NASA Contractor Report 156889

E83-10248
CR-156889

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R. L. Brooks

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G. A. Norcross

(E83-10248) SEASAT RADAR ALTIMETER MEASUREMENTS OVER THE FLORIDA EVERGLADES Final Report (GeoScience Research Corp.) 28 p HC A03/MF A01 CSCL 17I G3/43

N83-23653

Unclas 00248

February 1983

National Aeronautics and
Space Administration

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GeoScience Research Corporation
Route 4 Box 129
Salisbury, Maryland 21801

Prepared Under Contract No. NAS6-3117

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PREFACE

This study was performed under contract to the National Aeronautics and Space Administration (NASA), which involved a transfer of funds from the U. S. Geological Survey (USGS). We gratefully acknowledge the technical guidance provided by W. B. Krabill of NASA and W. D. Carter of the USGS.

We also appreciate the assistance of Howard Klein of the USGS in Miami, Florida, in providing recorded water level elevations in the Everglades for comparison with the satellite altimeter-derived elevations.

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INTRODUCTION

The Seasat radar altimeter was designed for open ocean tracking (Townsend, 1980). The altimeter also tracked over areas of smooth terrain including deserts, salt flats, ice sheets, ice shelves, tundra, and valleys (Brooks, 1981a) (Brooks, 1981b). The terrain studies revealed that although the onboard altimeter tracker did not respond quickly enough over most non-ocean features, the archived waveforms could be retracked to achieve accuracy levels of ±1 m.

The previous terrain studies all involved areas with little or no vegetation cover. It was not known how the Seasat altimeter would perform over areas with a vegetative cover such as swamps or tropical rain forest. Although the land itself might be sufficiently smooth for satellite altimeter tracking, would the radar pulse penetrate the vegetation? Would the surface return pulse be sufficiently strong and coherent for the tracker? If the answer were "yes", future altimeters could contribute to terrain mapping and water management studies for forest and swamp-land areas respectively.

To evaluate the Seasat altimeter performance over an area with vegetation, we sought an area with the following characteristics:

- vegetation cover
- relatively flat terrain
- ground-truth elevations.

The Florida Everglades met these requirements.

The following sections describe the Seasat groundtrack geometry, the data processing procedures, and the results.

SEASAT GROUNDTRACK

During orbit 694 on August 14, 1978, the Seasat groundtrack passed directly over the Florida Everglades in a southeast-to-northwest direction. The groundtrack, shown in Figure 1, entered the Everglades at 25°15'N latitude, 80°28'W longitude. Our data analysis started at that location, and extended to 26°52.5'N latitude, 81°19'W longitude for a total distance of 200 km.

No losses-of-lock occurred during the satellite altimeter transition from the Atlantic Ocean to the Florida Keys or from Florida Bay to the Everglades. The altimeter maintained lock across the entirety of the Everglades and continued in track mode well past the boundary of our study area.

The altimeter data rate was 10 per second, providing measurement spacing along the groundtrack at intervals of approximately 700 m.

