OCEAN COLOR IMAGERY - COASTAL ZONE COLOR SCANNER

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ABSTRACT

Investigations into the feasibility of sensing ocean color from high altitude for determination of chlorophyll and sediment distributions have been carried out using sensors on NASA aircraft, coordinated with surface measurements carried out by oceanographic vessels. Spectrometer measurements in 1971 and 1972 led to development of an imaging sensor now flying on a NASA U-2 and the Coastal Zone Color Scanner to fly on Nimbus G in 1978. Results of the U-2 effort have shown the imaging sensor to also be of great value in sensing pollutants in the ocean.

INTRODUCTION

In preparation for the flight of the Coastal Zone Color Scanner (CZCS) on Nimbus G in 1978, a breadboard scanner has been constructed for use on a U-2 aircraft. The scanner has ten spectral bands ranging from 433 to 772 nm center wavelength with spectral bandwidths from 20 to 27 nanometers. The gain of each channel was set, based on the 1972 CV 990 Ocean Color Expedition results, to be optimum for water as viewed from high altitude with the exception of one channel, at 733 nanometers, that has a gain like that of the LANDSAT MSS, optimized for land.

Provision has been made to adjust gains for time of day and seasonal sun angle effects and to offset the contribution of atmospheric backscatter to the signal. This allows the data collection system to be most efficiently used for recording the effects of ocean color without wasting dynamic range on the contribution of the atmosphere.

Flights began in April 1974 and have covered targets off the West Coast, lakes in California and Nevada, the Great Lakes, and the East Coast from the New York Bight to Florida and the Gulf of Mexico from Key West to Timbolier Bay.

The New York Bight has been of special interest because it provides an opportunity to study both the sediment plume of a major river and the effects of large-scale waste dumps going on continually in the Bight.

Data from the Bight, taken on a number of overflights, show the sediment plume in several parts of the tidal phase and a gap, possibly caused by a gyre, separating the plume from the dumping areas. Dispersion from the dump areas, seen on several occasions, shows a predominant movement to the Northeast and Southwest, toward Long Island and New Jersey, with little motion to seaward in the first few meters visible from the plane. This work has led to participation in an extensive program called MESA (Marine Ecosystems Analysis), a NOAA-led investigation of the New York Bight.

Investigations off Tampa, Florida were carried out, in cooperation with the State of Florida, to begin assessment of the ability of multispectral scanners to locate, identify and quantify so-called red tide blooms. Algae blooms, already fairly well developed, were easily detected and a program involving laboratory, ship and U-2 movements set up to begin in the Fall of 1975.

Investigations off Sanibel Island, Tampa Bay and Panama City, Florida, and Timbolier Bay, Louisiana were carried out in November 1974 with surface truth measurements carried out by personnel from Moody College, Texas A&M University aboard the RV Calypso. These measurements are being compared with the surface truth measurements to determine gradient levels that can be detected and the quantitative accuracy that can be realized.

TECHNIQUES

The U-2 Ocean Color Scanner (OCS) senses simultaneously in ten spectral bands with a spatial resolution of 3.8 milliradians from an aircraft altitude of 19.8 km. Swath width is 20 nautical miles with a recording time of 2 hours available per flight on magnetic tape of the scanner output. The scanner is supported by four Mitchell-Vinten 70mm cameras that are normally loaded with black and white film in three of the cameras filtered for green, yellow and red and one camera loaded with SO 242 color film with an ultraviolet haze filter.

The OCS has ten spectral bands ranging from 433 to 772 nanometer center wavelength as shown in Table I. The radiance for saturation is shown in Table I for a gain of 1 for each channel. Gain may be increased separately for each channel in steps of 1.5, 2 and 3 to allow for changing sun angle due to seasonal changes or time of flight. All channels except 9 are optimized for water scenes, including atmospheric backscatter as seen from 19.8 km. Channel 9 has the same level of gain as the LANDSAT Band 6 that covers 700 to 800 nanometers.

TABLE I

PARAMETERS OF THE U-2 OCEAN COLOR SCANNER

Channel	Center Wavelength (nm)	Bandwidth (nm)	Radiance (Gain x 1) $mw/cm^2\mu$
1	433	22.5	40.1
2	471	21.5	26.0
3	509	27.5	23.6
4	547	24.5	14.7
5	583	25.0	11.8
6	620	26.0	10.0
7	662	22.0	7.55
8	698	20.5	5.0
9	733	22.5	11.9
10	772	23.0	3.47

All ten bands are recorded in the analog mode and, at this writing, any four bands selected are digitized and multiplexed on the aircraft together with time code. A new digitizer, now on order, will allow all ten channels to be digitized simultaneously on the aircraft. The data system is operated by the U-2 pilot by on-off switch and a reset button for the digitizer. Reset will not be required in the new system. Time of data collection is usually determined from a flight plan prepared in advance although on some occasions the pilot has to exercise judgement such as when overflying an event such as a red tide that cannot be precisely located before flight.

