SIDE-LOOK RADAR: ITS USES AND LIMITATIONS AS A RECONNAISSANCE TOOL

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The short-time imaging of Darien Province, Panama, and the subsequent analysis of the imagery by geoscientists indicated a great potential for side-look radar as a reconnaissance tool in many areas of earth study, particularly where climatic conditions are adverse to aerial photography. Evaluation of additional radar imagery from other environments has demonstrated the reality of this potential. Rapid, all-weather imaging and the resulting synoptic, ground-range presentation point to radar as a valuable first-look tool. From acquisition-scale imagery or from an easily assembled mosaic, relief and slope data can be obtained; drainage patterns and basins can be accurately defined; and bedrock geology, surface material, and vegetation studies can be conducted. Structural configuration of bedrock and fracture patterns can also be determined with a high degree of accuracy. Utilizing the dual-polarization capability of radar permits, in addition, the qualitative determination of soil moisture content and may provide added vegetation data. The characteristics of the radar system and the factors that influence radar return should be known by the user, not only for interpretation but also for mission planning. The ability of side-look radar to rapidly acquire data under all weather conditions offsets the limitation of the relatively high cost for small-area surveys and a resolution capability less than that of the aerial photograph. The prime value of radar is realized from its synoptic presentation in the early stages of a survey.

•IN 1967, four complete coverages of a 17,000 square kilometer area in Darien Province, Panama, were achieved in approximately 6 hours of imaging time during a 6-day period in a heavily cloud-shrouded region. This mapping (Fig. 1) established side-look airborne radar (SLAR) as a geoscience tool of the future. A similar dramatic use of this non-weather-dependent tool was recently made during the history-making voyage of the tanker Manhattan when radar was revealed as the most effective sensor utilized in determining ice conditions in the Arctic waters. Little doubt has been left as to the value of SLAR where climatic conditions are adverse to aerial photography. During a period of 15 years of continuous effort in Panama, only 40 percent of the area imaged by SLAR had ever been photographed. A large percentage of the continent's surface is cloud-covered much of the time (Fig. 2); therefore, the value of a sensor that is essentially non-weather-dependent can easily be recognized. Rapid data acquisition is facilitated through the continuous imaging of swaths of the earth's surface as wide as 80 km (AN/APQ-69) and through the utilization of high-speed jet aircraft (YEA-3A) as platforms. Although currently available systems do not approach these maxima, the characteristic wide-swath, continuous imaging of SLAR results in rapid data acquisition compared to that by conventional photography.

IMAGE GENERATION AND PRESENTATION FORMAT

The wide-swath continuous imaging of SLAR results in a synoptic presentation that has proved to be especially valuable in the revelation of gross and subtle features often overlooked in photographic presentations (2). This arises from the presentation

Figure 1. Radar mosaic of Darien Province, Panama.