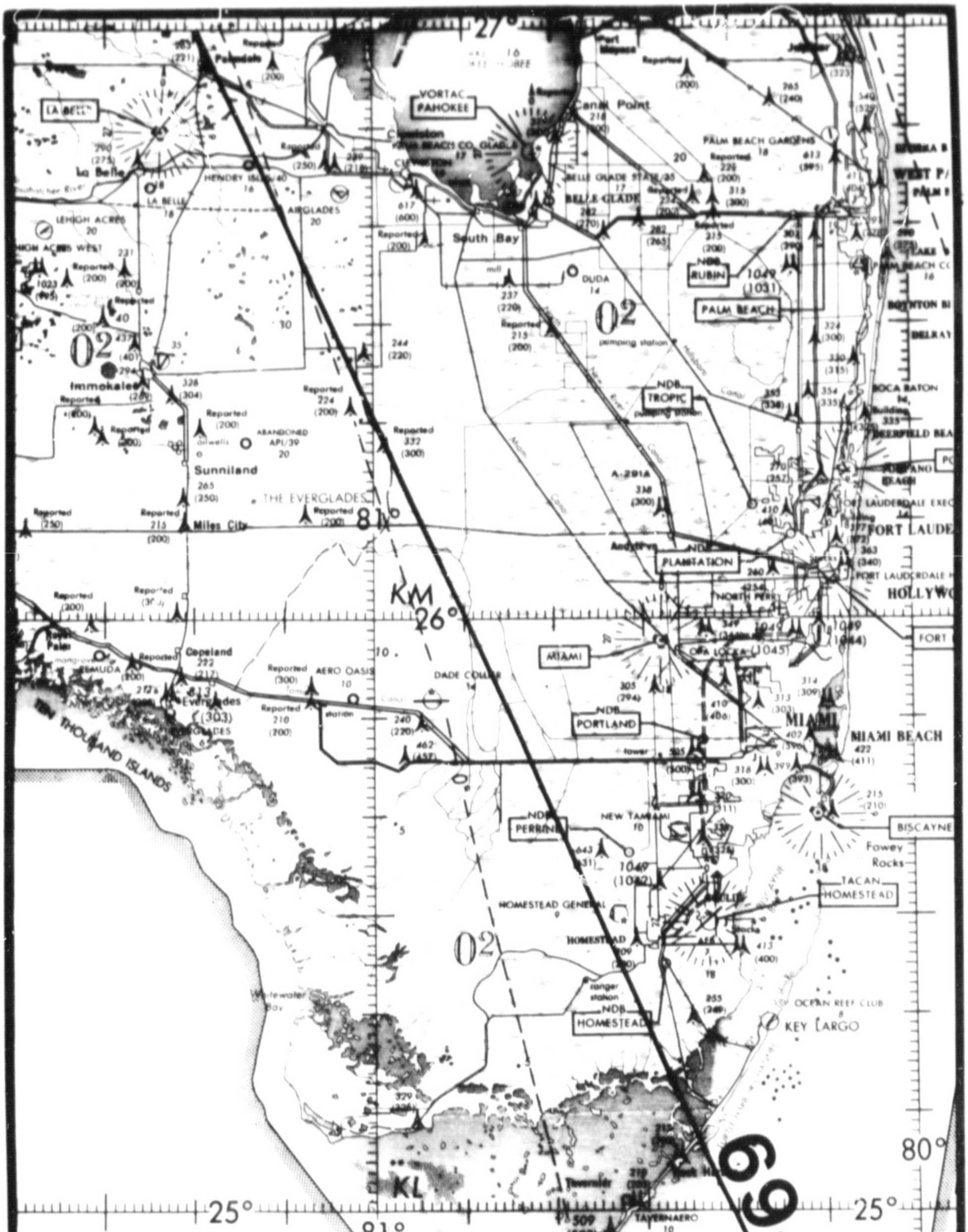

Figure 1 - Seasat Orbit 694 Groundtrack Across the Florida Everglades.

ALTIMETER DATA PROCESSING

A surface elevation corresponding to each altimeter height measurement was computed by algebraically subtracting the measured height (A) from the computed satellite height based on orbital computations (H). This surface height is with respect to the Seasat orbit reference ellipsoid (a = 6378.137 km, f = 1/298.257) and, in order to achieve surface heights referenced to Mean Sea Level (E), the geoid-ellipsoid separations (G) must be subtracted as

$$E = H - A - G$$

where all units are in meters.

The orbital computations generally provide H accurate to within a few meters. The error in H has a long wavelength and may be considered constant for the Everglades area involved in this analysis. To compensate for the error in H, orbit 694 was zero-set on the Atlantic Ocean just prior to crossing over Florida.

The altitudes (A) were recomputed for all the Seasat measurements over the Everglades. The recomputations were accomplished by repositioning the tracking gate at 50% of peak power on the surface return waveform ramp immediately preceding the peak power point. Previous experience with retracking the Seasat altimeter waveforms over terrain features in the United States has resulted in accuracies of ± 1 m when compared with large-scale maps (Brooks, 1981a).

The processing applied the GEM-10b geoid model. No smoothing or filtering was applied to the data.

RESULTS

TERRAIN

The Seasat altimeter data points were plotted on the eighteen USGS 1:24,000 scale quadrangles along the groundtrack. The sequence and geographic coverage of the quadrangles are shown in the map index in Figure 2. The majority of these quadrangles had contour intervals of 5 feet; six of the quadrangles, in less accessible areas, had no contours at all. All the quadrangles contained spot elevations. The attributes of each quadrangle are listed in Table 1.

The terrain profile along the groundtrack derived from the quadrangles is shown as the solid line in Figure 3. The dots in the same Figure are the altimeter-derived surface elevations. The maps and altimeter agreed very well except at: (1) the Little Lard Can Slough; (2) Conservation Area No. 3A; and (3) the Shark Valley Slough. Each of these three areas is discussed in the following.

The Shark Valley Slough is an important source of water for the Everglades National Park. Its variable surface height depends on the overland flow from the adjoining water impoundment area (Higer, et al, 1976). The Shark Valley Slough water levels are monitored by the Water Resources Division of the USGS, using water-stage recorder gauges. The gauge nearest the altimeter groundtrack was 5 km distant.

