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RADAR SIGNAL RETURN FROM NEAR-SHORE SURFACE AND SHALLOW SUBSURFACE FEATURES, DARIEN PROVINCE, PANAMA

CRES Technical Report 177-39

Bradford C. Hanson
Louis F. Dellwig

August, 1973

Supported by:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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CONTRACT NAS 9-10261

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ABSTRACT

Initial analysis of AN/APQ-97 radar imagery over eastern Panama was directed toward extraction of geologic and engineering data and the establishment of operational parameters. Subsequent investigations emphasized landform identification and vegetation distribution, accompanied by an analysis of the parameters affecting the observed return signal strength from such features.

One subject area described but not analyzed by previous investigators was near-shore ocean phenomena. Tidal zone features such as mud flats and reefs are more vividly expressed in the near range whereas they are subdued or non-detectable in the far range. Falloff is also observed within surf zones oriented parallel to range direction. Whereas surface roughness in large part dictates the nature of reflected energy (specular or diffuse), depression angle also appears to be an important factor in return signal intensity for tidal flats, reefs, and surf zones. In surf zones changes in wave train orientation relative to look direction, the slope of the surface and the physical character of the wave must be considered. Furthermore, the establishment of the areal extent of the tidal flats, distributary channels, and reefs appear to be practical only in the near to intermediate range under minimal low tide conditions.

INTRODUCTION

Depending on the relative roughness of the terrain, the radar return signal from vegetation, soil, rock, etc. is generally greater than the return signal from water. When water bodies such as lakes and rivers are imaged, they act as near-specular reflectors and as such normally direct most the transmitted energy away from the receiver. Hence imaging radar systems can be effectively utilized in mapping shorelines, etc., but the presently available systems are only of limited value for use over the world's oceans. However, with certain limitations, qualitative monitoring of near shore surface and shallow subsurface coastline features does appear to be practical using the present commercial imaging systems.

RADAR SIGNAL RETURN

Radar signals are normally returned from the terrain to the receiver by a scattering process (reradiation) with the intensity of radar return (signal strength) from the terrain determining the relative degree of brightness on the radar image. Of the parameters that influence radar return for any given system of fixed polarization and frequency, namely complex dielectric constant, incidence angle, and surface roughness, the latter two control return from tidal flats and reefs with incidence angle under certain conditions.

The local angle of incidence, θ, is the angle formed between an impinging beam of radar energy and a perpendicular to the imaged surface at the point of incidence (Figure 1A). The angle between a line from the transmitter to a point on the terrain, and a horizontal plane passing through the transmitter is the depression angle (α). The geometric parameters of radar imaging systems are such that on flat terrain along the swath width of an area imaged (near to far range), there is a continuous change in the angle of incidence from a maximum at far range to a minimum, near normal incidence, in the near range. This relationship is modified with the introduction of a slope to the surface (Figure 1B).

The energy incident on the terrain surface is "specularly" and "diffusely" reflected in varying proportions depending upon the roughness of the terrain. Surface roughness is a geometric property of the terrain; it is not an absolute roughness, but

