS OF VEGETATION TYPES**

In Figure 3 are shown the major vegetation types of Horsefly Mountain, based upon field study in August 1966 and extensive use of the U.S. Forest Service Timber Type Map, 1962, of the area. The seven major vegetation types are ponderosa pine forest, juniper woodland, white fir forest, hardwood forest, sagebrush on basalt rubble, chaparral shrub (old burn), grassland, and recently-burnt areas which are almost entirely vegetation free. Figure 4 is the HH and HV polarized K-band radar imagery used in this study.

Virgin ponderosa pine in this area forms a very open forest with a tendency towards over-mature trees and a grass understory. However, virgin forest is rare in the Horsefly region which has been extensively logged. What is left are a few relic large trees of ponderosa with various mixes of saplings and medium-height pole timber growing up around the remnants of the old forest. As the area is a portion of Fremont National Forest, the young growth is protected. Consequently the amount of young growth in the area is probably more than the normal. The dense young growth seems to cause slightly more uniform gray tones on the radar image of the forest than would be true in the virgin ponderosa pine.

White fir tends to occur in monospecific stands only in the most mesic sites; however, it is widely scattered in various mixes between 10 and 30 per cent in the understory of parts of the pine forest. Incense cedar is ubiquitous, but rarely constitutes more than 5 per cent of a stand.

Juniper woodland tends to be a lower elevation community associated with more xeric spots, although pine and juniper mix in some areas. Juniper is notably free in as-
sociating with other dominant forms of vegetation in the area. It may have a sagebrush understory, a grass understory, no understory at all, or it may mix with pine. Some juniper stands may be very dense, covering as much as 50 per cent of the ground, and yet in others the density may be 10 per cent or less. All gradations may be seen and it is therefore difficult to establish what one might call the normal structural form for juniper woodland.

Sagebrush under normal conditions in this region would obtain heights of two feet or so, and would form a fairly continuous shrub stand. However, the forest service has granted grazing rights to ranchers, and sagebrush as well as grassland has been heavily grazed. Densities or the order of 10 to 25 per cent are now common although in a few small areas densities may reach up to 45 per cent or even 50 per cent. But in any case most of these bushes or individual shrubs are small.

Chaparral shrub normally occupies formerly burned areas and consists of species of Arctostaphylos and Ceanosus. These shrub communities represent a successional stage following forest fire, and for that reason usually occupy well defined patches on previously forested slopes. Chaparral may be

![Major Vegetation Types at Horsefly Mountain, Oregon (boundaries corrected to geometry of radar imagery)](image_url)

**Fig. 3.** Major vegetation types at Horsefly Mountain, Oregon (boundaries corrected to geometry of radar imagery).
mixed with areas of pine forest but this condition seems to be remnant of a previous succession towards pine forest.

Essentially two kinds of grassland occur in the Horsefly Mountain area: (1) mesic meadows with thick, continuous grass which may occasionally be marshy; and (2) less mesic forest openings with sparse and often short grass. Further details of these vegetation communities, and in particular the detailed nature of the radar image texture, show as average gray scale values, and gray scale variations within a single community will be found in Morain (1967).

Cut-over ponderosa pine has a very marked radar image texture which normally permits its rapid distinction from surrounding vegetation types. In general, areas containing mixes of residual forest and an understory of saplings or pole timber rather consistently yield a coarser texture and a wider range of point gray scale values than do young stands without residual forest. This may well arise from increased surface roughness which generates signal returns from both tall and short trees.
Juniper woodlands have no visibly distinct image texture or gray scale associated with them either on the HH or the HV images. The most characteristic expression on the HV polarization is a smear.

White fir forest has a texture and gray scale closely akin to the pine forest although the texture of the white fir tends to be slightly less coarse, and slight differences in the two returns on HH and HV imagery occasionally appear.

Sagebrush shrub is difficult to distinguish on the radar from other non-forest types, including grasslands. Image texture is generally quite fine in non-forest areas, and simple visual inspection shows much the same gray scale for the various vegetation types occupying them. The differences which exist are therefore subtle enough to require electronic and other data processing of the images to see if some discrimination can be achieved. Much of the radar return in the sagebrush areas undoubtedly comes from basalt rubble littering the surface, rather than from the spare, dry shrubs.