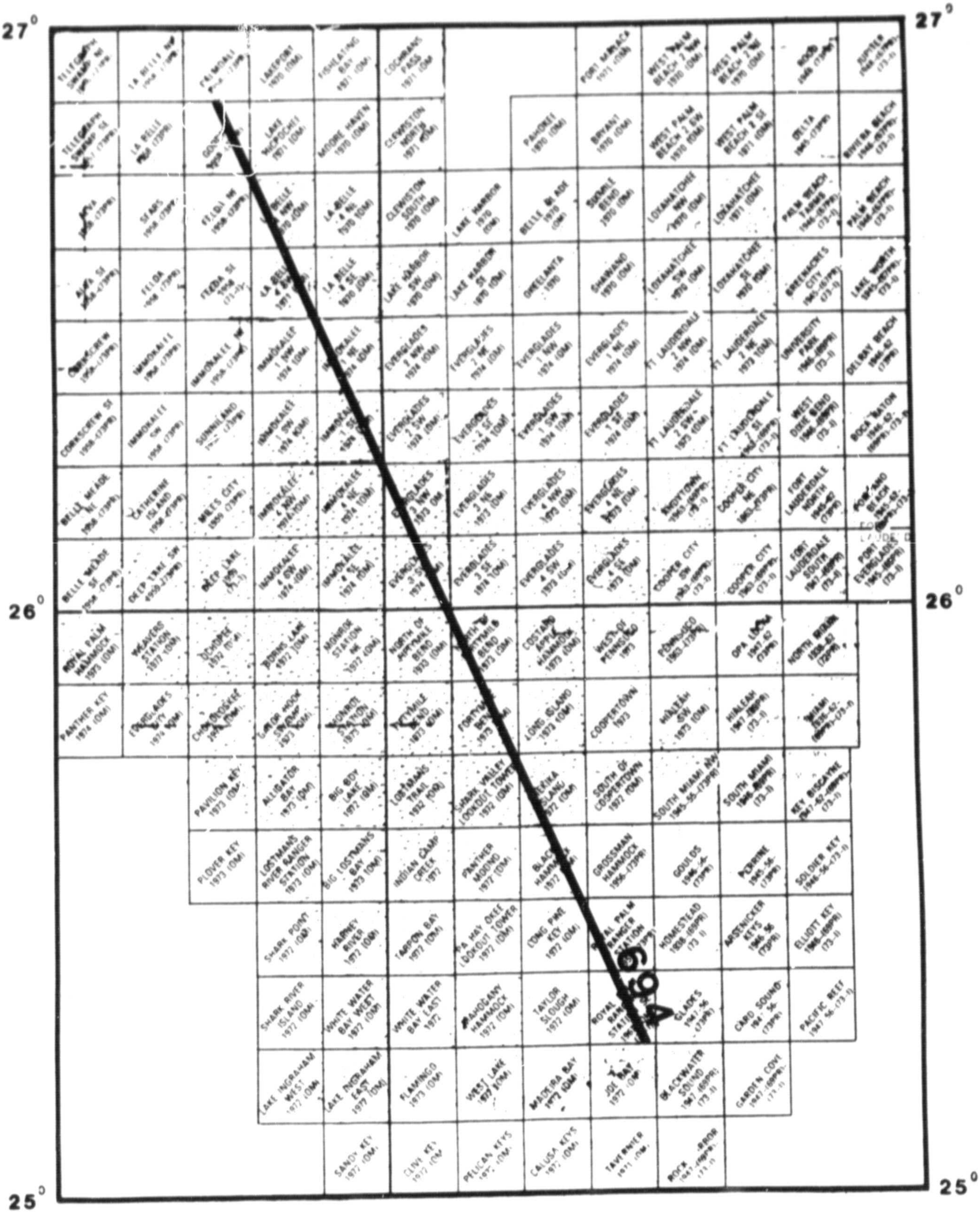

Figure 2 - Topographic Map Distribution along the Groundtrack of Seasat Orbit 694.

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MAP	CONTOUR INTERVAL	REMARKS
ROYAL PALM RANGER STATION SE	5 FEET	
ROYAL PALM RANGER STATION	5 FEET	
LONG PINE KEY	5 FEET	
BLACK HAMMOCK	NONE	ENTIRE AREA BELOW 10 FEET
CHEKIKA ISLAND	NONE	ENTIRE AREA BELOW 10 FEET
SHARK VALLEY LOOKOUT TOWER	NONE	ENTIRE AREA BELOW 10 FEET
FORTY MILE BEND	5 FEET	
NORTH OF FORTY MILE BEND	NONE	ENTIRE AREA BELOW 15 FEET
NORTH OF FIFTY MILE BEND	NONE	ENTIRE AREA BELOW 15 FEET
EVERGLADES 3 SW	NONE	ENTIRE AREA BELOW 15 FEET
EVERGLADES 3 NW	5 FEET	
IMMOKALEE 4 NE	5 FEET	
IMMOKALEE 1 SE	5 FEET	
IMMOKALEE 1 NE	5 FEET	
IMMOKALEE 1 NW	5 FEET	
LA BELLE 4 SW	5 FEET	
LA BELLE 4 NW	5 FEET	
GOODNO	5 FEET	

Table 1 - Description of 1:24,000 Topographic Quadrangles.

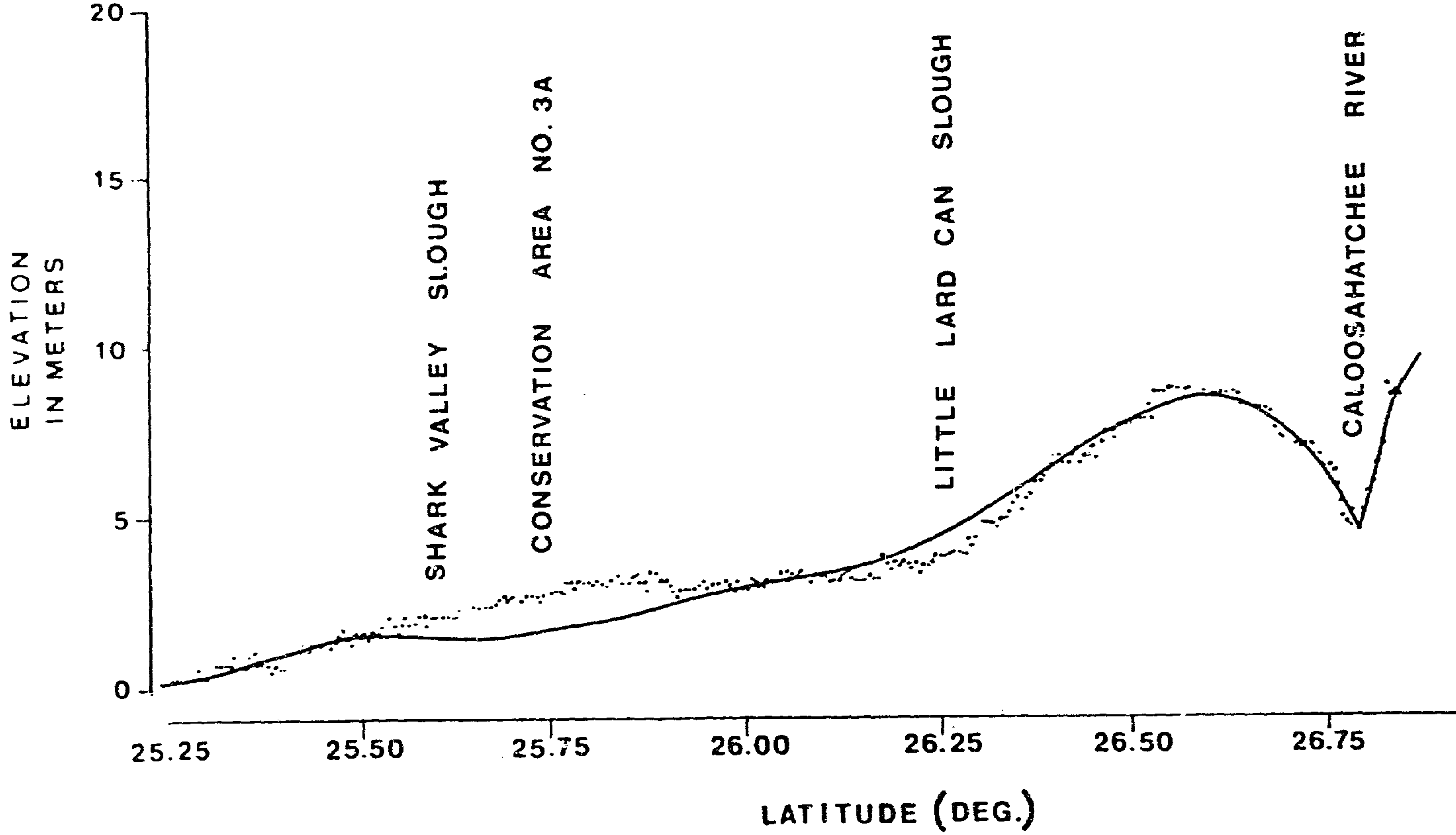

Figure 3 - Comparison of Map-Derived Elevations (Solid Line) with Satellite-Altimeter-Derived Elevations (Dots).