Glint from the ocean surface is a serious problem that can obliterate any information about the content of the water below the surface. Early flights, in April 1974, showed that glint would appear in imagery, even in flights flown in the morning with relatively low sun angles. It was determined that glint could largely be avoided by flying before 10:30 a.m. and after 1:30 p.m., local sun time, and by flying directly toward or away from the sun whenever possible.

After flights, data is formatted and processed to tapes of calibrated radiance. When imagery is produced, an offset is applied to each channel to remove the DC background due to atmospheric backscatter. Black and white negatives are produced using a digital image processor and utilized to produce false color imagery. For analytical purposes, to develop algorithms, the data is reproduced as graphs of radiance along scan lines and grid print maps.

RESULTS

The first flights were conducted in April 1974 with tests from Wallops Flight Center. A flight was conducted on April 27 with one pass over the New York Bight on a due North-South line. The pass over the mouth of the Hudson clearly showed the Hudson River sediment plume and a waste dump with dispersion. The result, shown in Figure 1, is a false color image using the channels at 471, 583, and 662 nanometers.

The bright blue spot just south of Long Island is sun glint with ship wakes, one in the square pattern of a dump barge. Figure 2 shows three camera images from the color camera taken at 30-second intervals. The circular glint pattern, in the southeast corner of each image, varies in diameter due probably to varying surface roughness. Since the scanner lines run through the center of each image, from East to West, the glint pattern appears on scanner imagery only when the glint pattern extends to the North far enough to be seen by the scan line. Subsequent flights were flown directly toward and away from the sun, whenever possible, and at times of low solar elevation.

Since Nimbus G will fly in a high noon ascending mode orbit, a scan tilt mechanism is incorporated into the Coastal Zone Color Scanner to tilt the scan away from the sun glint in either hemisphere.

A flight conducted on July 22, 1974 utilized the flight line information garnered from the first flight and avoided glint entirely. This flight, conducted at very nearly the same time as the April flight, and hence at a higher solar elevation, again shows the Hudson plume and an acid waste dump in the Bight. This image, Figure 3, obtained at slack water on the high tide, shows considerable detail but more detail can be seen by further enhancement. Figure 4 is a color enhanced image obtained by multiplying the ratio of Channel 4 divided by Channel 5 times the ratio of Channel 7 divided by Channel 5.

In response to a request from the State of Florida, a program is being developed to determine the optical properties of the Gymnodinium breve organism, known as "Red Tide" and to develop techniques for detecting algae blooms early in the event. This program will begin intensive effort in the summer of 1975 but some preliminary work was done in 1974 to familiarize personnel of the Department of Natural Resources of Florida with remote sensing techniques.

On September 9, 1974 a flight was flown conducted over the Tampa Bay area on the West Coast of Florida. No Gymnodinium breve was present but a concentration of the blue-green organism Oscillatoria erythrea was seen in the southwest corner of the image. Figure 5 shows the image, again made with enhanced data from Channels 2, 5, and 7. In addition to the algae bloom, sediments can be seen around the mouth of Tampa Bay, including a fan-shaped plume from Johns Pass, north of Tampa Bay.

Several flights have been conducted over the Chesapeake Bay in order to discriminate areas of high and low sediment concentration. In recent years, the clam population of the Chesapeake has been contaminated with bacterial levels so high that clamming was forbidden in many previously productive areas. In fact, in the summer of 1972, following Hurricane Agnes, all clamming was stopped in the Maryland portion of the Chesapeake.

Much of the pollution that enters the bay and is concentrated by clams comes from the Susquehanna River that drains large areas of Pennsylvania and New York before emptying into the Chesapeake. Bacteria laden particles enter the Bay and proceed toward the Atlantic but are subject to tidal motion, as well as river flow, as soon as they enter the Bay. It is desirable to determine sediment patterns as a guide to flow of material from the Susquehanna. Figure 6 shows a scanner image of the Upper Chesapeake Bay from the mouth of the Susquehanna to Gibson Island. The brighter areas are areas of high sediment concentration with anomalous areas of very low scattering, hence very little suspended particulate matter off the mouth of the Chester River and Bodkin Creek. These studies will be continued as often as possible to build up a base of experience on sediment motion in the Chesapeake.