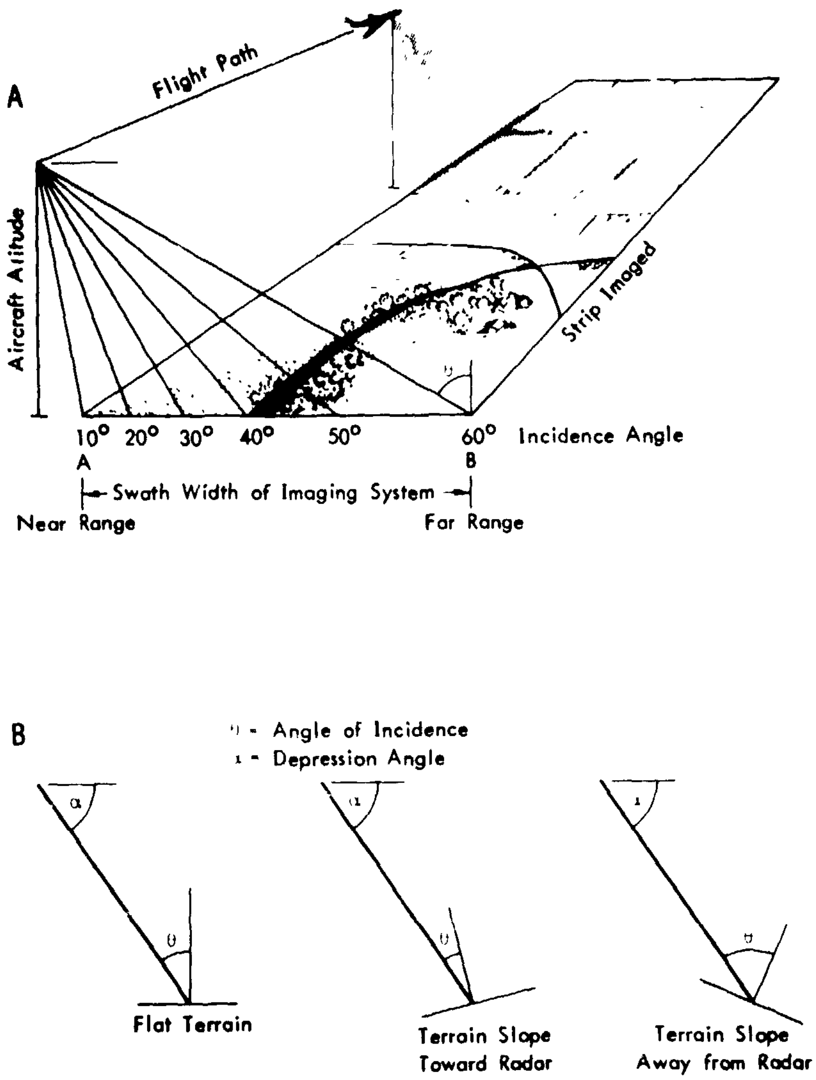


FIGURE 1. THE RELATIONSHIP BETWEEN ANGLE OF INCIDENCE, DEPRESSION ANGLE, AND TERRAIN SLOPE.

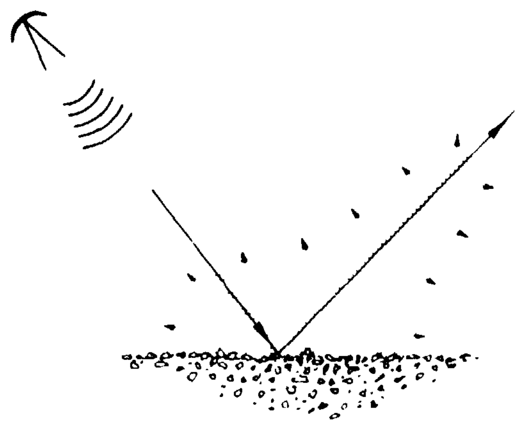
rather roughness expressed relative to wavelength units. Surfaces with micro-relief much less than a wavelength appear smooth (no return) whereas surfaces with micro-relief on the order of a wavelength or more, appear "rough". A smooth surface is characterized by specular or mirror-like reflection with the angle of incidence determining the orientation of the reradiation pattern (Figure 2A). Under these conditions the reflection obeys Snell's Law (angle of incidence equals angle of reflection) with virtually all the reflected energy being contained within a small angular region about the Snell's Law angle. Hence for a relatively smooth horizontal surface, strong backscatter is recorded only near vertical incidence. This would account for the observations by numerous investigators who have noted a strong radar return in the extreme near range (maximum depression-minimum incidence angle) for water bodies which span the entire width of the radar image. The wavelength (0.87 centimeters)—scale roughness on the ocean—being relatively small, most energy should be reflected away from the radar for incident angles exceeding 10 to 15 degrees as is demonstrated in this AN/APQ-97 image (Figure 3.1A).

If surface irregularities are a significant fraction of a wavelength, more energy will be scattered at angles other than near specular (Figure 2B). Although, any given moderately rough (relative to wavelength) horizontal surface will appear smoother at angles near grazing incidence, the intensity of radar return (backscatter) increases with decreasing incidence angle. However, as a given surface becomes excessively rough (in terms of wavelength), backscatter becomes independent of incidence angle.

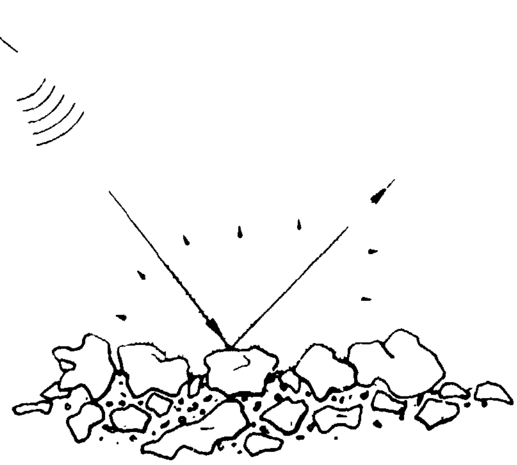
THE TIME FACTOR

Differences in the degree of radar return have been observed for nearshore features such as shell reefs, tidal flats, and surf zones along both Atlantic and

Note: The full swath width (approximately 20 km) is presented in each appropriate figure (3, 4, 5, 6, 9) in order to show the position of the near shore features relative to near ($\alpha = 78^{o}$) and far ($\alpha = 15^{o}$) range. In all such full swath width illustrations the near range is at the top of the page. Each full width swath is accompanied by an enlargement of the critical area.