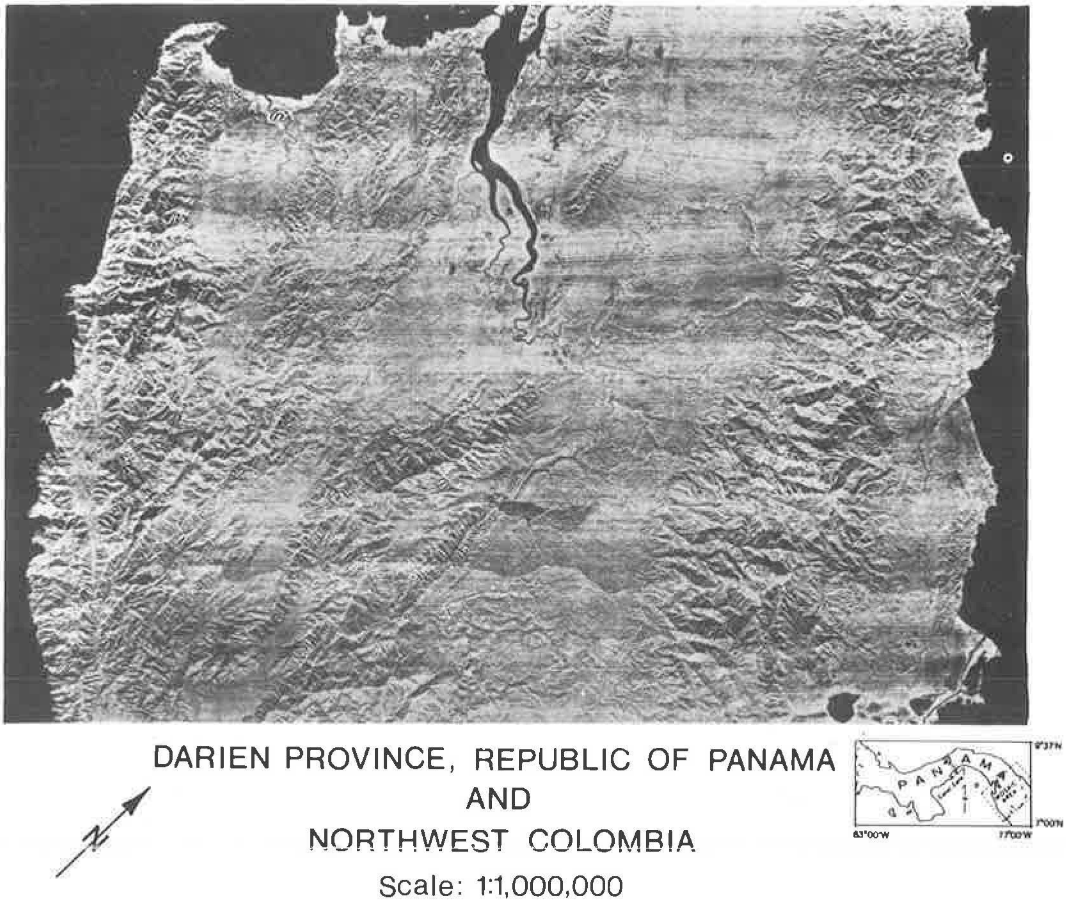
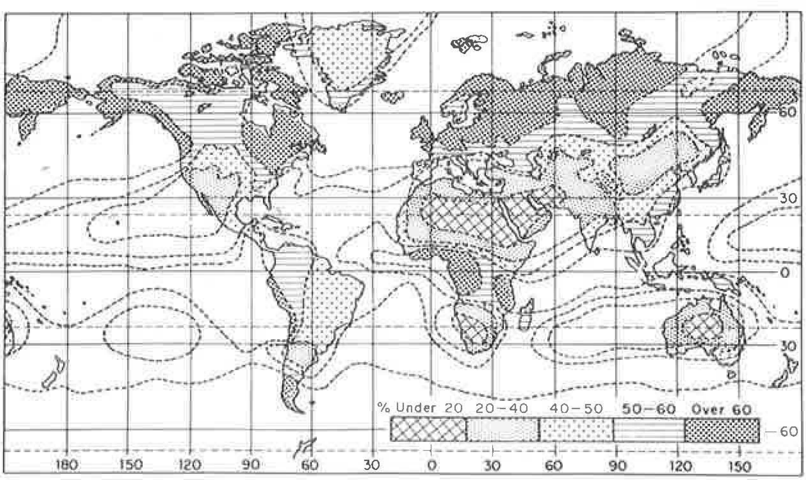


Figure 2. Mean annual cloud cover for the world in percentage of sky covered (Rumney, 1968).



on SLAR imagery of a large area in a small format so that the eye integrates what may be seemingly unrelated features in larger format. The degradation of often distracting detail due to a SLAR resolution somewhat less than that of the photograph is also a contributing factor to the dramatic presentation of gross patterns and features.

Although improvement in resolution can be (and on some classified radars has already been) achieved, the increase in detail distracts from the presentation of gross patterns. Although much detail is revealed through the magnification of radar imagery with a ±50-ft resolution as currently produced, realistically from the cost point of view, radar cannot be viewed as a practical tool for the acquisition of detailed surface information in small areas except when essentially real-time data are required and no other sensor is capable of data collection (for example, during the voyage of the Manhattan through Arctic waters).

To suggest that radar is of greatest value as a reconnaissance or first-look tool does not imply that radar imagery lacks in geometric fidelity. Imaging systems currently operating commercially produce imagery that conforms to mapping standards established by the U. S. Geological Survey. Several as yet classified systems achieve even greater geometric fidelity; however, distance can be measured with greater accuracy on currently produced imagery than on conventional aerial photographs. Thus SLAR, offering rapid, broad coverage within acceptable limits of accuracy, merits serious consideration as a tool for updating highway and drainage networks and vegetation distribution on outdated topographic maps.