In November 1974, an opportunity arose to conduct investigations in conjunction with surface truth measurements being carried out, in the Gulf of Mexico, by personnel from Texas A & M University aboard the RV Calypso. The Calypso was available for about one week to carry out investigations along the Gulf Coast from Key West, Florida to the Timbolier Bay area in Louisiana.

In cooperation with the Texas A & M personnel, a sampling plan was devised to provide coverage of a reasonably large area in a short period of time. A track was selected in the direction of the proposed aircraft flight and ten nautical miles long. The Calypso carried out extensive sampling at stations at the beginning and end of the ten-mile track and at the midpoint. Small, inflatable outboard boats were deployed on either side of the larger vessel collecting samples and making measurements at 1-mile intervals four miles out on either side of the larger vessel. The small boats were tracked by radar to verify location and each collected samples at 12 locations as shown in Figure 7. In this manner, an 80-square mile area was sampled in about 4 hours.

The large vessel track, A to B to C, is parallel to the aircraft flight line and the small craft tracks perpendicular to the flight path but parallel to the sensor scan line direction. This allows fairly easy comparison by selecting one scan line that falls along a set of readings. Figure 8 shows the radiance values for four spectral channels (2, 4, 5 and 7) along a position centered on 29°32'N, 85°28'W in the Gulf of Mexico off Panama City, Florida. Also shown are the chlorophyll measurements at the surface for each sampling point.

A preliminary algorithm has been applied to some of the measurements using two channels at a time. Using only two channels, Channels 4 and 7 appear the best in a formula where

$$\frac{R_7}{R_4} = a + b \log_e C$$

where R_4 = radiance (unenhanced) 547 nm

R_7 = radiance (unenhanced) 662 nm

a = 0.309

b = .0166

C = chlorophyll Mg/M^3

A comparison along the track is shown in Figure 9. The algorithm was next applied to the scene to produce the image shown in Figure 10. This is the first attempt at applying an algorithm to imagery and will be further refined to utilize more than one channel.

CONCLUSIONS

A scanner with spectral channels and dynamic range optimized for ocean color can detect subtle color changes even through the earth's atmosphere. If the sensor has a reasonably high signal-to-noise ratio, much of the atmospheric backscatter can be eliminated by subtracting a DC offset from the total signal and preserving the modulation caused by color changes in the ocean. Quantification of parameters such as chlorophyll concentration, on a global scale, will require extensive research effort, prior to the launch of the Nimbus G CZCS, to include high altitude aircraft scanner flights coordinated with far more extensive surface truth measurements than have been accomplished to date.