(A) NEAR-SPECULAR REFLECTION



(B) DIFFUSE REFLECTION

FIGURE 2. CONE OF RERADIATION (STIPPLED AREA) FOR SPECULAR VERSUS DIFFUSE REFLECTION.

FIGURE 3.1

FIGURE 3.2

Surf zone, Bahia Anchucuna, Caribbean coast, Panama

FIGURE 3.3

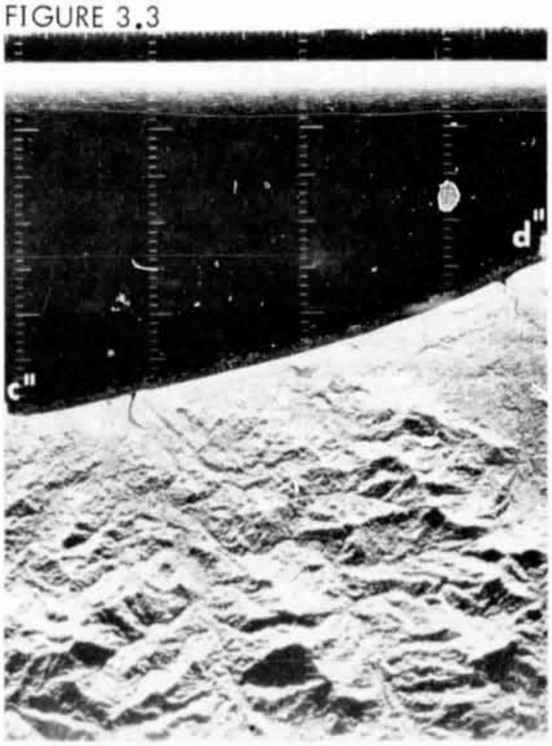


FIGURE 3.3

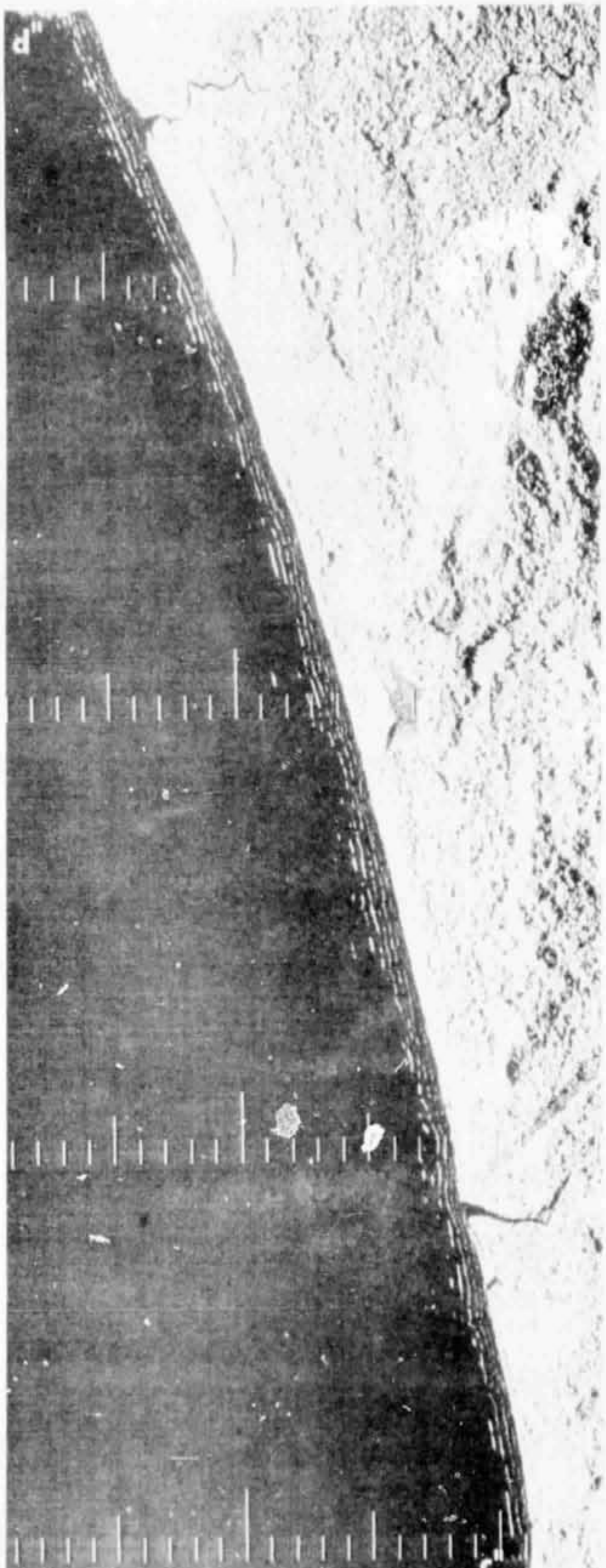
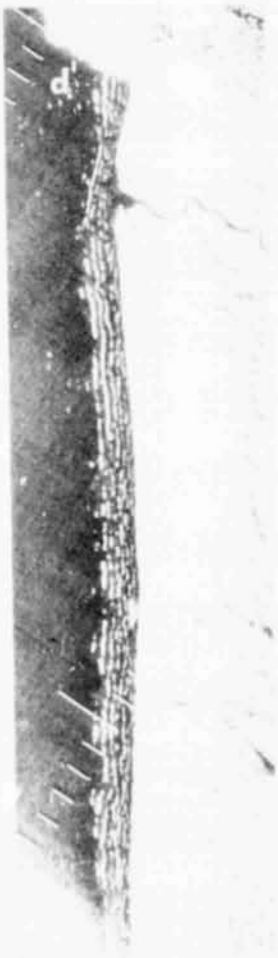


