UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY





STATUS OF USGS EFFORT TOWARDS WATER

DEPTH DETERMINATION WITH LANDSAT IMAGERY

By Alden P. Colvocoresses, 1918-

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RESTON, VA. 22092

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Memorandum for the Record (EC-73-Landsat)

By: EROS Coordinator, Topographic Division

Subject: Status of USGS effort towards water depth determination with Landsat imagery

Reference is made to EC-68-Landsat (Colvocoresses, 1979). This memo analyzed and compared the theoretical and empirical approaches to the subject problem as applied to Colvocoresses Reef in the Indian Ocean.

Enclosed is a letter dated November 26, 1979, from John DeNoyer which summarizes his experience in applying the theoretical approach in the Palau Island area. DeNoyer utilized the formula developed by the Environmental Research Institute of Michigan (ERIM) (Lyzenga and Polcyn, 1979; Doak, Lyzenga, and Polcyn, 1979) and found he had to materially alter the coefficients in the formula in order to make them fit the Palau model as derived from existing hydrographic charts. DeNoyer's recent letter plus a previous paper (Carter and DeNoyer, 1978) summarize the work he did in the Palau area including the limitations involved in using ERIM's formula. There are, however, several points mentioned by DeNoyer which warrant amplification.

DeNoyer points out that the formula can be applied with fixed coefficients only as long as surface reflectance, bottom reflectance, water column attentuation, and atmospheric transmission are constant. He states that changes in these conditions in the Palau area could easily be identified but might be more difficult in some other locations. I believe this is an understatement since all of these factors, under certain conditions, may vary as a function of water depth. Sea state, which is a dominant factor in surface reflectance may certainly change as a function of water depth. Vegetation type and extent, which greatly affect bottom reflectance, may also be controlled by water depth. In many areas water turbidity results from wave actions along shore lines and near shallow areas, and the atmosphere itself can be affected by water depth which may alter water and in turn air temperatures.

The use of the formulas developed by ERIM and utilized by DeNoyer are certainly justified when conditions warrant and where other collaborative data are not available. However, the empirical approach used by Colvocoresses and Martin (see Colvocoresses, 1979) is recommended wherever suitable data are available to make comparative readings. Using this approach, future hydrographic boat surveys in many areas might be limited to sampling based on selected transects from which extrapolation to other areas of similar characteristics can be made. Thus a system such as Landsat, coupled with limited boat surveys, appears to offer a feasible solution. In view of the cost of complete boat surveys and considering the extent of unsurveyed shallow-sea areas, this approach, along with the judicious use of the theoretical formulas, should result in a methodology for the mapping of the shallow seas at reasonable cost.

It is significant that during the past 2 years a sizeable percentage of the world's shallow seas have been imaged by Landsat in the high-gain mode, which is designed to optimize low-level responses such as underwater features produce. This coverage was requested of NASA by the Defense Mapping Agency for the purpose of evaluating and revising their nautical chart coverage. Nautical charting is basically concentrated along shipping lanes, and thus shallow sea areas removed from shipping lanes may never be mapped in any detail by hydrographic agencies. The interest in the shallow seas extends well beyond that of the big ship navigator, but at present there are no known programs for mapping the shallow seas except where they coincide with hydrographic charting requirements.

With the current acquisition of both normal and high-gain Landsat data of the shallow seas and the development of technology, as indicated above, relative to depth determination, the mapping of the shallow seas now appears feasible. Perhaps international agencies such as the United Nations or the International Hydrographic Organization can define and support appropriate programs which could lead to the mapping of this vast, and obviously important region of the Earth which is, today, basically neither charted nor mapped with any real precision.

Alden P. Colvocoresses

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Enclosure

## REFERENCES


Carter, W. D., and DeNoyer, J. M., 1978, Landsat images of part of the U.S. Trust Territory of the Pacific Islands and other Pacific outlying areas: 12th International Symposium on Remote Sensing of Environment, Manila, Philippine Islands, v. 1, p. 755-764, the Environmental Research Institute of Michigan.

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Doak, E. L., Lyzenga, D. R., and Polcyn, F. C., 1979, Remote bathymetry by Landsat in the Chagos Archipelago: Prepared for DMA by the Environmental Research Institute of Michigan, April 1979.