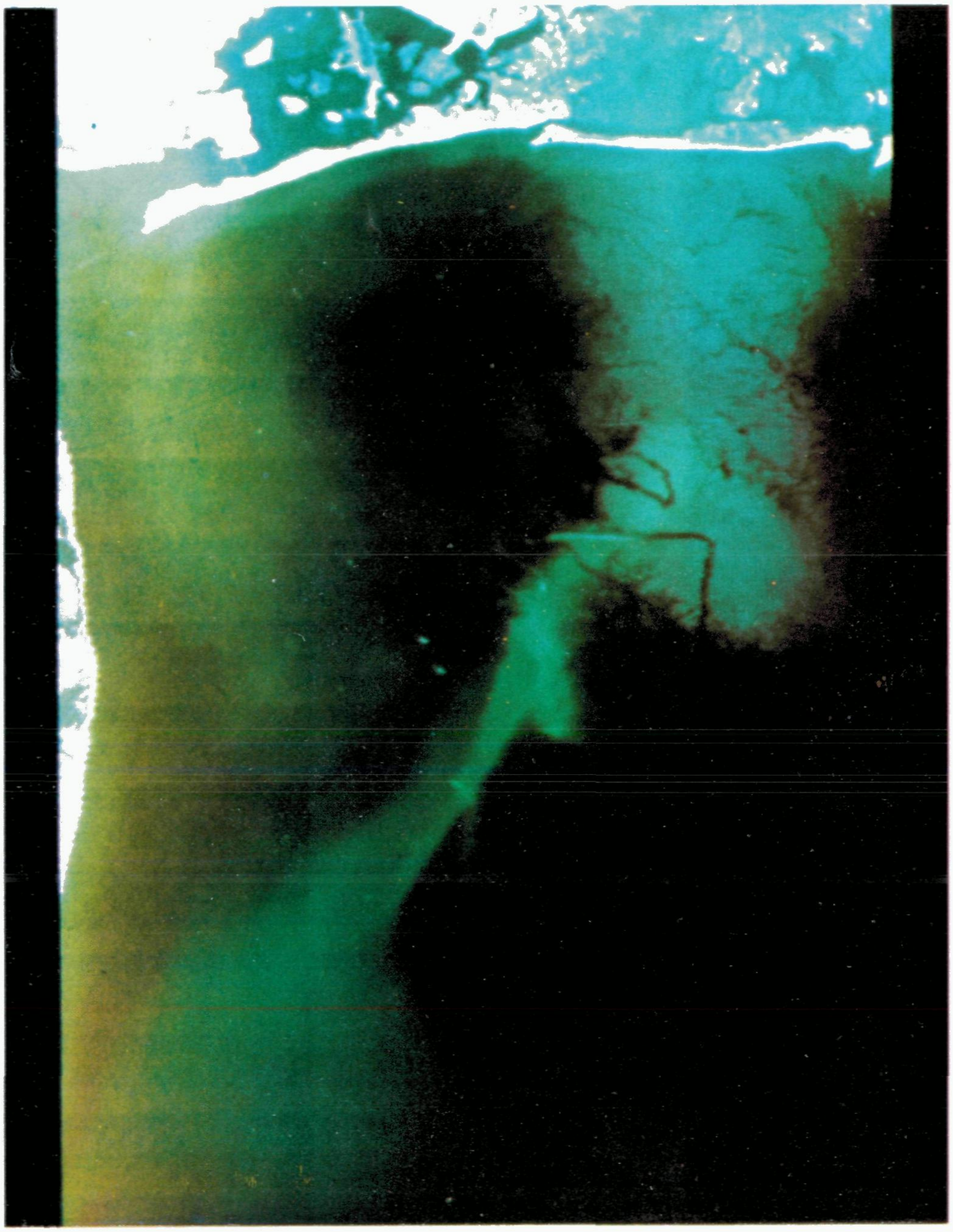


FIGURE 1

False Color Image, New York Bight, April 27, 1974
showing Sediment Plume, Waste Dump, Sun Glint

FIGURE 2

Color Photographs of New York Bight
showing Glint Patterns

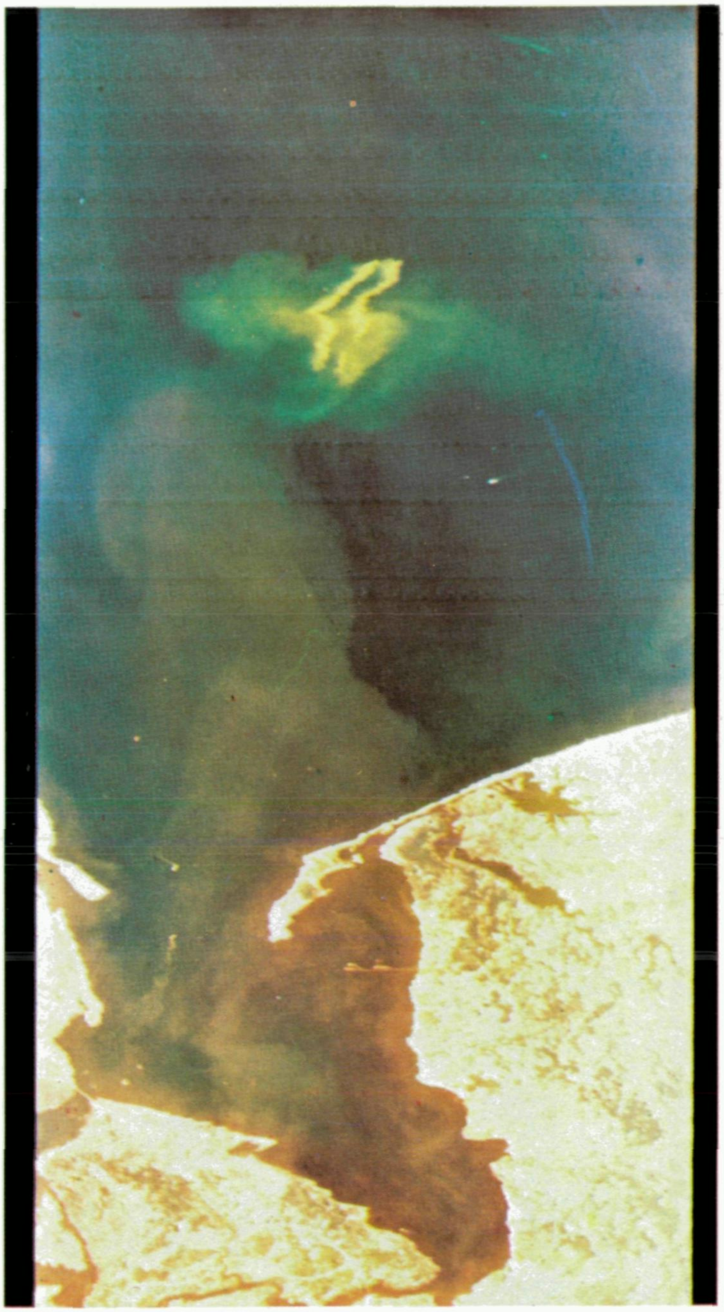


FIGURE 3

False Color Image, New York Bight, July 22, 1974
showing Hudson River Plume, Acid Waste Dump