The gauge and satellite altimeter-derived water levels are compared below:

DATE	SENSOR	LAT	LONG	WATER LEVEL (M)
Aug.14, 1978	Gauge	25°37'	80°42'	2.1 (USGS,1978)
Aug.14, 1978	Seasat	25°37'	80°39'	2.1 ±0.1

Conservation Area No. 3A is a major water impoundment area upstream of the Shark River Slough. Water is discharged from this Conservation Area through controlled gates in man-made levees. Water levels as monitored by gauges since 1963 have exhibited fluctuations as large as 1.6 m (USGS,1978). The nearest water level gauge in this area was again 5 km from the Seasat groundtrack. The correlation between this gauge and the altimeter was:

DATE	SENSOR	LAT	LONG	WATER LEVELS (M)
Aug.14, 1978	Gauge	25°46'	80°46'	2.9 (USGS,1978)
Aug.14, 1978	Seasat	25°46'	80°43'	3.1 ±0.1

The altimeter-derived elevations in the Little Lard Can Slough area are as much as 1 m lower than the maps indicate. This is a relatively inaccessible area with few spot elevations on the maps; it is believed that the map spot elevations are higher than the general elevations for this area due to the leveling being done only along the few access roads and trails on higher ground.

SIGNAL STRENGTH

The specular nature of the Everglades' surface provided an excellent reflector for the altimeter's radar pulses. The automatic gain control (AGC) levels over the Everglades varied from 39 to 55 dB, shown in Figure 4 correlated with the elevation computations. The sufficiency of this signal strength is best emphasized by noting that the average signal level over open ocean is 33 dB, or 6-22 dB lower. The strongest returns in the Everglades are from calm water.

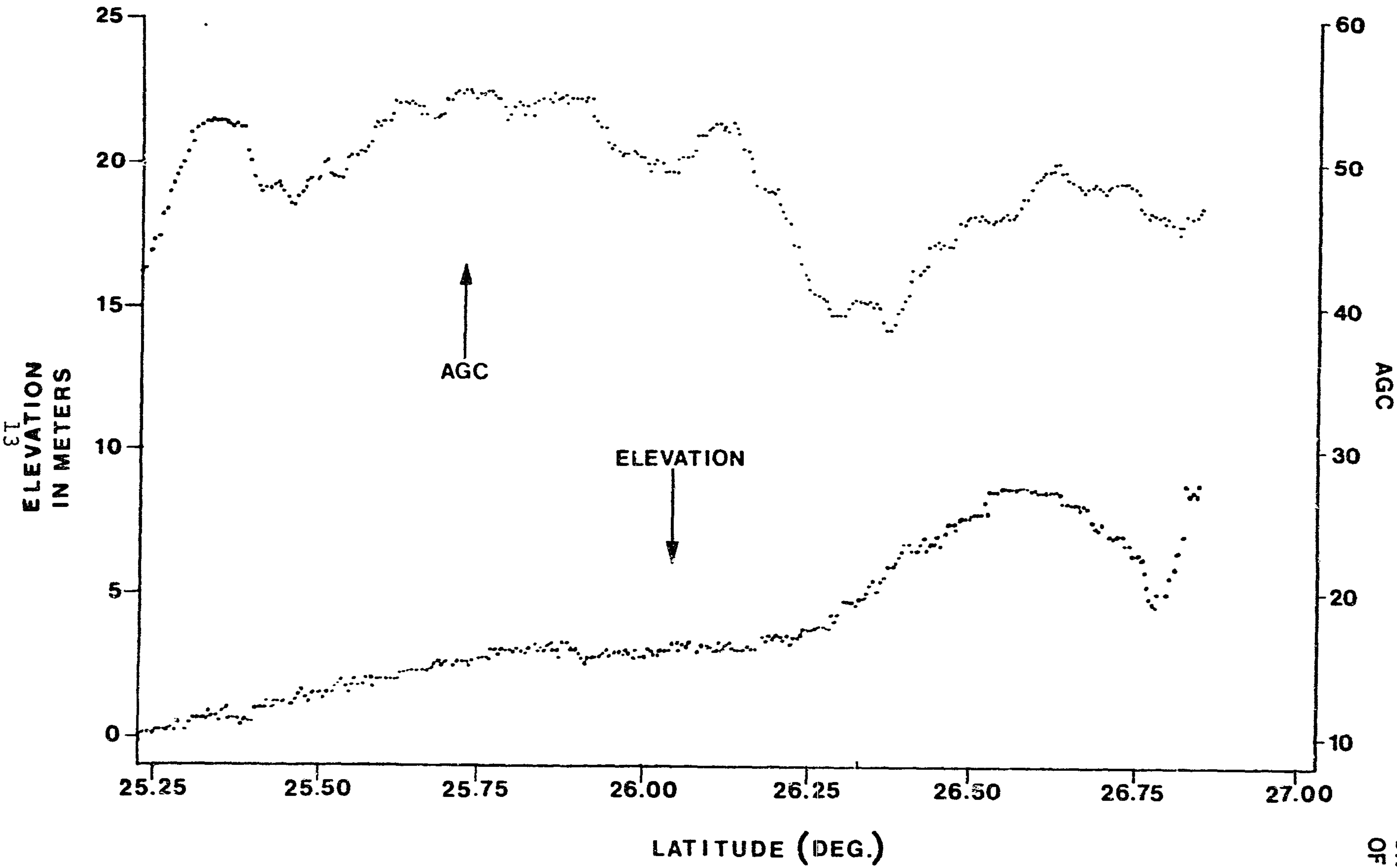

Figure 4 - Comparison of Altimeter Automatic Gain Control (AGC) Levels in dB with Altimeter Derived Surface Elevations.

