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Analysis of Two Seasat Synthetic Aperture Radar Images of an Urban Scene

Images from two orbits with different look directions can be registered and subtracted from one another with the resulting "difference image" highlighting those features which are direction sensitive.

ABSTRACT: *One of the major problems dealing with the interpretation of data obtained by satellite borne synthetic aperture radar* (SAR) *is the dependence of the backscatter of microwave energy on the orientation of the imaged features. This study concerns one scene of Southern California dominated by an urban area and imaged during both ascending and descending Seasat orbits. Because these orbits intersect at angles of less than 90°, there is no possibility that the normally rectilinear patterns of non-isotropic man-made scatterers (e.g., streets, buildings, bridges) will be imaged at look-directions which would provide very high returns from each orbit. Registration of digitally processed* SAR *data from these two orbits was conducted. The difference between the strength of the backscatter for the two was calculated and the resulting difference displayed as a continuous tone image. Thus, for the resulting image, very light or very dark tones denote areas where the strength of the backscatter from the two input images was quite diverse, whereas mid-tone grays indicate that the two input images were quite similar. The application and utility of this approach of using Seasat* SAR *data to identify areas where high radar returns are the result of the orientation of the feature relative to the radar antenna and not a characteristic of land use or ground cover is discussed in this paper. It is concluded that this approach may be an acceptable method for identifying those areas where orientation is the major cause of exceptionally high radar backscatter.*

INTRODUCTION

IT HAS BEEN pointed out that the look-direction of a radar remote sensor is of primary importance with respect to the backscattered signal received from oriented and faceted objects. Examples include geologic lineaments (Ford, 1980; Berlin *et al.*, 1980), sand dunes (Blom and Elachi, 1981), urban scenes (Bryan, 1979), and row crops (Ulaby and Bare, 1979). These and other examples of the strong returns due to the relative orientation of the Seasat SAR sensor antenna and specific targets are illustrated in Ford *et al.* (1980).

Because such returns tend to dominate and often saturate a scene, it appears that little can be done to aid the interpretation, especially if the interpretation is to be conducted in the automatic or interactive mode using the digital (but uncalibrated) data. However, even though these data are uncalibrated, they can be employed for detailed analysis as shown by Fasler (1980) in his texture studies and in the signature analysis studies by Clark (1980). In addition, Henderson (1980) and Wu (1980) have used similar Seasat SAR digital data for land-use studies.

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Study Site and Data Sets

To test an approach to identify those returns in the Seasat radar which are primarily a function of the orientation of the radar antenna and the Earth surface feature, an area which had been imaged during both ascending and descending satellite orbits was selected. The selected site straddles the boundary between Orange Co., California and Los Angeles Co., California and is centered approximately on the city of Costa Mesa, as shown in Figure 1. The sets of data obtained during Seasat orbit 351 (ascending, 20 July 1978) and orbit 1291 (descending, 25 September 1978) were selected. The ascending orbit 351 image is shown in Figure 2 and the descending orbit 1292 image is shown in Figure 3. These data were digitally correlated and registered to a geographic grid using a series of tie points and procedures described in Bryant and Zobrist (1977) and Clark (1980). Some basic details concerning the nature of the Seasat satellite and the resulting SAR data are available in Thompson and Laderman (1976), Jordan and Rodgers (1976), and Ford *et al.*, (1980). Earlier work describing some of the problems encountered with Seasat SAR data is described in Henderson (1980) and Wu (1980).

Of special importance is that the original sensor and the entire data transmission and processing stream were *not* calibrated. Consequently, a rigorous mathematical analysis would be on dubious philosophic grounds, as is pointed out by Schanda (1979).