In general, sites with pure chaparral may be recognized on HV imagery by their relatively fine texture in comparison to pine, their moderately high gray scale value, and by their position on slopes. Often the chaparral patches are enclosed by pine forest and are noted on the imagery mainly by breaks in texture. On HV imagery the image gray tone of chaparral lies between that of forest and mesic grassland. Gray scale cannot be used by itself, however, because it overlaps the gray scale values of a number of other vegetation types.

On HH imagery, burn patterns are not easily detectable, whereas on the HV imagery they normally are much more detectable. For example on the HH image it is not possible, by visual inspection alone, to distinguish between most types of nonforest vegetation. In addition the textual detail on the HH imagery masks the occurrence of some of the older burn areas because of the initiation of "forest texture" in places where tree regrowth has progressed enough to affect the radar return. On the HH image alone it may be quite difficult to discriminate between thin spots in forest density and burn areas in a late stage of succession. As this difference is more ecological than physiognomic (i.e. "geometric"), one would hardly expect any discrimination on the radar image.

Mesic and dry grassland types have low to moderately low average radar returns respectively. Though they are often quite small many mesic grassland spots are detectable on HH and HV imagery by their very dark appearance. Although the mesic grassland sites have lush growth and hence a relatively high dielectric (which would lead one to expect a higher rather than lower radar return—see Simonett et al., 1967) the radar returns are low. We expect that this apparent anomaly arises from the tangled, matted matrix of the mesic grassland in which the radar signals bounce around, thereby substantially decreasing the return.

The lighter gray tones (higher radar signal return) of the dry grassland may arise because the grass blades are more vertical and less matted than in the mesic type. In addition, part of the return may come from pebble-strewn bare ground between the grass culms. The influence of a uniform surface of small pebbles on radar return in similar grasslands in Escalante Valley, Utah is to increase the amount of radar signal return (Morain and Simonett 1966).

**Interpretation and Discussion of IDECS-Processed Imagery**

**Color-Combined Imagery**

A number of color combinations cannot be considered here because the subtle color gradations are not reproducible in black and white. The four which are reproduced are examples where the contrast in black and white is adequate for illustration of the topics discussed.

Figure 5 shows a color-combined image with a forest-type map overlay which has been adjusted to fit the geometry of the radar image. The central medium gray area (which appears violet on the color combination) is sagebrush. The areas above and below with paler tones (green on the color image) consist of ponderosa pine. Within the sagebrush area little pockets of pine forest are also discriminable. Areas of dark gray to the south of Otto Boy Flat and on the upper slopes of Horsetly Mountain, (darker green on color combination) correlate partially with areas of white fir forest rather than pine. The area south of Otto Boy Flat contains at least 50 per cent pole timber of white fir coupled with some emergent relict pine. In this area of Oregon white fir frequently occurs on the more mesic north-facing slopes (as near Otto Boy Flat) or at higher elevations (as on Horsetly Mountain). The information on the upper slopes of Horsetly Mountain is ambiguous because of the degradation in image quality along the edges of the color television system. In addition unremoved antenna side-lobing may
also contribute to the return in this area. Finally, a number of very dark gray areas (deep blue on color combination) are mesic grassland sites.

In Figure 6 the map overlay is used as a base to display the highest part of the radar return signal on the HV polarization image. These areas of high intensity, shown as specks of dark gray (bright red on the color combination), are dense sapling and pole timber in the pine forest. In a few instances emergent relict pine is also present. A number of small gray spots (red) just north of Otto Boy Flat are not shown on the forest service vegetation map. These may perhaps be pockets of denser growth too small to show on the forest service map, although point-by-point stereoscopic examination with air photographs indicate that these sites could just as well be small topographic irregularities as actual dense spot areas of regrowth. It is most difficult to reconcile each point on the radar image with the aerial photographs because of the vast difference in scale and information content.

In Figure 7 the clipping level on the gray scale of the HV image has been decreased but it is still apparently confined to ponderosa pine-dominated regions, as no areas containing pure stands of white fir or areas that have fairly heavy mixtures of white fir are emphasized in gray (red on color slide). This is an important distinction because where white fir appears in monospecific stands it is usually dense. On the HV image then it appears that white fir gives fewer high-return point values than do dense stands of ponderosa pine, a judgement which is confirmed on inspection of the probability density functions for fir and pine (Figure 9). Although in general the density of vegetation directly affects the magni-
K-BAND RADAR IN VEGETATION MAPPING

FIG. 7. HV radar image clipped at moderate intensity level.