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# United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092


November 26, 1979

Mr. Rick Scudder
Office of Environmental Quality Control
550 Halekauwila Street, Room 301
Honolulu, Hawaii 96813

Dear Mr. Scudder:

Mr. Frederick J. Doyle has asked me to respond to your letter requesting information on the analysis of Landsat images of the Palau Islands. A paper on this work is in preparation but has not been completed. In the absence of a completed paper, I will outline the method of analysis, the capabilities, and the limitations of the methods.

The method of analysis is adapted from work done by Fabian Polcyn at the Environmental Research Institute of Michigan, Ann Arbor, Michigan. Depth calculations are based on absorption of light that has traveled vertically through the water column, been reflected at the bottom, and traveled through the water column again and been recorded at high (3 times) gain by the satellite. The expression for the radiance value V, recorded by the satellite is:

$$V = V_S + V_O \exp(-2\alpha Z)$$

Where $V_S$ is light returned from deep (no bottom reflection) water, $V_O$ is the light that would be returned from a bottom reflection at zero depth, $\alpha$ is an attenuation coefficient for the water path, and Z is the depth of water. This equation can be solved for Z to give:

$$Z = -\frac{1}{2\alpha} \ln\left(\frac{V-V_S}{V_O}\right)$$

Since the digital counts are proportional to the radiance values, the digital counts for each pixel can be used directly. $V_S$ is determined directly from the data by taking the average reflectance from deep water. Care must be taken in the selection of $V_S$ so that the samples will have the same surface and scattering characteristics as the shallow water data. Values for V are read directly from the digital tape for each pixel where a depth Z is computed. Values for $V_O$ and $\alpha$ must be obtained by other methods.

Polcyn's work in the Bahamas made direct measurements of water attenuation and bottom reflection at the time of the satellite overpass. My work in the Palau could not support direct measurements. Values for $V_O$ and $\alpha$ were estimated from comparing results with hydrographic charts. This was done by making a first estimate of $\alpha$ equal to Polcyn's value for the Bahamas and $V_O$ such that

$$0 \leq \frac{V-V_S}{V_O} \leq 1$$

Since the maximum digital count that can be recorded is 127, the initial estimate for $V_O$ was taken as:

$$V_O = 127 - V_S$$

The results of the first calculations indicated that the computed depths were systematically too small. Both $V_O$ and $\alpha$ were adjusted to give values that corresponded to nautical charts of the area. Depths for the entire island chain were then computed. In making these adjustments it became apparent that values for $V_O$ and $\alpha$ are not separable. There is a broad range where any consistent values for $V_O$ and $\alpha$ will give equally reliable results. It is also necessary to account for the tide in obtaining these calibration constants and in computing depths.

Band 4 of Landsat was used for these calculations since it provides the deepest water penetration. Band 5 can also be used for shallow water areas where the bottom is a very good reflector (white sand or coral) and band 4 may saturate. Confusion occurs if the depth calculations are attempted over land. This problem was resolved by using band 7 to separate water and land areas. Land was identified by setting the depth equal to zero for all pixels where the band 7 digital count exceeded the average reflectance of water plus one standard deviation. The calculations were carried out by constructing a lookup table for the values of $\alpha$ and $V_O$ rather than computing each depth for each pixel. This resulted in a significant saving of computer time.

The results of the investigation indicated that depths to 20 meters could be estimated within 10%. The last digital count that could be used accounted for 3 meters depth change and indications of the 20- to 23-meter range could also be identified.

The assumptions used in the model require that the surface reflectance, the bottom reflectance, the atmospheric transmission, and the attenuation and scattering of the water column must be constant over the area where any set of values for $\alpha$ and $V_O$ are applied. Errors from these sources were identified where clouds and cloud shadows occurred, where currents carried sedimentary loads, and where bottom reflectance changed. In Palau these errors could be easily identified. It may be more difficult in some other locations.

In my view, this method is very complementary to conventional hydrographic surveys. The Landsat data provides depth information on shallow areas that are difficult or impossible to chart from ships. The ships are most effective at depths greater than Landsat can map. For intermediate depths where both are effective, Landsat could be used to augment ship surveys and to plan effective use of the ships.

Thank you for your interest in this topic. Please feel free to contact me if you have additional questions.

Sincerely,

John M. DeNoyer

John M. DeNoyer
Research Geophysicist