VEGETATION

Examination of the Seasat altimeter surface return waveforms over the Everglades revealed very interesting features. In addition to the reflection from the surface, earlier (in time) reflections of lower amplitude appeared.

An example of such a waveform is shown in Figure 5. The 60 Seasat altimeter waveform gates are numbered -30 to +30; the separation between each gate is 3.125 msec, equivalent to 0.4684 m in range. Time progresses from gate -30 to +30. In Figure 5, the prime waveform return is from the surface in Conservation Area No. 3A and has a power amplitude of 700. Smaller amplitude peaks occurred 7 gates and 26 gates (peak-to-peak) earlier than the surface return. The return which is 7 gates earlier has an amplitude of 30; it is 3.3 m (7 gates x 0.4684 m/gate) higher than the surface, and is interpreted to be sawgrass. The earlier return with an amplitude of 110 is 12.2 m (26 gates x 0.4684 m/gate) higher than the surface and is interpreted to be the height of the tree canopy.

Another surface return waveform from Conservation Area No. 3A is shown in Figure 6. This waveform shows a rather strong return from a height of 9 gates, or 4.2 m, above the surface. This is interpreted to be the sawgrass height. No significant return from trees is observed, but a slight amplitude rise 21 gates earlier than the surface return may indicate the presence of a few trees at a height of 9.8 m.

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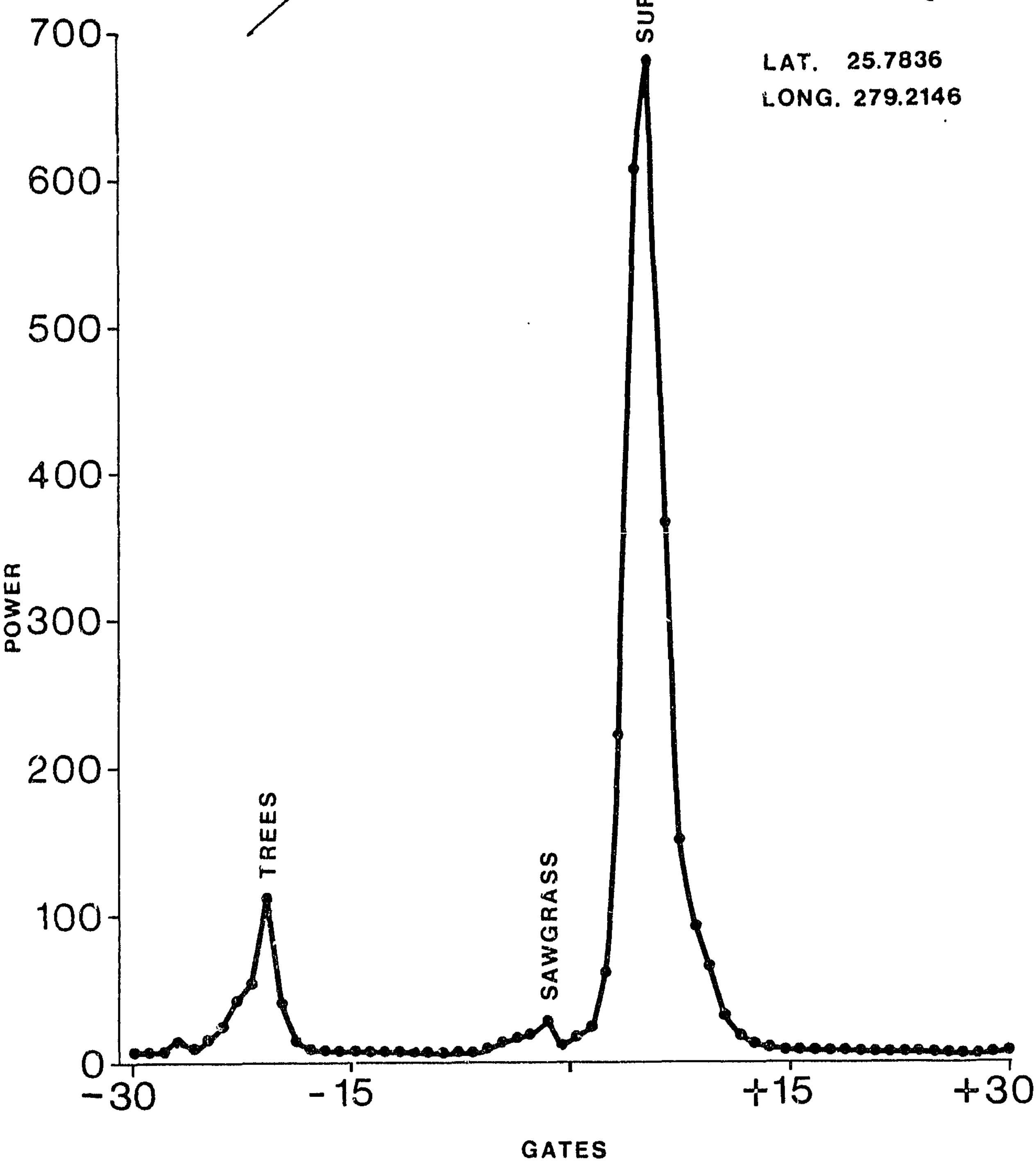

Figure 5 - A Surface Return Waveform from Conservation Area No. 3A with Earlier Returns Indicating Sawgrass and Tree Canopies.