Following the original registration of the two SAR data sets, one data set was subtracted from the other. This difference was multiplied by one-half and the value of 128 was added to the result (thereby avoiding any negative values); that is,

Difference image = 0.5 × (Input 1 - Input 2) + 128
in which: Input 1 is the image from orbit 351
Input 2 is the image from orbit 1291

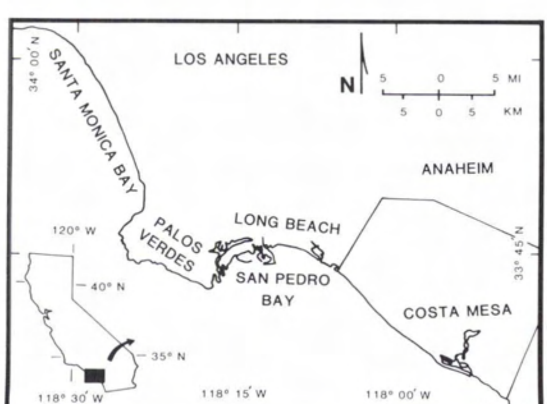

Fig. 1. Location map of the study area and environs. The study area is shaded and centered on the community of Costa Mesa, California.

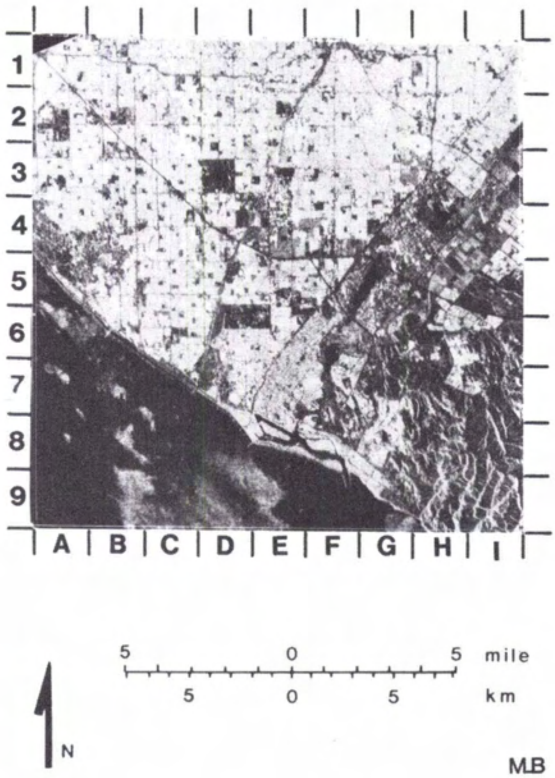

Fig. 2. Digitally correlated Seasat data from ascending orbit 351, 20 July 1978. See text for discussion of selected features.

In this procedure the resulting difference image has a final value of between 0 (no data, or black) and 255 (saturation, white).* Figure 4 is a contrast stretch of the original difference image so that 0.5 percent of the values were set at 0 and the same amount set at 255. Thus, the contrast of the difference image was increased and some features were enhanced on the visual image (Figure 4).

Analysis

The first stage of the analysis of the difference image was to construct a series of land-use maps at the scale of 1:24,000 based on (a) ground check, (b) high altitude (60,000 ft) color infrared aerial photography collected on 2 September 1979 at a scale of 1:120,000, and (c) U.S. Geological Survey (USGS) land-use maps (USGS, 1979). The land-use classification used was as presented in Anderson *et al.* (1979). An example from the resulting map set is shown in Figure 5.

* An alternative procedure would be to display the absolute difference of the two images as a continuous gray tone. Thus, areas of no difference would be dark, those of maximum difference would be light. Such an image might be slightly easier to interpret.