Radar imagery of areas whose sizes exceed SLAR's swath-width capability can be easily and effectively mosaicked (Fig. 3). Figure 4 shows how the difficulties of mosaicking slant-range imagery (horizontal scale normal to flight line compressed in the near range) can be overcome if the return signal is recorded in a ground-range format (horizontal scale equal in all directions). Geologic trends not previously identified have been revealed not only in the radar mosaics of Panama but also in the mosaic of Massachusetts, an area previously subjected to intensive surface and photographic investigation. The versatility of SLAR imagery has best been demonstrated by Wing (17) in his expansion of an earlier study of Darien Province by MacDonald (8). Utilizing the radar mosaic, as well as acquisition scale imagery often under magnification, resulted in the revelation not only of gross patterns but also of considerable detailed structure.

EASE OF INTERPRETATION

To the potential user of SLAR imagery, normally 2 questions immediately come to mind: (a) How much training is necessary for effective interpretation? and (b) Is stereoscopic coverage available? Although the energy recorded (and transmitted) by the radar is in a different electromagnetic spectrum frequency range from that of solar energy and the controlling factors for the interaction of any given target are different with this energy from those with light, the similarity of the film records is obvious. Techniques of interpretation are also similar. A skilled photo interpreter need only become familiar with parameters that control radar return, understand their effect on the return signal, and recognize the effect of the side-looking configuration of the sensor on the geometry of the return signal. As in photography, variations in tone, texture, shape, and pattern signify variations in surface features and structures. Groups of potential interpreters, not necessarily skilled in photo interpretation, have been trained thoroughly in 4 or 5 days, and small groups or individual photo interpreters can be trained in 1 or 2 days.

In areas of moderate to high relief, the characteristic shadowing of the side-looking system reveals relative relief to the unaided eye. Stereoscopic coverage is feasible (Fig. 5), and methods for producing contour information are under study. The 60 percent overlap not only ensures the 3-dimensional stereoscopic display but also ensures the placement of each terrain unit in near and far range positions. Therefore, in areas of high relief the excessive shadowing that might mask large areas in the far range is reduced to a minimum in the near range; and in areas of low relief subtle features that might escape detection in the near range are accentuated through shadowing of the image in the far range (Fig. 6).

Figure 3. Kentucky test range mosaic (ground-range radar display) containing 3 horizontal splice lines.

Figure 4. Comparison of geometry of ground-range and slant-range imagery (8).

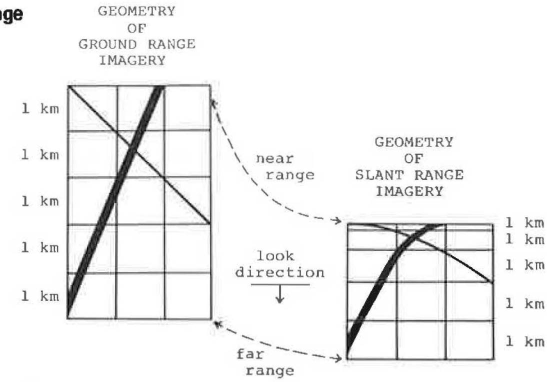


Figure 5. Radar-stereo pair.