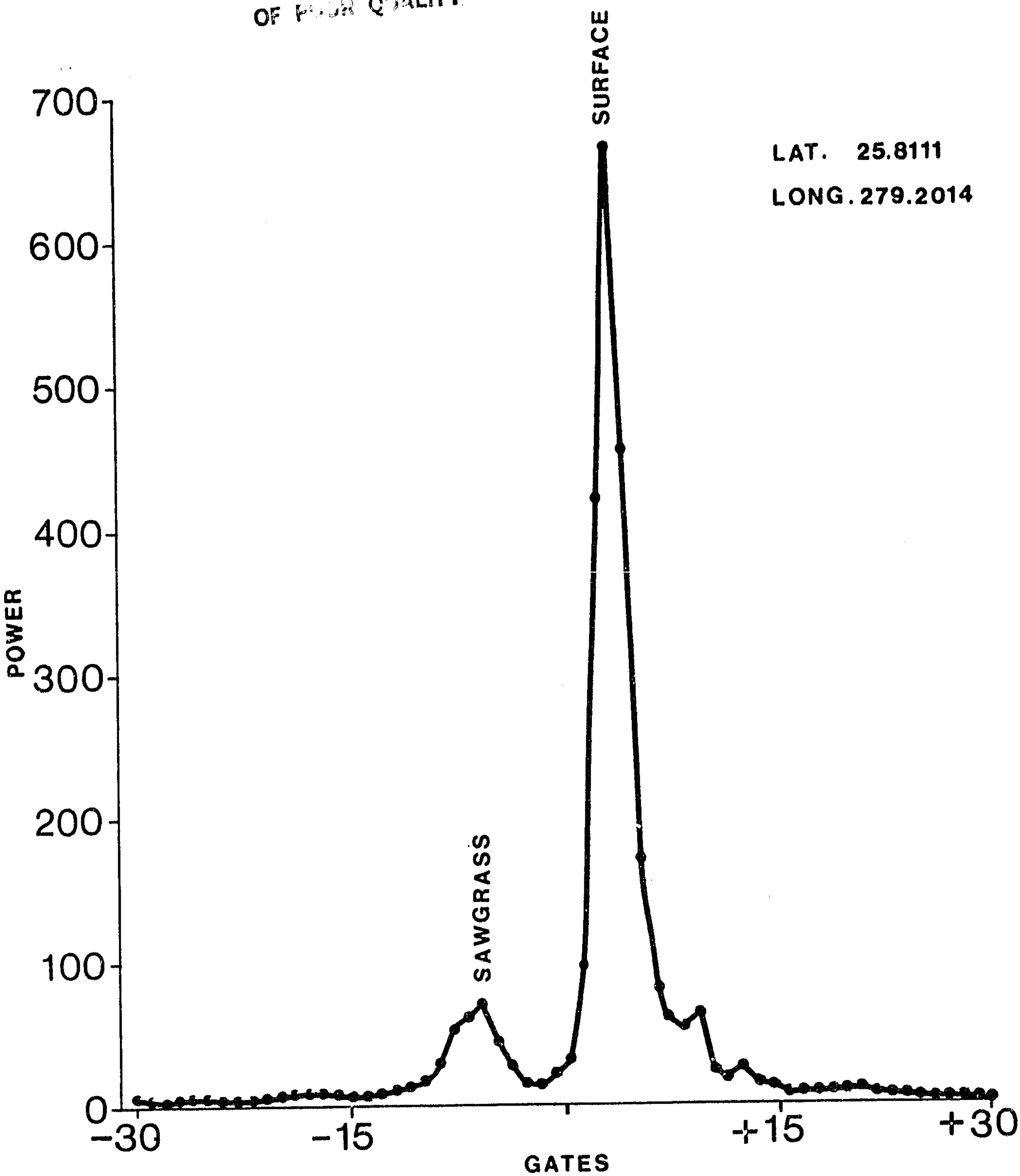

Figure 6 - A Surface Return Waveform from Conservation Area No. 3A with an Earlier Return Indicating Sawgrass Canopy.

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The third and final waveform example is displayed in Figure 7. This is an area to the west of Conservation Area No. 3A. The topographic map indicates that this is a non-water-covered land surface; the altimeter waveform exhibits no strong returns from vegetation.

Based on a composite of the 26 consecutive waveforms across Conservation Area No. 3A, the elevations of the vegetation canopies as well as the surface elevations are presented in Figure 8. The solid lines in the Figure represent the calculated elevations, while the patterns have been assigned according to our interpretation of the waveforms.

A composite has also been prepared for the altimeter waveforms across the Black Hammock Quadrangle. In this example, shown in Figure 9, waveforms from 23 consecutive measurements have been utilized to compute the surface and vegetation canopy elevations. This area differs from the earlier example in that the first three waveforms do not indicate the presence of trees, while the later waveforms over the Shark Valley Slough provide evidence of a higher third tree level.

We have analyzed many more waveforms, too numerous to be presented here. The waveforms are consistently in agreement with the indications of vegetation on the topographic maps. The maps, of course, do not include vegetation heights. A field verification in the Everglades will be required to corroborate our analysis concerning vegetation heights. Funding limitations have, to date, precluded a field check.