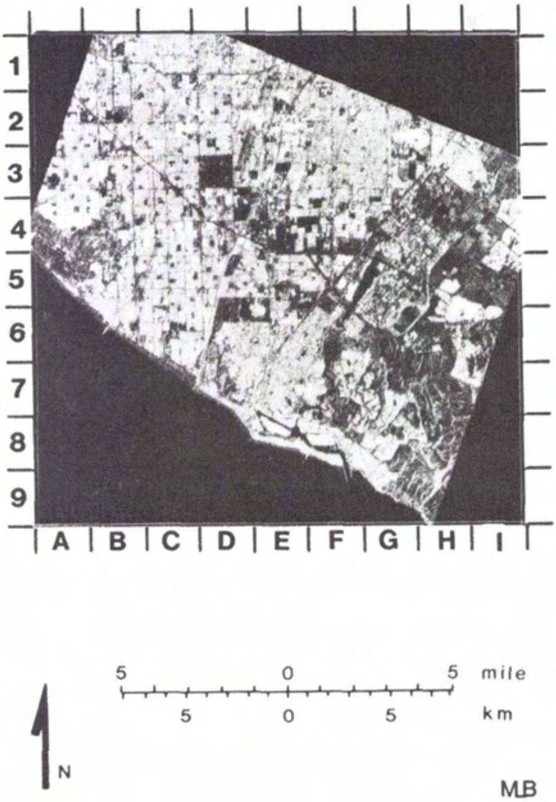

FIG. 3. Digitally correlated Seasat SAR data from descending orbit 1291, 25 September 1978. See text for discussion of selected features.

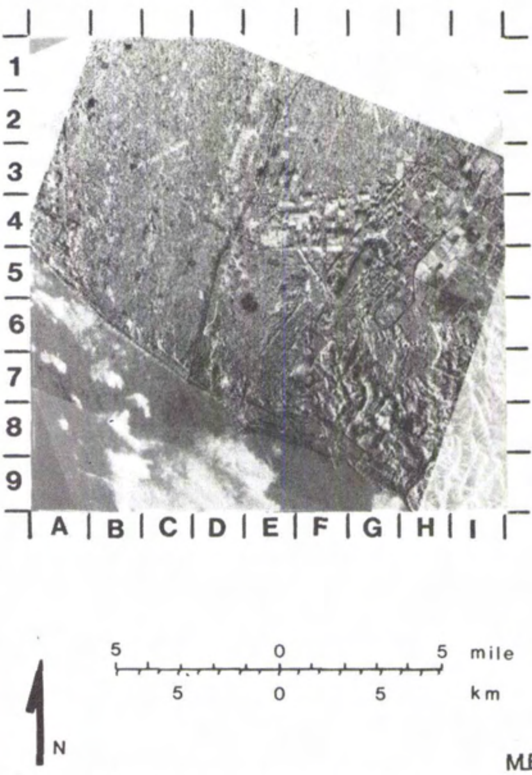

FIG. 4. A contrast stretch of the difference between Figure 2 (orbit 351) and Figure 3 (orbit 1291). This procedure tends to enhance some of the identified features to facilitate their visual interpretation.

When studying the original data sets (Figures 2 and 3), several features, notably Mile Square Park (Figure 2, dark square at location 3-D) and the Orange Co. (John Wayne) Airport (Figure 2, elongated dark area, 5-G), are immediately apparent. A large dark-toned block in the south central portion of the image (Figure 2, 5 and 6, D and E) is also clearly visible. These three features, together with numerous others, consist of smooth surfaces (at the L-Band 23 cm wavelength). Thus, their response to the radar is as specular reflectors and they yield extremely low backscatter to the antenna. These features are not oriented; the return to the sensor is essentially the same for each of the two Seasat SAR look directions. As noted in Figure 4, features of this nature will have medium grey tones on the difference image.

Likewise, features which have consistently high returns on the two input images, for example, the majority of the residential areas in the east-central portion of the image (e.g., Figure 2, 5-C) or in the north central portion (Figure 2, 2-G) will, on the difference image, have similar tones within the medium grays. In these latter residential areas, the streets are all oriented north-south, or orthogonally. Because the bearing of the spacecraft ground track at these latitudes (approx. 34°N) is N22W for ascending passes and S22W for descending passes, the orientation of the features (primarily building walls) relative to the spacecraft look direction is greater than the empirically defined 10° to 15° necessary for the orientation to have a decided effect on the radar signal backscatter (Ford, 1980; Bryan, 1979; Demarcke, 1980).

The case has thus been made that features which have provided very similar tones on the two Seasat passes will appear as the medium gray tones on the difference image. Features which appear as decidedly different tones on the input images will appear as either light or dark tones on the difference image. These are the features which need to be studied in considerable detail prior to any attempt to do land-use classification based in part or in whole on the Seasat data. Several examples observed on the difference image (Figure 4) will be discussed.