Attitude of radar return (Simonett et al., 1967), obviously other factors than density alone must be involved in the white fir and ponderosa pine areas. In the pine forest on the northern flank of Horsefly Mountain a number of open patches in the forest are also discriminated at this clipping level. If further study shows that radar is commonly sensitive to differences such as these, then it seems that this type of analysis could be quite helpful in studying radar imagery of areas of very gentle slopes where topographic complexities are not present.

Two environments where such discrimination may be valuable are: gently sloping areas in tropical savannas (which have notable differences throughout the year in the state and condition of plant communities), and in previously glaciated sub-artic regions where many complex mosaics of plant communities also occur on gentle topography.

In Figure 8 the clipping level has been dropped to the lowest gray scale levels of the HV image. All the higher returns are discarded. All pale gray areas lie above the clipping level, all dark gray areas (red on color slide) lie below. It is noticeable that considerable discrimination within the low-return sagebrush area is being achieved. A number of pale gray (non-sagebrush) areas, which were not mapped by the U.S. Forest Service, are in reality small clumps of ponderosa pine within the sagebrush region. The radar imagery therefore makes a distinction which is related to the actual vegetation distribution. Another area of interest is in the north-

FIG. 8. HV radar image clipped at a low level.
ern and eastern fringes of Otto Boy Flat. The area of dark gray (bright red on the slide) in this region may well represent a zone of bare basalt rubble lying between the forest and the true grass flats in the center of Otto Boy Flats. This basalt rubble zone was not

Fig. 9. Image textures and probability-density curves for natural vegetation, Horsefly Mountain, Oregon.

Fig. 10. Structural Variation in Ponderosa Pine Forest between Paddock Butte and Horsefly Mountain, Oregon.

mapped by the U. S. Forest Service, but was observed in the field. Much of the fine mottling in the central portion of the sagebrush zone is a very mixed area of little stringers of pine mixed with the sagebrush. The pine tends to occur in small clumps beading across small washes.

PROBABILITY-DENSITY FUNCTIONS

In our earlier publication on Horsefly Mountain (Morain and Simonett, 1966) probability-density functions were given for a number of inferred vegetation types to indicate the possible utility of such frequency/density curves in studying plant communities. In the present study probability-density functions have been derived for mapped and field-checked vegetation types. The $HH$ and $HV$ radar images were masked with black photographic paper and areas on the image corresponding to each vegetation type were cut out. The regions were then exposed to the flying-spot scanner and sample data was fed to a pulse-height analyzer to produce the probability-density functions. The curves in Figure 9, although uncalibrated in an absolute sense, are internally consistent because all were obtained without changing instrument parameters.

Probability-density functions for white fir, ponderosa pine (mixed relict and regrowth timber), sagebrush, juniper and mesic grassland are presented in Figure 9. The curves have some variations in shape for each of the natural plant communities involved. These differing curve shapes indicate that radar interaction with plant communities (and other objects present, such as the basalt rubble in the sagebrush region) is dissimilar for these types. The probability-density functions thus confirm that data-space sampling on a single image, or in two-space on two images coupled with color combinations, is a proper (i.e., valid) discriminatory tool in studying natural plant communities. The probability-density functions and the color
slides thus lead us to essentially the same conclusion: the radar image contains subtle differences which the unaided or untutored eye at first sight cannot distinguish. The IDECS color combining system brings these subtle distinctions to the attention of the interpreter, and thereby expands his detection and discriminatory abilities.

A map of structural variation in ponderosa pine forest between Paddock Butte and Horsefly Mountain, Oregon is given in Figure 10. Using the masking procedures described above, three pine structural subtypes were sampled for probability-density functions. The latter, shown in Figure 11, are internally consistent, but as they were obtained with a different instrument setting than the samples in Figure 9, a comparison cannot be made. The curves in Figure 11 show that sufficient differences exist between the various structural sub-types to warrant further study, although in general Morain's (1967) earlier conclusions, based on visual inspection of the imagery, that "Few differences between any of the pine types can be detected on HH imagery" and "The orthogonally depolarized component of signal backscatter (HV) from sub-types within the pine forest is relatively uniform," are correct. The sub-types should be further evaluated by a documentation of the range of differences detectable by eye and by electronic sampling techniques. Such a comparative study is beyond the scope of the present article, but will be performed by us at a later date using fully calibrated system.

References