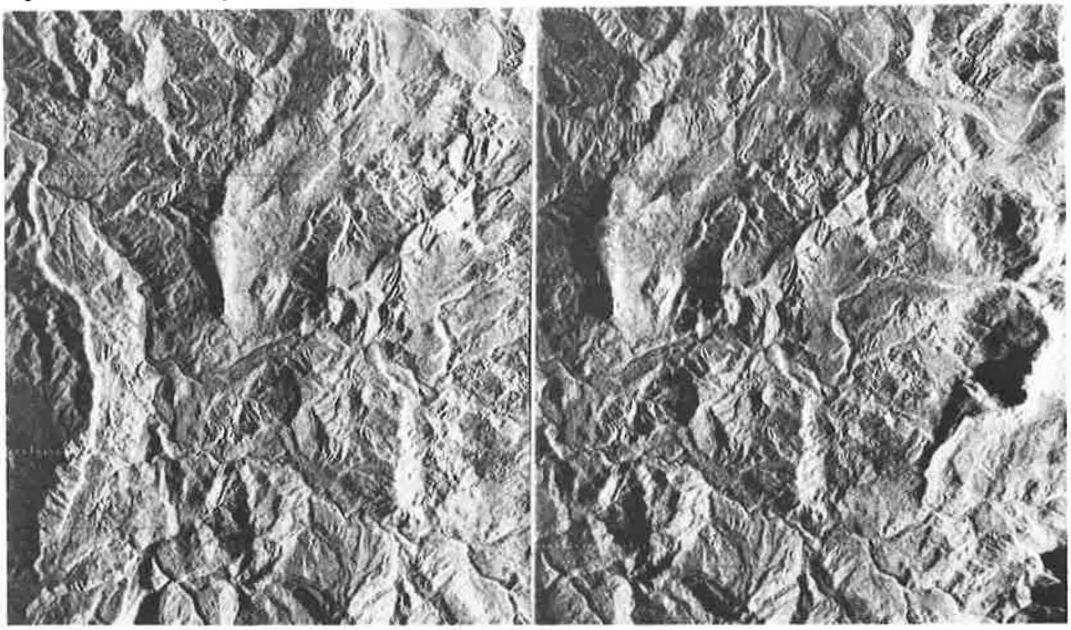
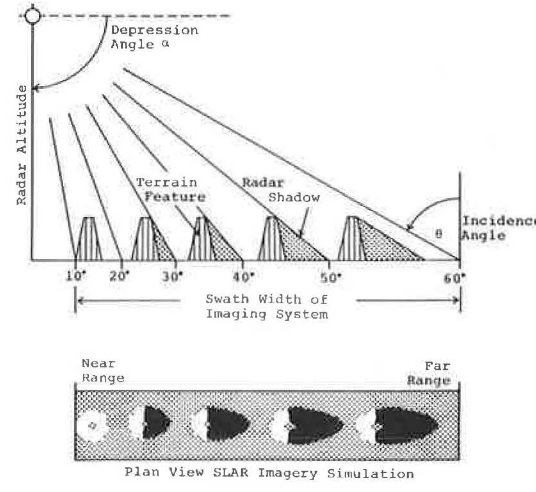


Figure 6. Shadowing characteristics of SLAR imaging systems.



SURFACE CONFIGURATION AND HYDROLOGIC DATA CONTENT

Quantitative slope, not qualitative relief, data are desired in most engineering or geoscience studies. Interferometer techniques have been used with good results for the preparation of topographic maps (Fig. 7), although the cost of data reduction is essentially prohibitive. Recognition of the value of this technique has prompted additional research and development with anticipation of the utilization of this technique in mapping.

For the determination of spot elevations (6, 13), simple techniques of shadow analysis of single radar images may be utilized. However, both methods require knowledge of aircraft elevation and slant distance to target and are based on the assumption that the radar shadow is falling on a flat surface, a condition not often realized. McCoy (14), utilizing a knowledge of the range of depression angles across an image, obtained an expression of slope in the zone where the radar beam grazes the slope and generates no shadow. However, if a slope is imaged twice along parallel flight paths from the opposite or the same direction, the slope angle can be accurately determined theoretically as a function of depression angles and slant-range measurements (which may be easily calculated from a ground-range display). However, practical accuracy requires careful selection of identical points on both images, accurate measurements, and accurate determination of depression angles. Such measurements are time-consuming and impractical for regional studies. Nonetheless, with stereoscopic coverage, an altimeter profile, and a potential of spot elevation and slope determinations, reasonable estimations of volumes of cuts or fills can be made from ground-range imagery.

Drainage basin data are desirable at the reconnaissance level of investigation. Radar imagery as a tool for drainage basin analysis was evaluated by McCoy (14), who, primarily utilizing AN/APQ-97 imagery in the early slant-range format (Fig. 8), concluded that the drainage area, basin perimeter, bifurcation ratio, average length ratio, and circularity ratio could be measured directly from the imagery with little difference from values derived from 1:24,000 USGS topographic quadrangles. Stream numbers, lengths of streams, and drainage density show sufficiently consistent differences between map and radar-derived values to permit, by use of an appropriate equation, the conversion of radar-imagery values to map values. Because of the consistency of difference, use of the conversion factor reduces the stream length and related data error to acceptable limits for hydrologic reconnaissance studies. The use of such a factor is necessitated by the loss of low-order stream detail on the radar imagery. A not-to-be-overlooked source of error in areas of high relief is shadowing that may obscure portions of a given drainage basin, but positioning of such areas in the near range of the image (11) or imaging the areas from 2 directions can nullify the potential loss. Inasmuch as McCoy's investigation was conducted by the use of a slant-range imagery, even greater fidelity in a ground-range presentation should be expected.

