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CALCULATIONS OF WATER DEPTH FROM ERTS-MSS DATA

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ABSTRACT

ERTS-1 MSS data taken on October 10, 1972 of the Little Bahama Bank are being used to demonstrate the use of ERTS-1 data for mapping of shallow water features for the purpose of upgrading world navigation charts. Marked reflectance differences occur for the shallow water areas in Bands 4, 5, and 6. Digital processing of two adjacent data tapes within the ERTS frame covering an area of about 40 by 40 miles has been completed. Correlation of depth measurements to 5 meters has been successful. A mathematical model for depth measurements using ratio of voltages in Band 4 and 5 has been successfully developed and is being tested for accuracy. Additional studies for areas near Puerto Rico and in Northern Lake Michigan will be undertaken. Satellite data will also provide geographical evidence for verifying existence or nonexistence of doubtful shoal waters now appearing on world charts and considered to be hazardous to shipping.

1. INTRODUCTION

The opportunity for global coverage afforded by earth orbiting satellites such as ERTS-1 makes possible for the first time to completely survey the oceans in a short time and in a common format and thus update the world's navigation charts.

The International Hydrographic Office has expressed concern over the status of shipping charts around the world, many of which cannot be updated due to lack of technical resources on the part of some countries. Meanwhile, some maps contain data based on survey records from the early 19th century, when the simplest techniques subject to a variety of errors were used for depth soundings.

Doubtful shoals occur for many reasons; positions are known only approximately. The same shoal may have been reported by two different ships with inaccurate geographical coordinates (Ref. 1). Location information is one of the most frequent sources for ambiguity on the shipping charts.

Chart makers are forced to use such labels as Position Approximate, and Existence Doubtful in reference to some reported sightings. Depths measured by lead lines tend to give too large a depth because of bending of the line. Echo Sounders can give errors from suspended materials that cause depths to be too shallow. Storms bring rapid changes so that even recent maps may be in error due to shifting sand bars and coastline readjustments. If only surface ships are used for hydrographic surveys, a long slow process is involved and sampling procedures are necessarily incorporated.

Satellite remote sensing affords a solution to some of these problems. Shallow waters less than 50 feet (17 meters), the most dangerous from the point of view of ship safety, are measurable from ERTS-1. Because of the 100 mile by 100 mile format, location information referenced to well known large land masses are possible and will do much to improve maps.

All points within the 10,000 sq mile frame can be observed and shallow waters easily identified on Band 4 with Band 6 or 7 used to mark land/water boundaries. Doubtful shoals can be eliminated. Existence or non-existence of doubtful shoals can be ascertained especially in regions where water clarity permits optimum light penetration. The problem that remains is to determine the accuracy of depth measurement with satellite remote sensors.

The ERTS investigation designated UN 200 carried out for NASA by the Environmental Research Institute of Michigan is planned to answer this question.

2. THE EXPERIMENTAL TECHNIQUE

Previous work (Refs. 2,3) on remote sensing techniques identified multispectral ratio processing as a promising technique for the remote detection of water depth. The technique employs the relation shown by the equation

$$z = \frac{1}{f(\theta,\phi)(\alpha_1-\alpha_2)} \ln \frac{k_1 V_1 H_1 \rho_1}{k_2 V_2 H_2 \rho_2}$$

where z = water depth

α_1, α_2 = extinction coefficients of water at two different wavelengths

ρ_1, ρ_2 = bottom reflection in two different bands

k_1, k_2 = constants of the instrument which are known

H_1, H_2 = incoming solar radiation

V_1, V_2 = analog signals observed in the multispectral scanning of the shallow features.

For the satellite case, V_1 and V_2 are obtained from Bands 4 and 5 of the MSS digital tape. The incoming solar radiation is available from standard references. The extinction coefficient is obtainable from ground measurements, or estimated on the average for a given geographical area based on a knowledge of the conditions and adjustments to the known values for clear water. ρ_1 and ρ_2 are reflectances for the bottom materials, some types of which are known. Since the ratio for bottom reflectances appears in the equation, only relative spectral information is needed.