One area of low tone on Figure 4 is located at the junction of 5-E and 6-E. This round feature appears as a small indistinct medium bright spot on Figure 2 and as a very bright, large and angular

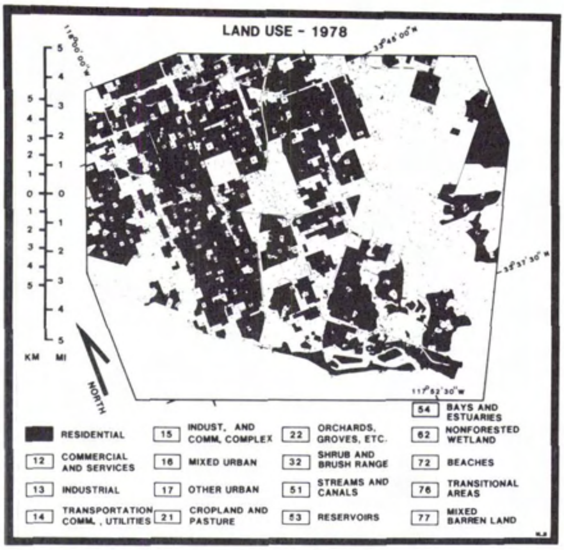

FIG. 5. Example of the series of land-use maps constructed for this study. This map illustrated the distribution of the residential areas. In the northern and western portions of the study area, many of the small blocks of non-residential (white) land use are neighborhood schools, which are classed as "commercial and services." Compare with the radar data and note the independence (function of the orientation) of this land-use type with respect to the radar look direction.

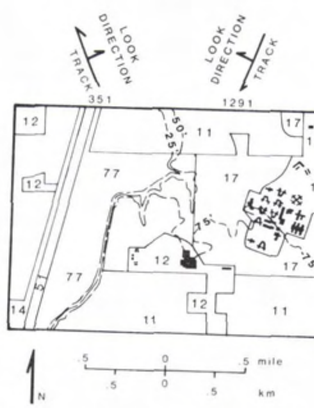

FIG. 6. Land-use/land-cover map of the area around Fairview State Hospital (Figures 2, 5 and 6, D and E). The hospital complex is the set of buildings at the right center. The long arrows indicate satellite direction during the identified orbits; short arrows indicate the look direction of the radar. Numbers refer to the land-use classification from Anderson *et al.* (1976), viz.: 11 = residential; 12 = commercial and services; 14 = transportation, communications, and utilities; 17 = other urban or built-up land; 51 = streams and canals; 77 = mixed barren land. Dashed lines are topographic contours. Figure centered at approximately 33° 39′ N; 117° 56′ 30″ W.

spot on Figure 3. The feature is the Fairview State Hospital, a complex of multi- and single-story buildings which, in total, cover slightly more than 100 acres (not including grounds) (Figure 6). The interesting aspect of this complex is that the buildings are not oriented true north-south; rather, most are oriented approximately S20W, which is nearly parallel to the descending track of Seasat. On the ascending pass (orbit 351, Figure 2), the orientation of those walls is not orthogonal (or nearly orthogonal) to the radar look direction. This situation is exactly the same as previously noted for the Disney Studio and Providence High School area of Burbank, California on aircraft L-Band radar data (Bryan, 1979). Adjacent to and west of the hospital is one of the large vacant land areas which was mentioned earlier in the discussion.