GEOLOGIC DATA CONTENT

As a tool for geologic data collection, radar has a well-documented capability, a capability largely attributable to synoptic presentation, suppression of distracting detail, reduction of resolution, and radar shadowing. An early study of imagery (2) covering the Boston Mountains of Arkansas (Fig. 9) revealed a pronounced north-south fracture pattern that had not been previously detected through detailed aerial photograph evaluation and field study. A low elevation overflight of the area after the pattern was detected on radar imagery showed the alignment of discrete segments of streams that had developed in zones of concentrated fracturing, zones apparently detectable only under the conditions stated above.

A more recent investigation (18) of radar imagery in the Burning Springs, West Virginia, area resulted in sharper definition of fracture orientations that could be achieved through study of aerial photographs or field measurements. Weathering along joints had influenced stream development, and the trends of fractures were reflected in well-defined topographic features. The accurate definition of diversely oriented and developed fracture patterns and the identification of major zones of weakness or movement may prove extremely valuable to the engineer, especially in the preliminary planning stages of projects requiring the quarrying or removal of large quantities of rock

Figure 7. Topography of Harper's Ferry mapped by radar data (left) and by photogrammetric techniques (right).

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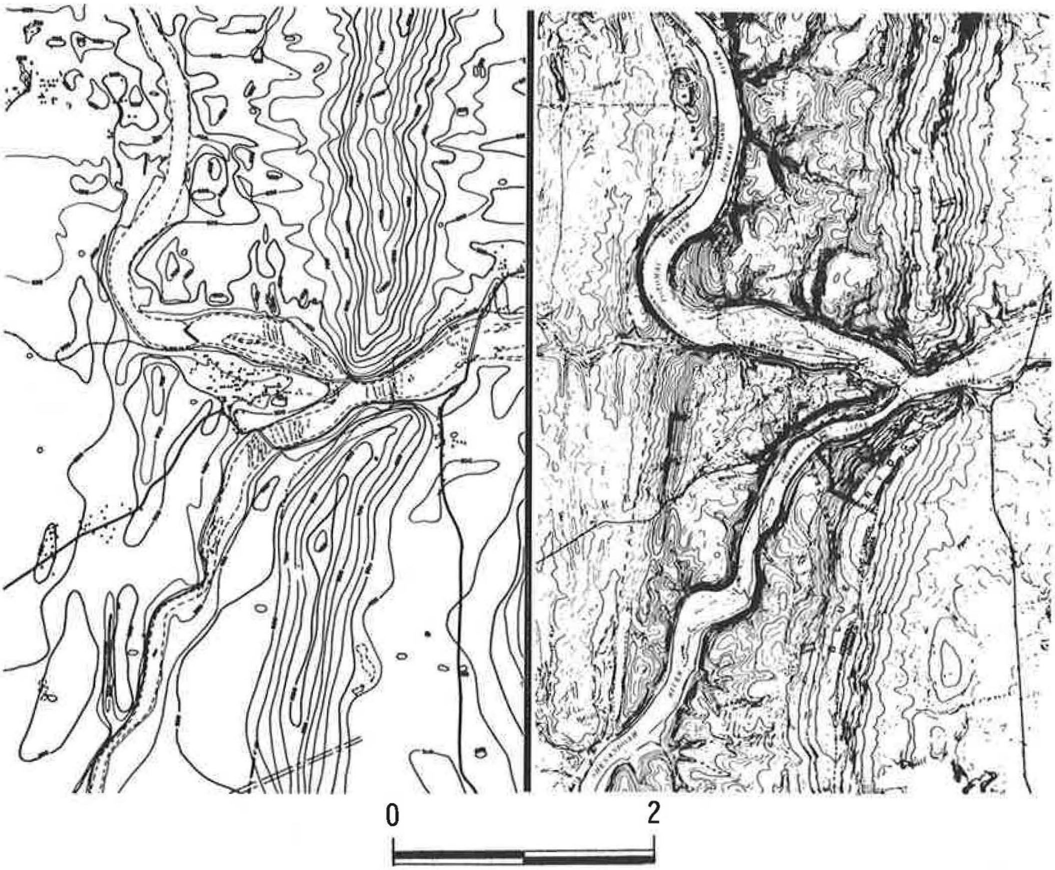


Figure 8. Drainage maps derived from topographic map and radar imagery.