3. RESULTS

An ERTS-1 frame taken over the Bahama Islands was used in the initial investigation to date. The ERTS Frame 1079-15165 was taken on October 10, 1972 (79th day since launch of ERTS-A) at 15 hours, 16 minutes, 50 seconds. Principal point of image is 27.45°N, 78.82°W (Northwest of Grand Bahama Island). Solar elevation is 74.4°. Frame covers approximately 100 x 100 nautical miles, with Grand Bahama Island in the lower right-hand corner and the Little Bahama Bank covering most of the lower half of the frame. There is a 30% cloud cover for the frame as a whole, but most of the clouds are in the upper half. There is a small patch of clouds in the center of the Bank and over Grand Bahama Island.

In Figure 1, the multispectral scanner (MSS) channel 4 (.5-.6 μm) clearly shows underwater features in the bank north of Grand Bahama Island. Most of these can be identified on the Hydrographic Office depth chart, (see Fig. 2) but there are a large number of streaks in the center of the frame which are not on the published chart.

MSS channel 5 (.6-.7 μm) shows some of the shallower areas of the bank, as well as land and clouds.

MSS channels 6 and 7 (.7-.8 μm and .8-1.1 μm) show no underwater features. Water absorption is so high in these channels that the only signal received over water is due to surface reflection.

Going from channel 4 to 7, land areas become progressively brighter, shallow water areas become darker, and clouds remain at about the same brightness. Sale Cay (on the right) thus appears dark against a light background in channel 4, is almost indistinguishable in channel 5, and stands out clearly against a dark background in channels 6 and 7.

The multispectral characteristics are evident in the comparison for the four bands from the MSS. The digital tapes were then used to produce a relative depths chart shown in Figure 3.

This density map was made from the digital output from MSS channel 4. The darkest symbol (e.g., in the lower left-hand corner) corresponds to a signal less than 24 volts (amplification arbitrary). A blank corresponds to a signal of greater than 38 volts. The interval from 24 to 38 volts was divided into 7 equal subintervals and a separate symbol assigned to each. Every 4th line and point of the data was used in making the map (each line of the original data corresponds to an east-west strip 79 meters wide, and each point along the line occupies 56 meters, so each symbol on the graymap represents an area of 216 x 316 meters).

This map gives an indication of water depth, within the range of 0-10 meters. The bottom-reflected signal is proportional to

$$e^{-\alpha(\sec\theta + \sec\phi)z}$$

where α is the attenuation coefficient, θ is the observation angle, ϕ is the solar zenith angle, and z is the depth. α is on the order of 0.2 m^{-1}, so the bottom-reflected signal is approximately proportional $e^{-0.27z}$, where z is the depth in meters. The bottom-reflected signal is obtained by subtracting off the deep-water signal, which is about 23 volts for channel 4.

The shallowest areas (corresponding to blanks on the map) return a signal of about 41 volts. Using this as the reference level z_o, we have

$$V_b(z_o) \equiv V(z_o) - 23 = 18 \text{ volts}$$

The bottom-reflected voltage at any other depth z is then given by the relation

$$\ln V_b(z_o) - \ln V_b(z) = 0.27\ (z-z_o)$$

From the Hydrographic Office depth chart, the depth in the white areas is about 1 fathom (6 feet). Using this value for z_o, the depths corresponding to each of the symbols on the map are given in the following table:

SYMBOL	VOLTAGE RANGE	DEPTH RANGE (Ft.)
-	37-38	7-9
•	35-36	9-11
▬	33-34	11-13
*	31-32	13-16
Ⅰ	29-30	16-20
θ	27-28	20-24
M	25-26	24-33
M	0-24	33-∞

The deepest areas in the north-western part of the bank are thus about 5 fathoms, which agrees with the depth chart. The white streaks in the center of the bank appear to be about a fathom below the surface.

Calculations based on two channels of information give absolute values for depth where some knowledge of bottom reflection is known. This was done only at those points where both channels 4 and 5 received bottom reflection signals.

For the sand bars (white streaks in Fig. 3), calculation of water depth was completed since the general reflection characteristic for wet sand had been previously determined. Agreement with HO chart 5990 was evident: the chart refers all depths to the mean lowest water level, so that adjustments due to tidal action need to be completed for final comparison.

4. DISCUSSION

The ERTS satellite image for the Little Bahama Bank shows features <u>not</u> present on the HO chart 5990 for the Northwest and Northeast Providence channels. This chart was revised in 1969 but it uses data from British surveys between 1836 and 1885 and U.S. Navy Surveys to 1963. There are indications of shifting currents being responsible for the build-up of sand shoals and the ERTS imagery supports that observation. It appears that sand build up over this bank indicates a potentially harmful condition which can eventually kill the protective coral bank to the "islands". Cutting shipping channels arbitrarily could change the sand deposition profile. This action will be investigated as part of the verification phase of the experiment.