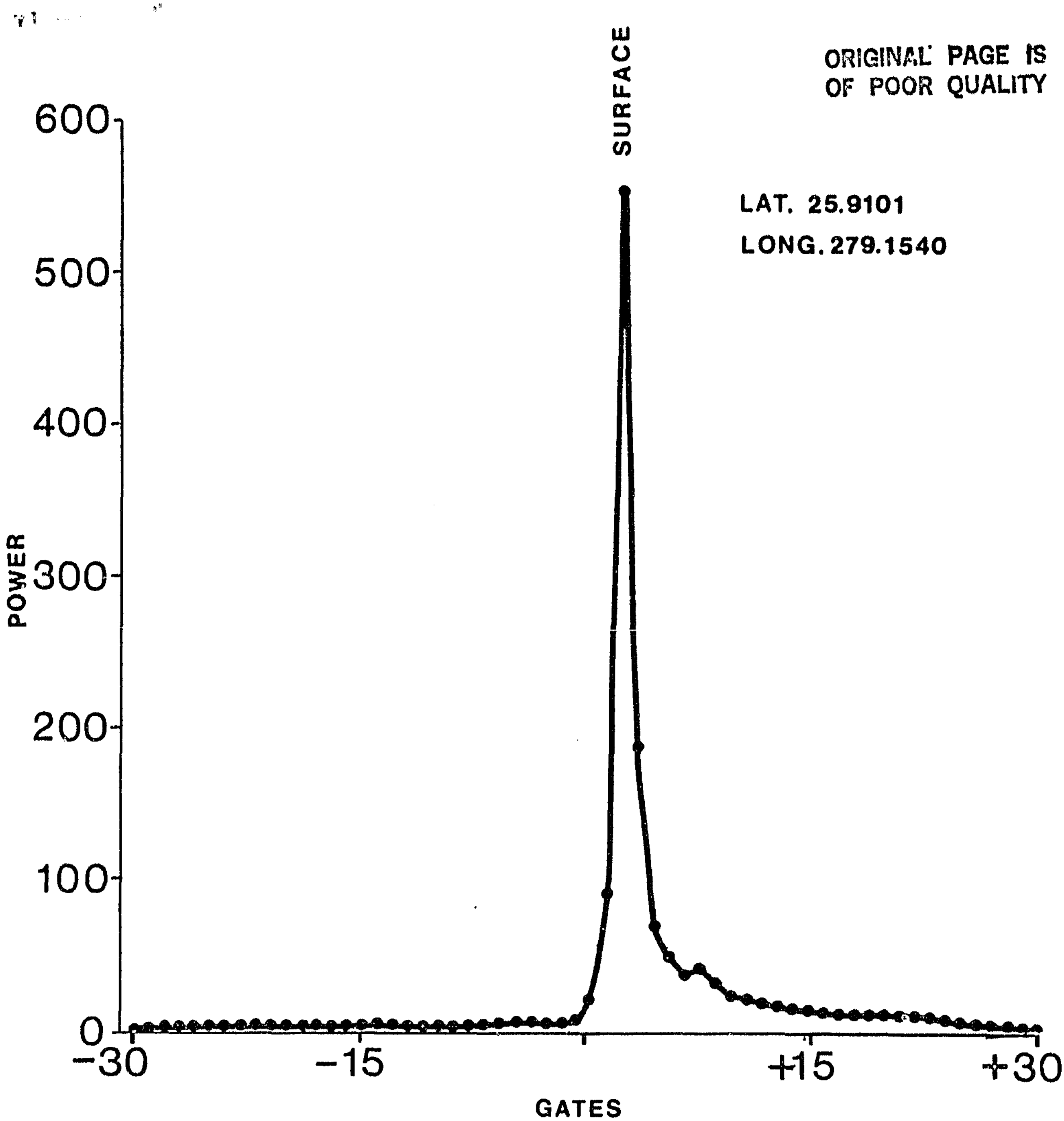

Figure 7 - A Surface Return Waveform from a Land Area. No Significant Vegetation Canopy is Indicated.

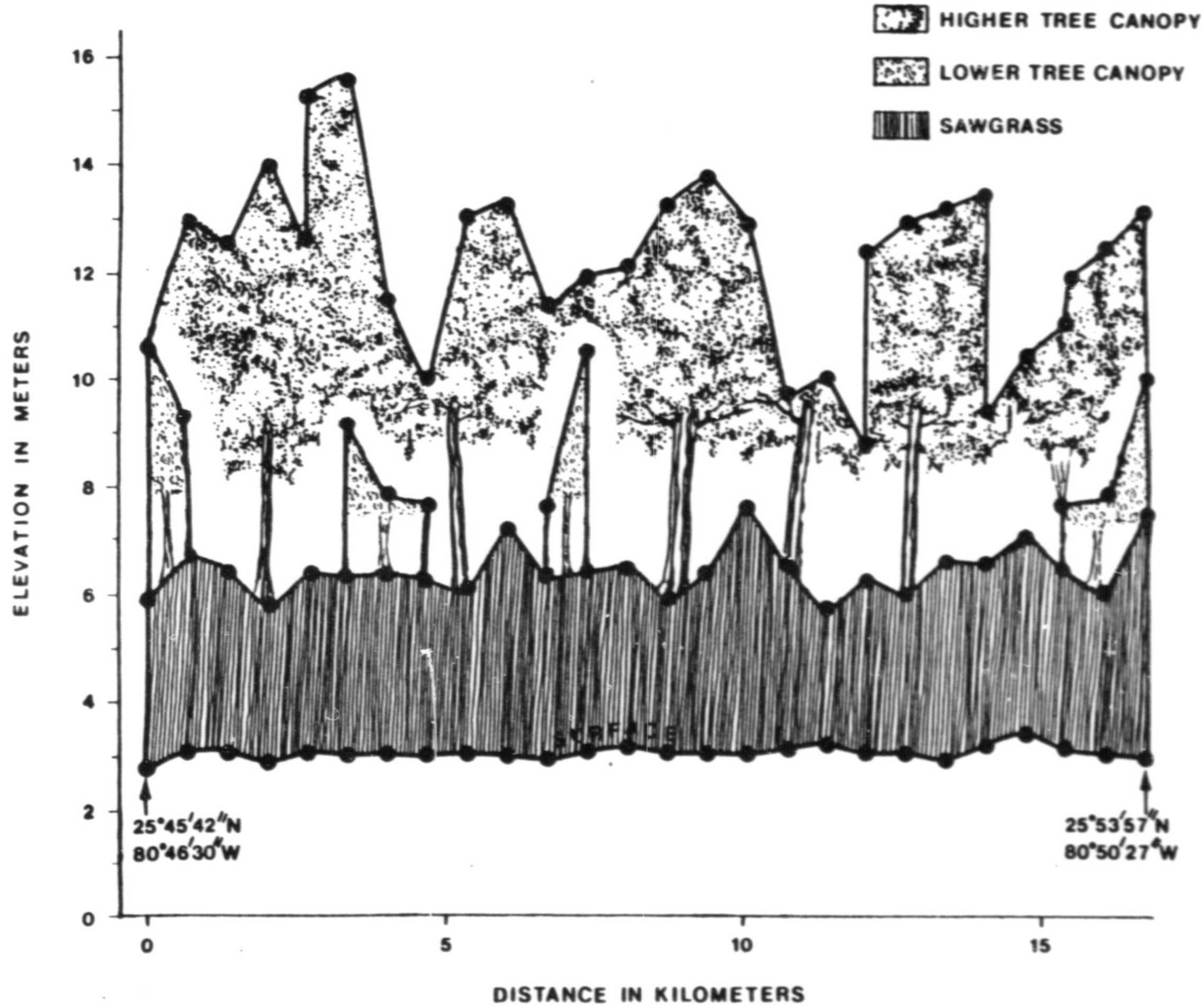

Figure 8 - Surface and Vegetation Canopy Elevations from 26 Consecutive Waveforms over Conservation Area No. 3A.