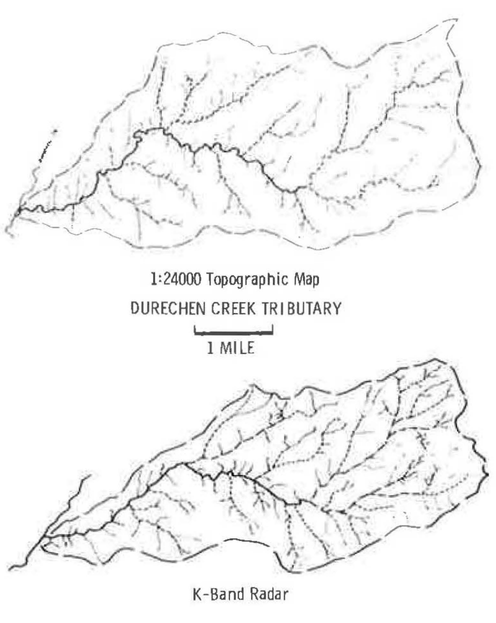


Figure 9. AN/APQ-69 radar imagery showing north-south linear trends in the Boston Mountains.

materials or in the preliminary route selection through unmapped areas in which ground reconnaissance is not feasible.

As on aerial photographs, lithologies are separable on the basis of tonal, textural, pattern, and shape characteristics. For example, in the evaluation of imagery of Panama, limestones were identified by the development of karst topography, and igneous intrusions and lava flows were identified on the basis of shape (Fig. 10). Most rock units in this environment could be traced on the basis of topographic expression. In less intensely vegetated areas, one might rely more heavily on flora distribution and topographic fracture texture patterns, both of which may be directly influenced by rock type. Mapping on the basis of residual soils is not feasible at this time, unless a correlation between soil and vegetation can be identified.

With the identification and separation of lithologic units, the definition of structure offers no difficulty. The degree to which units can be isolated and minor structures identified is to some extent a function of resolution. On classified high-resolution radar imagery of the Ouachita Mountains, a more detailed separation of lithologic units and easier identification of small-scale structure could be made than on imagery from other, coarser resolution radars. However, with improvement of resolution comes an increase in distracting detail so that the definition of minor features is at the expense of major (4).

DUAL-POLARIZATION RADAR: A TOOL WITH POTENTIAL

The potential value of simultaneously recording like- and cross-polarized return was early demonstrated by Dellwig and Moore (5), who made a preliminary evaluation of anomalously depolarized return signals in the Pisgah Crater area. About the same time, Morain (15) noted that the relatively uniformly textured and even-toned return from the vegetation on the like-polarized return was shown to be separable into areas of variable tones on the cross-polarized return. The degree of depolarization was directly related to vegetation type, the area boundaries paralleling those defined by the U. S. Forest Service map. More recently, McCauley (personal communication) has established a relation between the geometry of the surface of some volcanic rocks and sandstones and the cross-polarized return signal, suggesting that anomalously low cross-polarized return is dominated by specular reflection from planar rock surfaces that are large in comparison with the wavelength of the incident radar. Although of undetermined value at present, some potential for future utilization of the cross-polarized return in further discrimination of rock and soil (and vegetation) types is indicated.

A currently better defined capability of dual-polarized radar is in the revelation of a qualitative estimate of soil moisture content (Fig. 11). MacDonald and Waite (12), utilizing like- and cross-polarized return, discriminated between wet and dry areas in the near range in portions of the Gulf Coast with sufficient accuracy to warrant further investigation of this capability. The high degree of correlation between the electrical properties of soil and soil moisture content indicates that in a like manner areas of permafrost in the Arctic regions could be easily delineated. Definition of soil moisture content having been achieved with Ka-band imagery suggests an even greater potential for soil moisture content determination for the as yet untested long wavelength radars.