5. SUMMARY

ERTS-1 data tapes from the MSS can be used for mapping shallow water features. It was demonstrated that depths can be calculated by ratio processing for those shallow depths that return a signal in both channels 4 and 5. By performing analysis of channel 4 data only, a more complete depth map can be made on a relative depth basis. However, if additional control points are known, and if the reflectances of bottom materials are taken into account, an absolute depth map can be made. Even without depth information, the satellite data is still useful because existence of shallow features are detectable and their geographical positions more accurately known than heretofore possible.

The economic benefits derived from the improvement of the world charts has been analyzed initially by Zissis et. al (Ref. 4). World $ losses of about one billion per year in shipping are estimated. Reduction in losses due to those factors that would be traceable to improved navigation charts amounts to several millions per year.

6. REFERENCES

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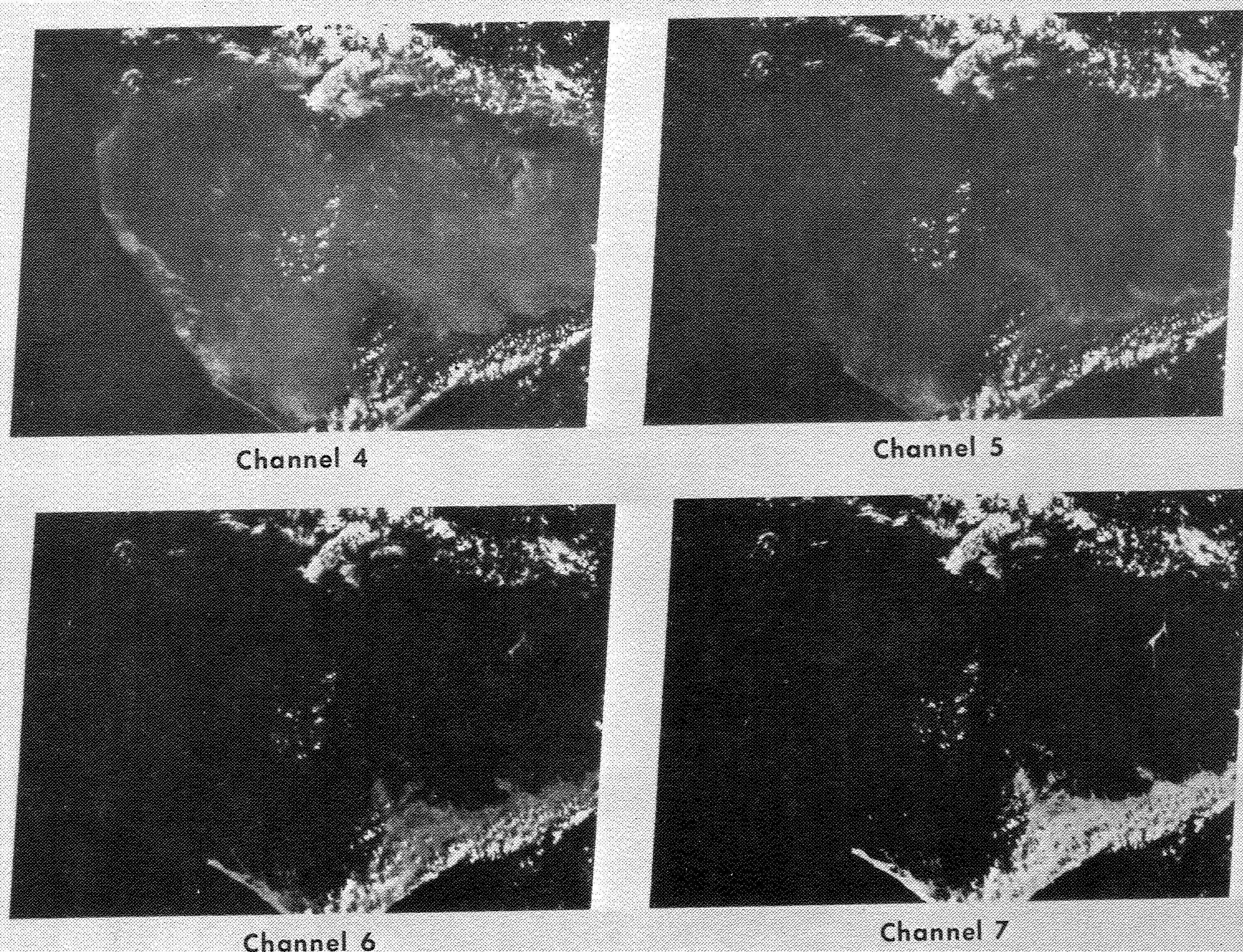