FIGURE 3.2



Pacific coastlines of Darien Province, Panama. Tidal 'uctuations directly control the aerial extent of tidal flats and shell reefs and indirectly control the position of the surf zone. Therefore, when comparing different image orientations of the same area, the time lapse factor is of extreme importance.

The aircraft platform for the AN/APQ-97 Ka-band (.86 cm wavelength) radar for RAMP (Radar Mapping in Panama) project was the YEA-3A. Project records indicate that total air time per day over Panama never exceeded 4 hours. Moreover, a new unexposed roll of film was installed for each flight, the exposed film being removed on landing. Air speed averaged 480 to 560 km/hr. The maximum width of the Isthmus for which coverage was flown is approximately 160 km. Thus fligh time from the Atlantic to the Pacific and return, allowing for turn-around and re-positioning time, would rarely exceed 45 minutes.

All images utilized in comparative analyses are from a single flight. Calculating from the above factors the time lapse between compared images is estimated as not to exceed 30 minutes. Thus the tidal factor appears to be insignificant.

SHELL REEFS AND TIDAL FLATS

In Panama shell reefs are narrow, linear accumulations of shell ell fragments oriented perpendicular or at a high angle to the shoreline (Le 1971). Generally reefs are detached from the coast but may extend back into the mangrove swamps. Their width is on the order of 100 meters with an average length of approximately 1 kilometer. Incidence angle appears to be the dominant factor governing return intensity for the reefs located along the Pacific coast of Darien Province within the Gulf of San Miguel (Figure 4.1a, 4.2a). Note also that distributary patterns within the mud flat areas are detectable onl, at near range (Figure 4.1b, 4.2b).

Tidal flats are generally non-organic, fluviomarine accumulations developing in shoal areas which are protected from strong wind and current action (Lewis, 1971). They are believed to represent the first stage in the development of mangrove swamps and exhibit a slight undulating surface devoid of vegetation. These are areas of high radar return at near range incidence which exhibit a more subdued return intensity in the far range (Figure 5.1a). At similar incidence angles, changes in radar look direction do not appear to have an effect on the return intensity, areal extent, nor

FIGURE 4.1

FIGURE 4.2

Shell bars, Golfo de San Miguel, Pacific coast, Panama

detectability of the tidal flat (Figure 5.2a). Thus changes in intensity of radar return from tidal flats and shell reefs appear to be directly proportional to changes in depression angle. Small depression angle differences (Figure 5.2b) effect little change in return intensity; this is in contrast with larger differences which result in easily recognizable contrasts (Figure 5.3, 5.4).

SURF ZONES

Falloff in surf zones is exemplified at Bahia Anchucuna on the Caribbean side of Darien Province (Figure 3.1, c-d). If the apparent falloff actually is the result of a natural decrease in the areal extent or activity in the surf zone, an area of low return resulting from a low depression angle should not appear as an area of high return at a greater depression angle (Figure 3.2). Similarly, there should be an observable return difference if the range of incidence angles was relatively small (Figure 3.3) for the entire surf zone. Such is not the case.