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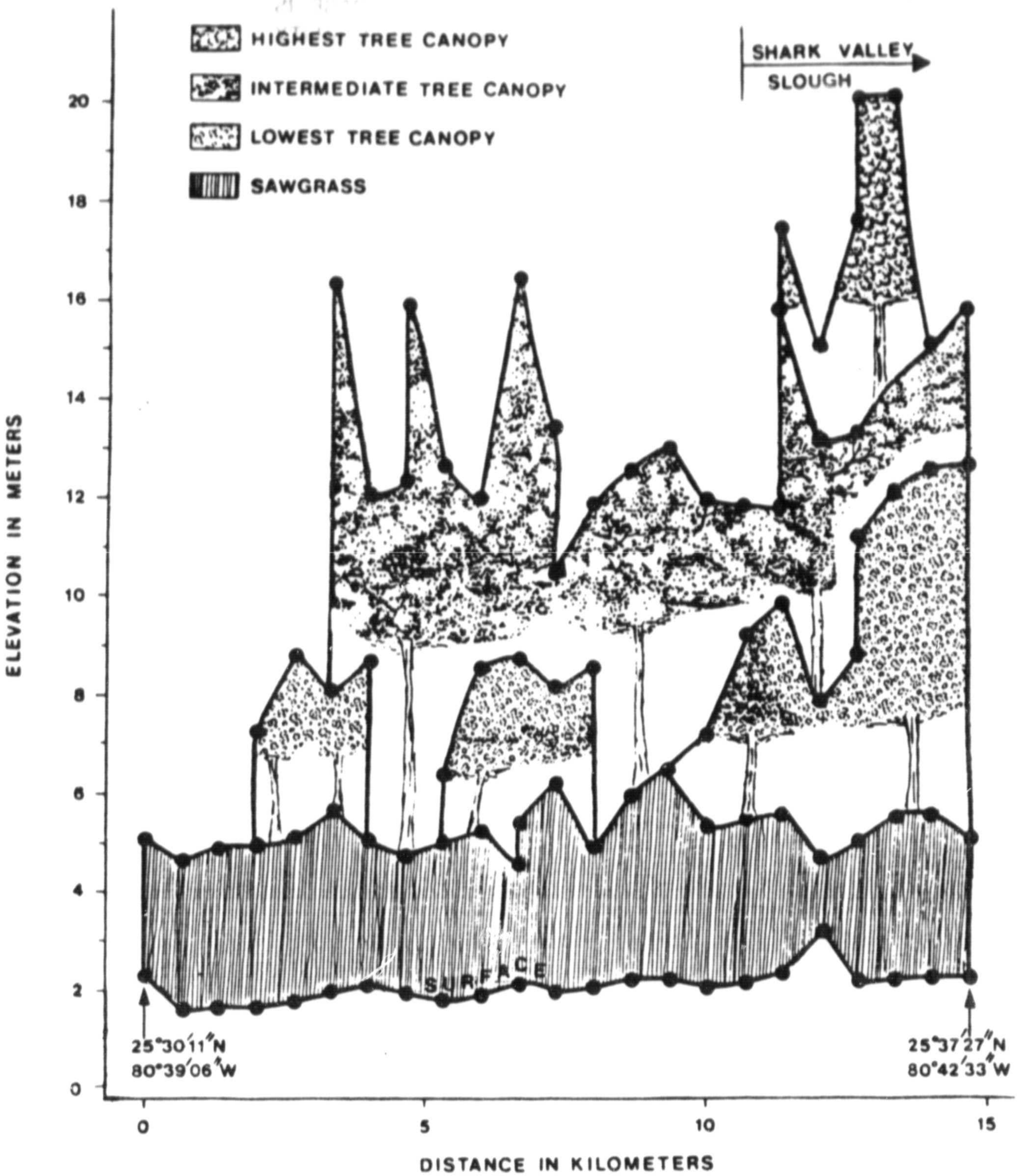

Figure 9 - Surface and Vegetation Canopy Elevations from 23 Consecutive Waveforms across Black Hammock Quadrangle.

FUTURE SATELLITE ALTIMETER DESIGN CONSIDERATIONS

The Seasat radar altimeter performed surprisingly well in the Everglades, considering that such an application was not planned during its design stage. There are, however, several design considerations which would enhance the performance of future satellite radar altimeters for remote sensing of similar areas. These are:

- faster tracker update so that retracking would not be required
- increased measurement rate to 20 per second, providing measurements at approximately 350 m intervals
- additional early waveform gates so that higher tree heights (up to 30 m) may be sampled.

Monitoring of water levels would be facilitated if repeating satellite groundtracks could be provided at 30-day intervals.

SUMMARY

The performance of the Seasat radar altimeter over the Florida Everglades was quite good. The radar penetrated the vegetation cover and provided terrain and water level elevations with ±0.5 m accuracy. In addition, examination of the surface return waveforms indicate that the heights of vegetation canopies were also sensed.

Our conclusion is that future satellite radar altimeters could contribute to the mapping and range management of areas similar to the Everglades. The contribution would consist of the following:

- supplemental vertical control
- monitoring of water levels
- monitor growth of vegetation (not as yet field-verified).

Persons interested in this application of satellite altimetry should make their requirements known to NASA planners so that future altimeter designs may incorporate appropriate capabilities.

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