

SECTION 113

THE TONGUE OF THE OCEAN AS A REMOTE
SENSING OCEAN COLOR CALIBRATION RANGE

by

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The land and ocean areas of the earth both receive, in the visible region of the electromagnetic spectrum, their energy from the same source - - the sun. The spectral signature resulting from the interaction of the solar radiation with ocean areas differs, in several respects, from the spectral signatures of terrestrial scenes. In general, terrestrial scenes remain stable in content from both temporal and spacial considerations. Ocean scenes, on the other hand, are constantly changing in content and position. Additionally, the solar energy that enters the ocean waters undergoes a process of scattering and selective spectral absorption. The result of these processes is to produce an ocean scene of low level radiance and a spectral distribution which has the centroid of the spectrum shifted heavily toward the 450 nanometer wavelength. Ocean scenes are thus characterized as low level radiance with the major portion of the energy in the "blue" region of the spectrum. Terrestrial scenes are typically of high level radiance with their spectral energies concentrated in the "green-red" regions of the visible spectrum. Because of these differences, it appears that for the evaluation and calibration of ocean color remote sensing instrumentation, an ocean area whose optical ocean and atmospheric properties are known and remain seasonably stable over extended time periods is needed. The Tongue of the Ocean, or TOTO for short, is one ocean area for which we have a large data base of oceanographic information and a limited amount of ocean optical data (1).

PHYSIOGRAPHY OF TOTO

The Tongue of the Ocean is located about 220 nautical miles east of Key West, Florida. It is one of the two major submarine channels in the Bahama Banks. (See Figure 1) It is approximately 100 nautical miles long and 20 nautical miles wide, and one nautical mile deep. It is connected to the Atlantic Ocean by Northeast Providence Channel and Northwest Providence Channel and trends southeast into the Grand Bahama Bank, terminating in a circular cul de sac. (2)

Figure 2 is a photograph taken during the GEMINI V flights on August 22, 1965, 1839 hrs G.M.T. From this photograph we can view the southeastern portion of TOTO. The most striking features are the cul de sac where the water is over 750 fathoms deep and the sand bores which are covered by about six feet of water. Note the uniformity of the "water color" in the cul de sac.

Figure 3 is a later photograph taken during the APOLLO IX missions on March 8, 1969, 2010 hrs G.M.T. shows the axial portion of the TOTO channel and the near flank. The southern portion of Andros Island and Golding Cay, which lies in about the middle of Andros Island is also shown. Note again, as in Figure 2, the uniformity of the "color" of the deep TOTO waters.

The northwestern portion of TOTO and Andros Island are shown in this high altitude photograph taken from the NASA RB-57-F aircraft during Mission 147 in November 1970, Figure 4. The complex of buildings and harbor facilities are a part of the Navy Atlantic Undersea Test and Evaluation Center, abbreviated AUTEK.

OPTICAL CHARACTERISTICS OF TOTO WATERS

During the past two years AUTEK has been used as an operating area for conducting three "ocean color" remote sensing experiments. As part of the surface truth portions of these experiments radiometric and spectral radiometric measurements were made in both shallow and deep waters of TOTO.

A review and analysis of these measurements indicates that the intrinsic optical properties of the deep waters of TOTO are quite uniform and relatively stable over extended time periods.

One of the optical parameters used to characterize ocean waters is the diffuse light attenuation coefficient, "K", it is defined as the logarithm of the ratio of underwater irradiance to the surface solar irradiance per meter. In the graph of Figure 5 the curves shown as solid lines were derived from measurements taken with a Water

Clarity Meter which was designed by the Visibility Laboratory of Scripps Institution of Oceanography. (3) The dashed curve was obtained from measurements made by K. J. Hanson, NOAA, AOML-Sea-Air-Interaction Laboratory with an Eppley Underwater Pyranometer (Model 2). Note that the slope of this curve is approximately equal to those of the Water Clarity Meter curves. The differences in the position of the curves are due to the design of the two instruments. The pyranometer measures the broad band solar irradiance from 300 to 3,000 nanometer wavelengths while the Water Clarity Meter measures the solar irradiance corresponding to the sensitivity of the human eye to the visible spectrum.

A second optical parameter somewhat similar to the "K" coefficient employs the concept of the attenuation of a highly collimated beam of imagery forming light, i.e. beam transmittance (4). This is designated as the (α) coefficient per meter. In TOTO waters we have found the median value of $\alpha = 0.12(M^{-1})$ to be a fairly representative value. In Figure 6 is plotted the variation of " α " with depth, and on the same scale the temperature with depth. It is of some interest to note the trend of α to vary with temperature.

In Figure 7 is plotted the spectral irradiance of upwelled light in the deep TOTO waters. As mentioned earlier, the ocean is a low level radiance scene. Note that the maximum spectral irradiance is about 3.5 microwatts per square centimeter per nanometer and is centered at 460 nanometers. The solar incident power corresponding to this wavelength was 105 microwatts per square centimeter per nanometer, so we have had a peak attenuation of 30 fold. In Figure 8 for comparison also plotted are the energy curves for shallow water, that is for about six meters of water covering a white sand bottom. We see that the selective absorption processes have not proceeded to extinction in the shallow water and that some energy in the 600 to 700 nanometer band has been transmitted out of the water. It follows that if we have a knowledge of the shallow water depth and bottom reflectance characteristics, the water depth can serve as an optical filter to vary the spectral content of shallow water scenes.

CONCLUSION

In order to meaningfully evaluate the performance and to calibrate ocean color remote sensing instrumentation, a large area of the ocean, with a typical marine atmosphere, is needed. Terrestrial sites are not suitable since they do not have the characteristics of ocean scenes. Recent work in TOTO has indicated that these waters are ideal for an ocean color remote sensing calibration range.

REFERENCES

- (1) "Environmental Atlas of the Tongue of the Ocean, Bahamas", SP-94, U.S. Naval Oceanographic Office, Washington, D.C. 20390, 1967.
- (2) "Submarine Geology of the Tongue of the Ocean, Bahamas", TR-108, U.S. Naval Oceanographic Office, Washington, D.C. 20390, 1962.
- (3) "An Oceanographic Illuminometer for Light Penetration and Reflection Studies" SIO Ref 68-11, July 1968, Scripps Institution of Oceanography, Visibility Laboratory, San Diego, California 92152.
- (4) "Light in the Sea", S.Q. Duntley, Journal of the Optical Society of America, Vol. 53, No. 2 Feb 1963.

FIGURES

- Figure 1. The Tongue of the Ocean is located about 220 nautical miles east of Key West, Florida. The boundary of TOTO is shown as the dashed line just east of ANDROS ISLAND.
- Figure 2. From this photograph taken on orbit 19 of the GEMINI V mission on 22 August 1965 at 18:39 G.M.T. hrs we can view the southeastern portion of TOTO.
- Figure 3. In this later photograph taken on 8 March 1969 at 20:10 hrs G.M.T. during the APOLLO IX mission shows the south end of ANDROS ISLAND up to Golding Cay.
- Figure 4. The northwestern portion of TOTO, ANDROS ISLAND and AUTEK are shown in this high altitude photograph taken from the NASA RB-57F aircraft during mission 147.
- Figure 5. "K" coefficient from TOTO waters.
- Figure 6. "a" coefficient for TOTO waters and temperature variation with depth.
- Figure 7. Upwelled spectral irradiance for deep TOTO waters.
- Figure 8. Shallow and deep water upwelled spectral irradiances for TOTO waters.