Note however, that the surf zone located in the vicinity of the Rio Atrata where it empties into the Gulf of Uraba (Figures 6.1, 6.2), exhibits a high return intensity regardless of range; in fact the return appears better defined in the far range. In the areas previously evaluated with respect to falloff, the surf zone was oriented essentially parallel to the radar look direction. However, the surf zone in this area is oriented approximately 45° to the look direction; and in the near range (Figure 6.1) the back of the wave, and in the far range the front of the wave (Figure 6.2) has been imaged.

In imaging, the incidence angle continuously changes along the swath width (Figure 1A). The effective incidence angle is at a maximum for the far range (minimum reradiation) and at a minimum on approaching normal incidence in near range (maximum reradiation) for a horizontal surface. If surface slopes are inclined at an angle toward the imaging radar and the effective angle of incidence decreases (with increasing terrain slope angle) to a point where the angle of incidence (θ) equals zero, normal incidence (maximum reradiation) is the result (Figure 1B). Conversely, if terrain slopes are inclined away from the imaging radar, the angle of incidence increases (with increasing terrain slope angle) to a point where grazing (minimum reradiation) is the result (Figure 1B). Thus it should be possible to obtain

FIGURE 5.1 Tidal flats, Bahia de Panama, Pacific coast, Panama

FIGURE 5.2 Tidal flats Golfo de San Miguel, Pacific coast, Panama

FIGURE 5.3

Tidal flats, Pacific coast, Panama

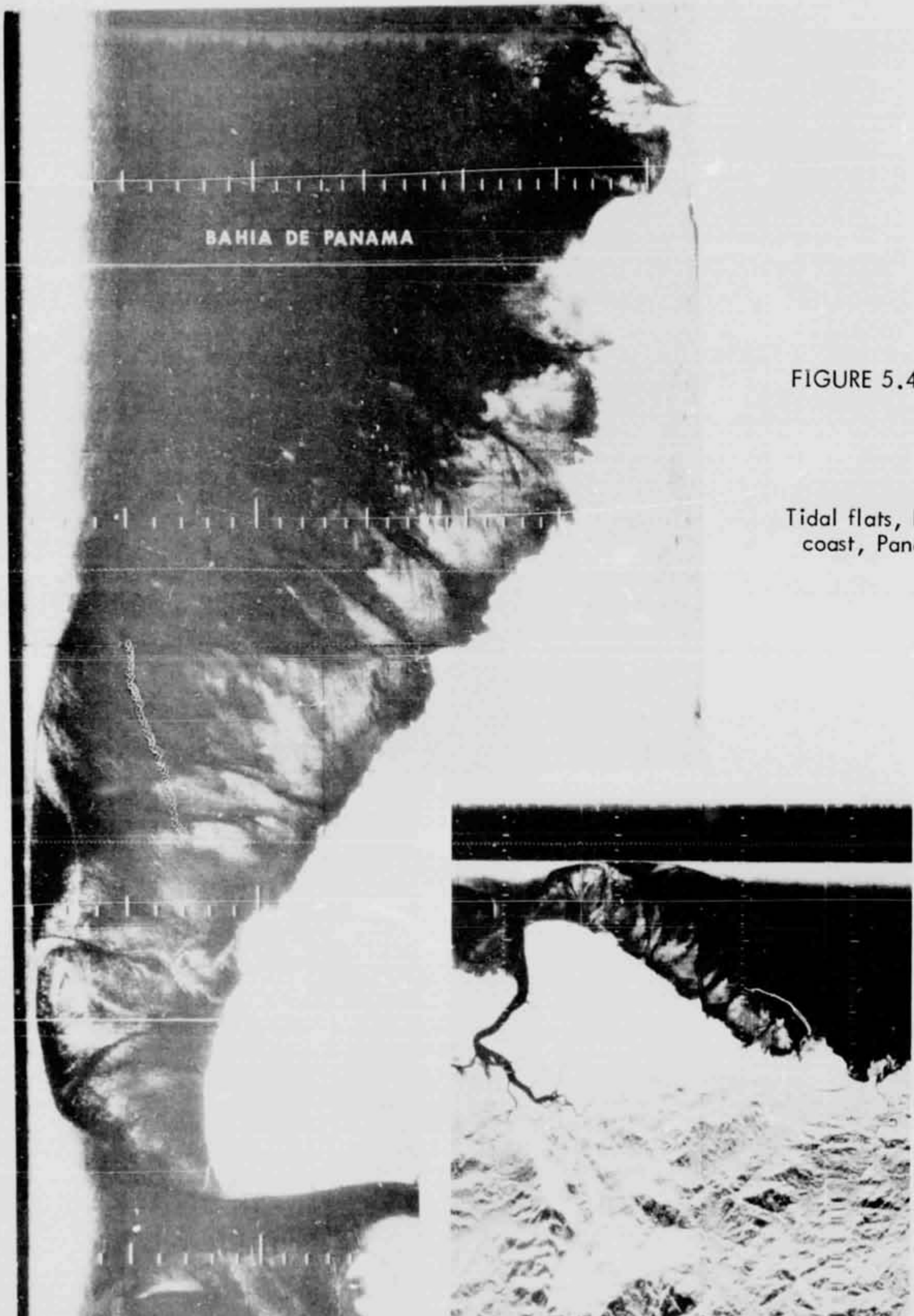


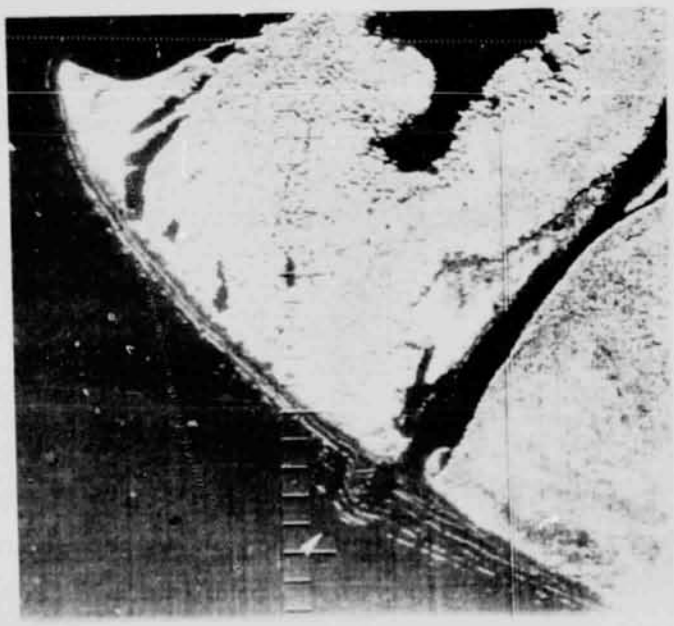
FIGURE 5.4

Tidal flats, Pacific coast, Panama

FIGURE 6.1

Atrato Delta, Golfe de Uraba, Caribbean coast, Colombia

FIGURE 6.2