The land use here is a golf course near the hospital (No. 17, Figure 6) and barren land in the more western portion (No. 77, Figure 6). We note, however, that there is at the far western end of the vacant area a bright linear feature which appears prominently on Figure 4 in the north central portion of location 6-D. This is a small bluff which has a rise of 70 ft in a run of 160 ft, giving a slope of approximately 23°. This number is especially important because it is within 2° of the average incidence angle of Seasat radar for a flat surface. (The depression angle of Seasat varies from 67° in the far range to 73° in the near range (Sabins *et al.*, 1980).) Consequently, for this inclined surface, the face of the slope will be nearly perpendicular to the incoming radar beam and will provide an extremely strong return to the radar antenna. We note in the northern portions of Figure 6 that the orientation of the feature is approximately N72W. There is still a sufficiently strong return to provide the bright image on orbit 351 (Figure 2). In Figure 3 (orbit 1291) however the slope is a *dark* curvilinear feature. The resulting difference between the two is the bright curvilinear feature seen in Figure 4. If, for example, we were only to study the data from orbit 351, it could easily be concluded that this feature is a portion of some railroad track, freeway, bridge, or utility line. This interpretation would be dubious because, to yield the extremely bright return in the urban scene, such a cultural feature, should be oriented within approximately 10° to 15° from normal to the look direction of the radar antenna. Such is obviously not the case. If we include the data from the descending orbit, the slope appears as a dark curvilinear feature, and this would generally be the case of both natural slopes (due to a shadow or low backscatter) and also for railroads if the satellite ground track is not approximately parallel to the railroad, due to the generally smooth and broad right-of-way through urban areas. Hence, although the analysis of the two images simultaneously does not definitively identify the feature as a slope, the analyst, through the use of the difference image, has been alerted to differential returns which are sensitive to the orientation of the radar antenna. These areas should have a more detailed study. Note the weak returns from the Santa Ana River (area 51, Figure 6) on orbit 351 and the strong return from the right bank in the image from orbit 1291. This high return is a result of a combination of the slope and the orientation of the river bank relative to the radar look direction. (See Schanda (1980) for a similar discussion from other Seasat radar images.) Very similar arguments are valid for the area on the west side of the airport (Figure 2, 5 F and G) where the building orientation in an industrial park and light manufacturing area is very near to that of the spacecraft ground track on descending orbit 1291. Also, for the residential building (condominia) at location 5 H and I in Figure 2, a difference in return from the two Seasat data sets is noted. Here, however, the difference is not as pronounced because many of the buildings in the entire complex are oriented at a variety of angles, thus both reducing the strength of the return during orbit 1291 and enhancing it during orbit 351.

In addition to alerting the user to these areas which are sensitive to Seasat radar antenna pointing direction, the difference image has been proven to have an unexpected advantage, that is, to enhance some features which would otherwise be unnoticed. Looking in the northern portion of Figure 4 (location 3-C), a broad white linear feature oriented N60E with a length of approximately 2 miles is noted. This feature is surrounded by several neighbourhoods and land-use classes and is nearly invisible on the data of orbit 351. The feature is the East Garden Grove Wintersburg Channel. If we consider the channel as a lineament, in the geologic sense, we note that it is parallel to the look direction of the ascending orbit and thus, by analogy with the geologic lineaments (Ford, 1980), it is suppressed (when the radar antenna is oriented along the length of the feature). However, it does appear, but only faintly, in the data from orbit 1291. The difference picture clearly portrays the location of this straight portion of the channel. By reversing the analogy, therefore, it may be suggested that the approach used in this paper may have meaningful application to the study of geologic lineaments, an area receiving considerable attention by the radar remote sensing community.

Conclusion

Because Seasat operated in only one mode (L-HH), several problems which are detrimental to the use of the radar data secured by the satellite have arisen. One of the major ones is that of the orientation of the features. L-HH data from any imaging radar system can cause such features to be enhanced or suppressed, or in some cases (e.g., when linears are parellel to the look-direction of the radar) to essentially disappear from the scene. One distinct advantage that Seasat has had is that many scenes were viewed from both ascending and descending orbits. Unfortunately, because of the short operating period, numerous scenes were not so favored. Because the satellite was not polar orbiting, the look-directions of the radar on the two basic orbits (ascending and descending) were neither in the same direction, orthogonal to, nor opposite to one another. Herein is the crux of the technique to identify those features within a given geographic region which were imaged from two directions by Seasat SAR and are sensitive to radar orientation. It has been demonstrated that images from the two orbits with different look directions can be registered and subtracted from one another with the resulting "difference image" highlighting those features which are direction sensitive. The technique is dependent upon a precise registration.* However, once that has been achieved, the subtraction technique is relatively straightforward. Texture studies and signature analysis studies provide additional and complementary methods for alleviating this perplexing problem encountered in the analysis of Seasat SAR data.

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* This problem is under considerable study at the present time; registration of SAR data becomes especially more difficult as the local topography on the scene increases.

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