RECOMMENDATIONS FOR USE

As in any sensor utilization, the maximum value from radar imagery can be realized only as a result of efficient mission planning with full understanding of the characteristics, capabilities, and limitations of the sensor. The film record of radar return may tend to be misleading because of its similarity to an areal photograph taken with oblique sun angle. However, the response of a surface to radar is not the same as that to light; a host of parameters, some not yet fully evaluated, interact to influence the radar return signal. System parameters include resolution, polarization, depression angle, aircraft elevation, and orientation of flight lines relative to the potential target's structure. Surface parameters of importance are dielectric constant

Figure 10. Radar imagery of eastern Panamanian isthmus showing (left) northwestern Darien range—(d) anticlinal fold, (e) synclinal fold, (f) valley in Upper Eocene shale, and (g) karst topography developed on Lower-Middle Oligocene carbonates—and (right) Chiman coastal area—(a) igneous plug, (b) caldera ring, (c) igneous dikes, (d) caldera, and (e) north-south striking fault (18).

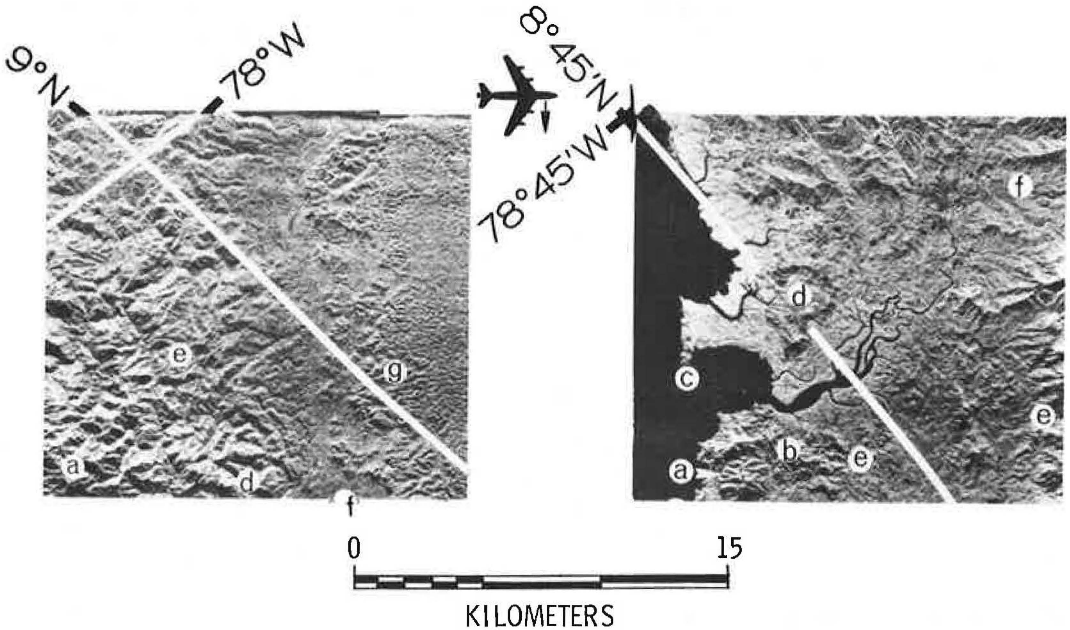
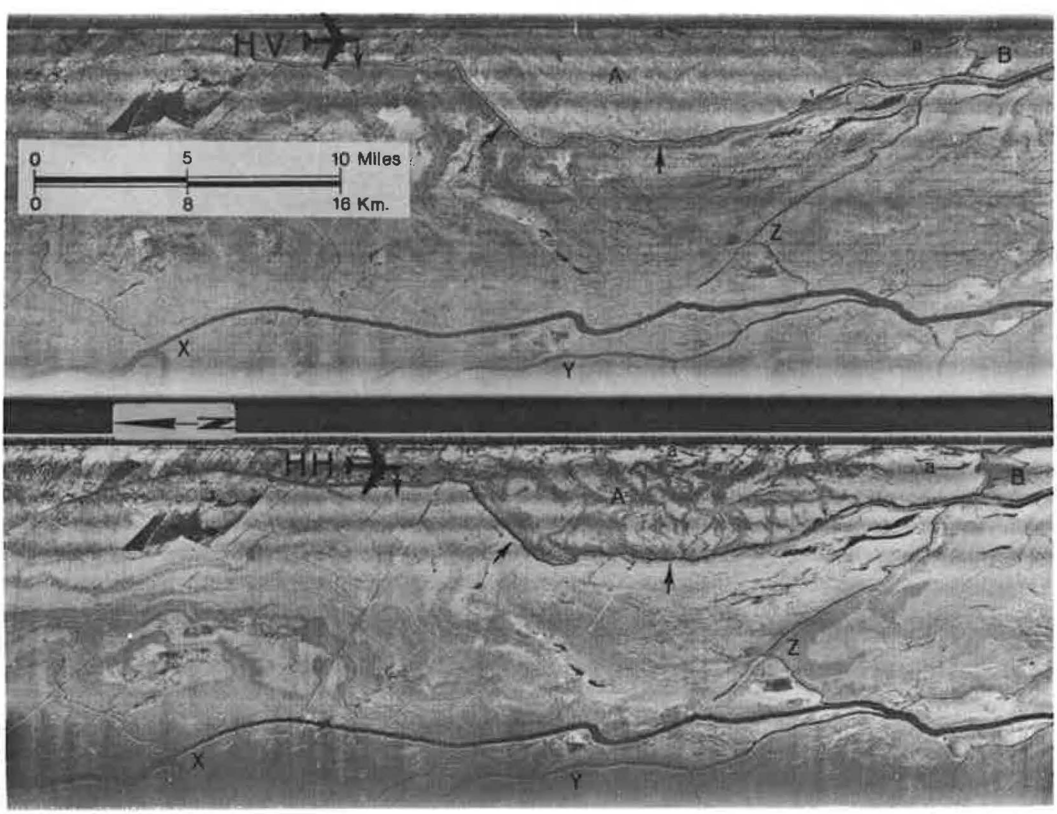