maximum reradiation in the far range by increasing the terrain slope angle to a point where the impinging radar beam is normal to the slope of the surface. Recognizing the shortcomings of imagery evaluation without the benefit of surface data, further comparisons appear to substantiate the suggestion that wave geometry is an important factor. At Point A (Figures 7.1, 7.2), what is apparently a surf zone pattern is inclined at approximately 45° to the impinging radar beam, in both cases the back of the wave being imaged. In Figure 7.1, A in an intermediate range position, the return appears to be relatively high; whereas in Figure 7.2, the return is essentially negligible. Several parallel zones (B) also appear in the intermediate range image but do not appear in the far range position. At Point C, in the near range position (7.1), the breaker pattern is rather ill-defined when imaged from the back side but in the far range (7.2) when imaged from the front side is precisely defined.

Unfortunately, little data for a return from water, foam and spray are available. A recent paper by Shemdim, et al. (1972) states that drops above the water surface will not be detected (X-band radar), thus discounting a potential of return from the spray of breaking waves. In the study of wave patterns from other imagery, it has been suggested by some that the return from the breaking waves is essentially a return from foam. Without the available surface data, these conclusions are reached only on the basis of pattern, a pattern which is subject to alternative interpretations. Assuming that passive microwave radiometer antenna temperatures are inversely proportional to radar return, based on the work of Edgerton and Trexler (1970) (Figure 8), one should expect that reflections should be at a maximum outside of the zone of foam and in the zone of turbulence. Sparse as the data may be, the suggestion is that the bands of high return are wave surface rather than foam or spray dependent. It is obvious that surf zones offer great potential for future investigation.