MSS ERTS DATA, 10 OCTOBER 1972
LITTLE BAHAMA BANK

FIGURE 1

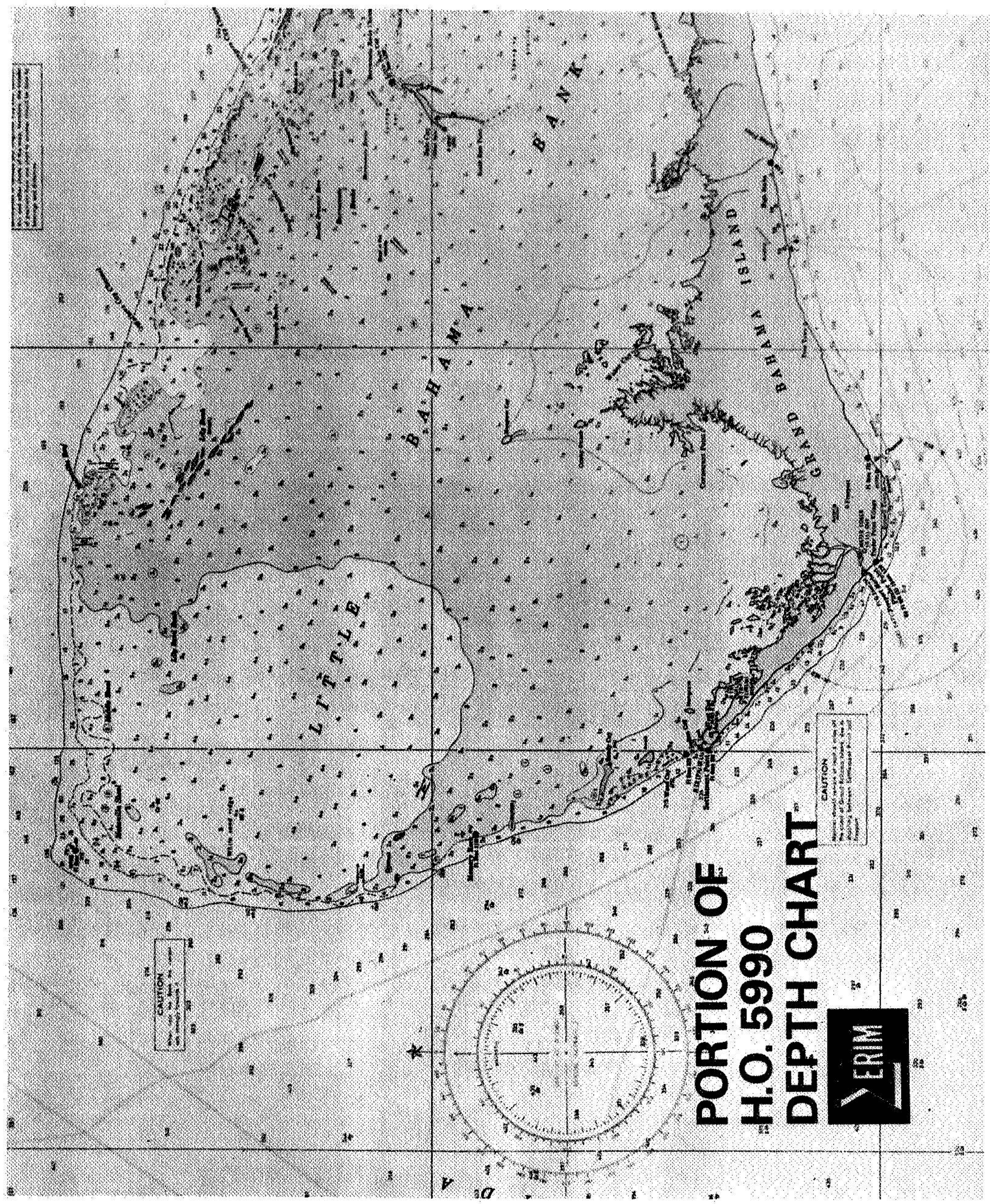
PORTION OF
H.O. 5990
DEPTH CHART
ERIM
LITTLE
BAHAMA
BANK
GRAND BAHAMA ISLAND
CAUTION