Figure 11. Like-polarized (HH) and cross-polarized (HV) radar imagery along Atchafalava River, southwest of Baton Rouge, Louisiana (light-toned areas on HH image are true swamps, and dark-toned areas are better drained).



of surface materials (including moisture content), surface configuration (roughness) relative to wavelength, and relief relative to the depression angle.

Systems available to users at this time are high-frequency systems (K- and X-band) with which no significant penetration should be expected. Limited studies show that, with the long wavelength radars (P-band), some penetration will be obtained even though the effect is somewhat clouded by the smoothing of surfaces (resulting in low return) that appear rough to short wavelength radars (1). However, an important future potential is indicated. Resolution is at present limited in nonclassified systems at approximately 30 ft. Whether improvement in resolution would be desirable depends on the nature of the survey, as, for example, a reconnaissance or "first-look" survey (for which radar is best suited) that requires no better resolution than that provided by existing commercial systems. Transmission polarization can be controlled in some systems although the effect is not fully understood. However, simultaneous recording of like- and cross-polarized return has proved to be advantageous to a limited degree not only in the discrimination of vegetation, soil moisture, and rocks but also in the definition of cultural features such as transportation and communication nets (7).

Depression angle is normally fixed. Ideally, low-relief features in flat terrain are most pronounced at near grazing angle (far range) and, if linear, oriented parallel to the direction of flight (10). In areas of high relief, however, the maximum data content is in the near range where shadowing is reduced to a minimum.

Although depression angle is not variable, optimum coverage of a given terrain unit can be obtained by variations in elevation (11). Shadow zones can be completely eliminated if an area is looked at from 2 different directions. Flight-line orientation is especially critical in low-relief terrain. Parallelism of the flight line with the orientation of linear topographic trends maximizes the display; the expression of such features diminishes as the look direction approaches parallelism with the linear trend.

Surface parameters, are, of course, not subject to control. Maximizing return must result primarily from system parameters adjusted insofar as possible and, if feasible, flights conducted during periods of vegetation defoliation.

Radar must be considered primarily a reconnaissance tool; it is of great value in planning a Pan American highway where aerial photography and ground surveys are not feasible but of very little value in planning highway networks within the limits of the 48 states. However, the potential of broad-scale, rapid, non-weather-dependent data acquisition suggests radar as an ideal tool for updating existing maps and for rapidly assessing communication network damage resulting from natural catastrophes such as floods, hurricanes, and earthquakes.

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