CONCLUSIONS

Thus, although surface roughness may be the dominant control of reflection (specular versus diffuse) on land surfaces; depression angle coupled with look direction and slope angle are the significant influencing factors in return variations

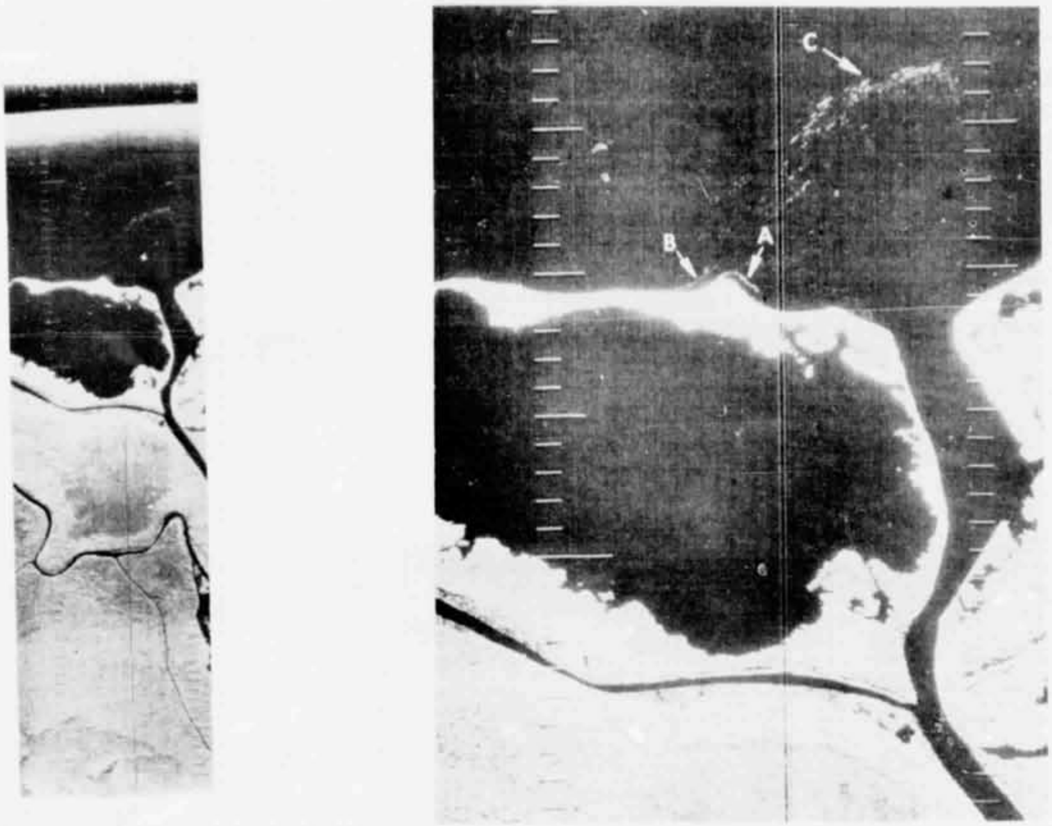
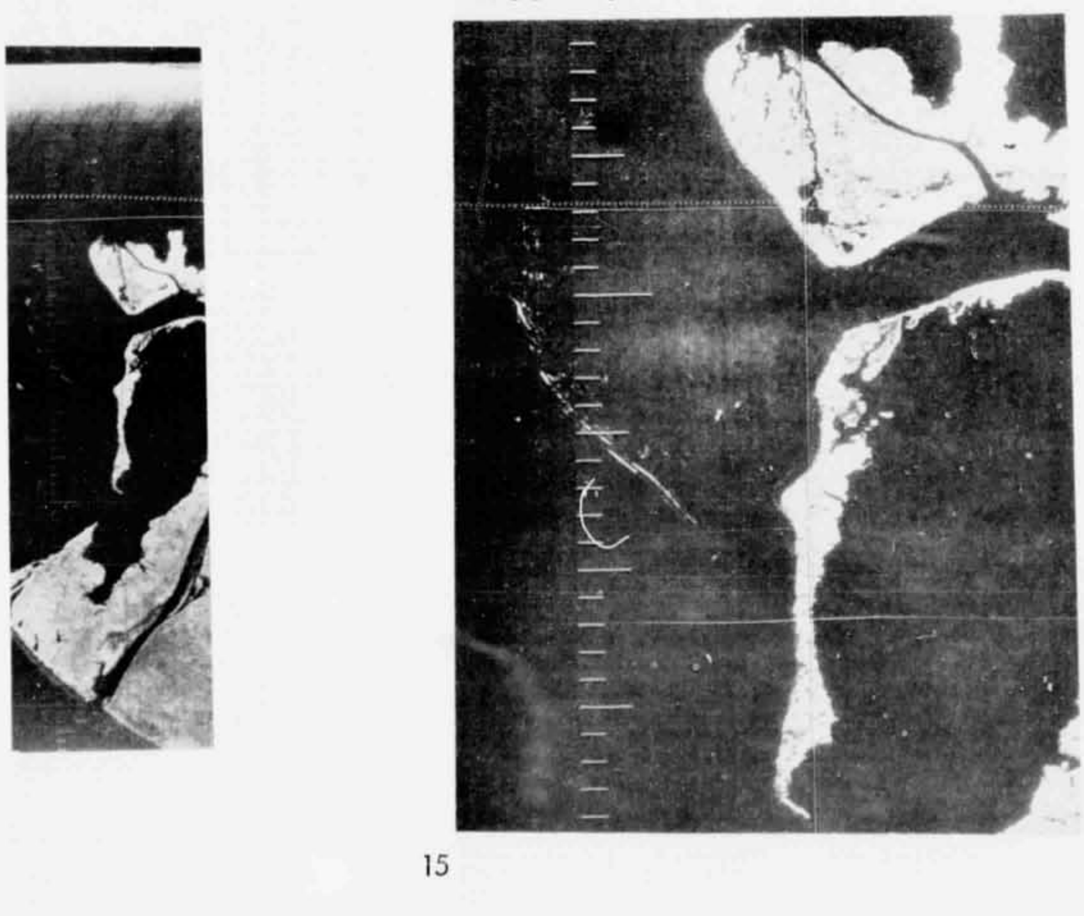