FIGURE 2

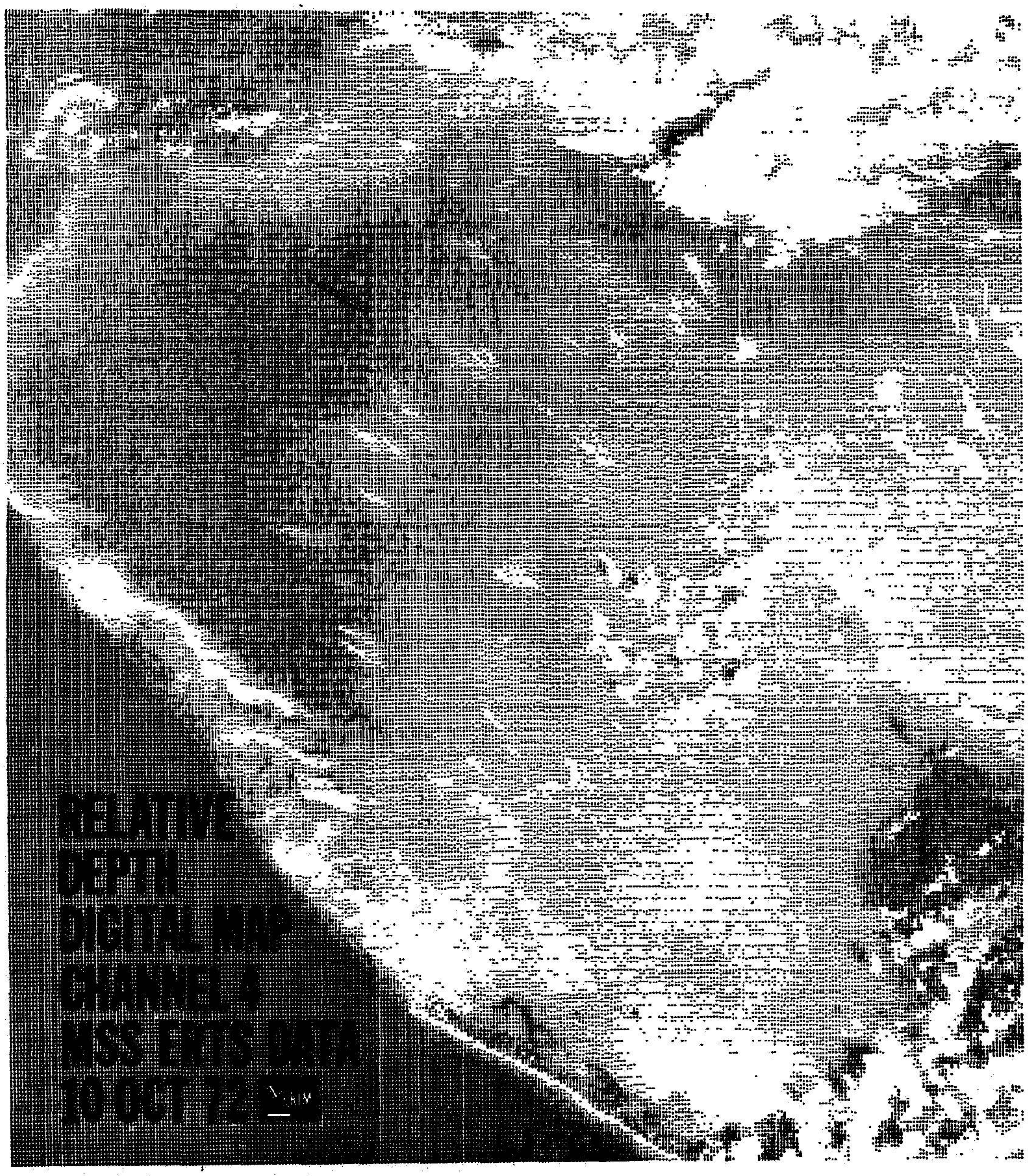

FIGURE 3