FIGURE 7.1

Atrato Delta, Golfe de Uraba, Caribbean coast, Colombia

FIGURE 7.2



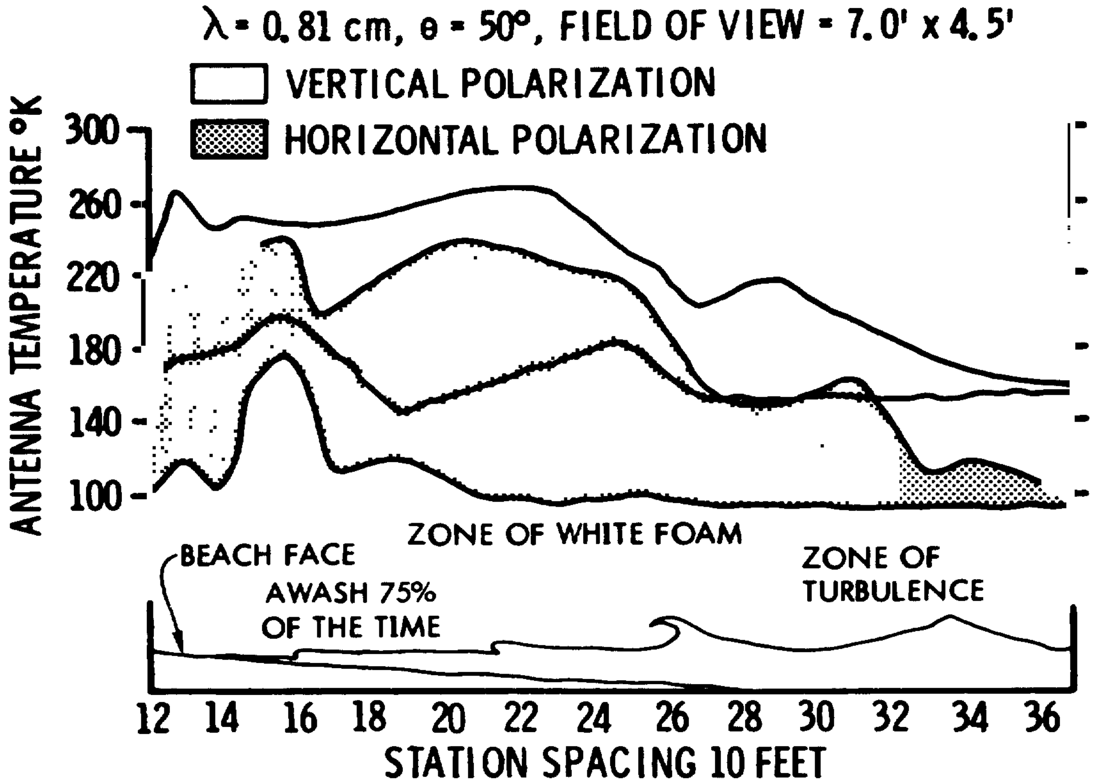


Figure 8. Traverses along Newport pier showing maximum and minimum vertical and horizontal polarization antenna temperature.

observed for shoreline reefs and tidal flats and probably to some degree surf zones. Analysis of shoreline conditions demands that the significance of the effect of each of these system factors be ascertained.

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