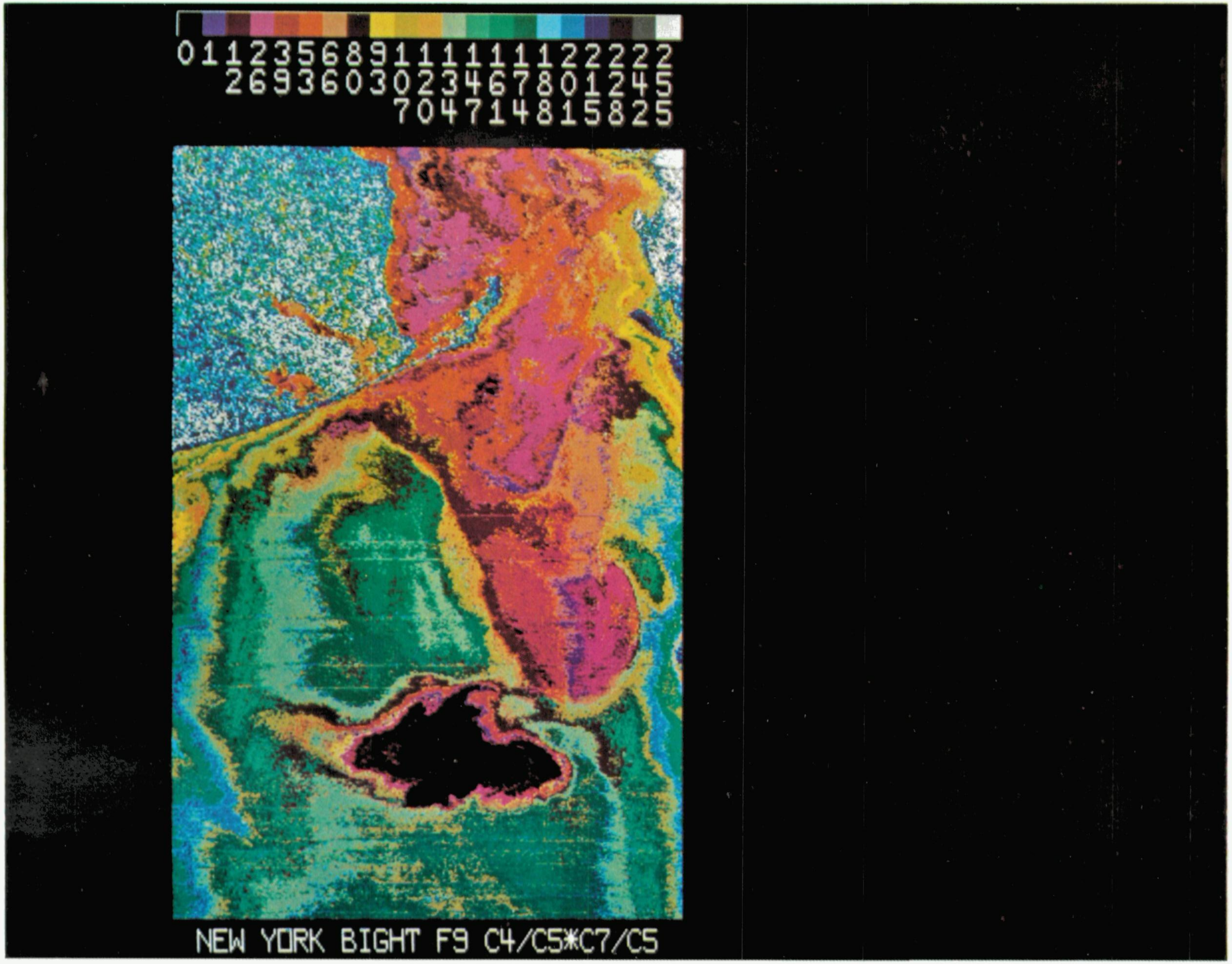


FIGURE 4

Enhanced Color Image of Figure 3
showing Detail of Hudson River Plume

FIGURE 5

False Color Image of Tampa Bay Area, Sept. 9, 1974
Dredge Spoil from Johns Pass, Oscillatoria Erythrea

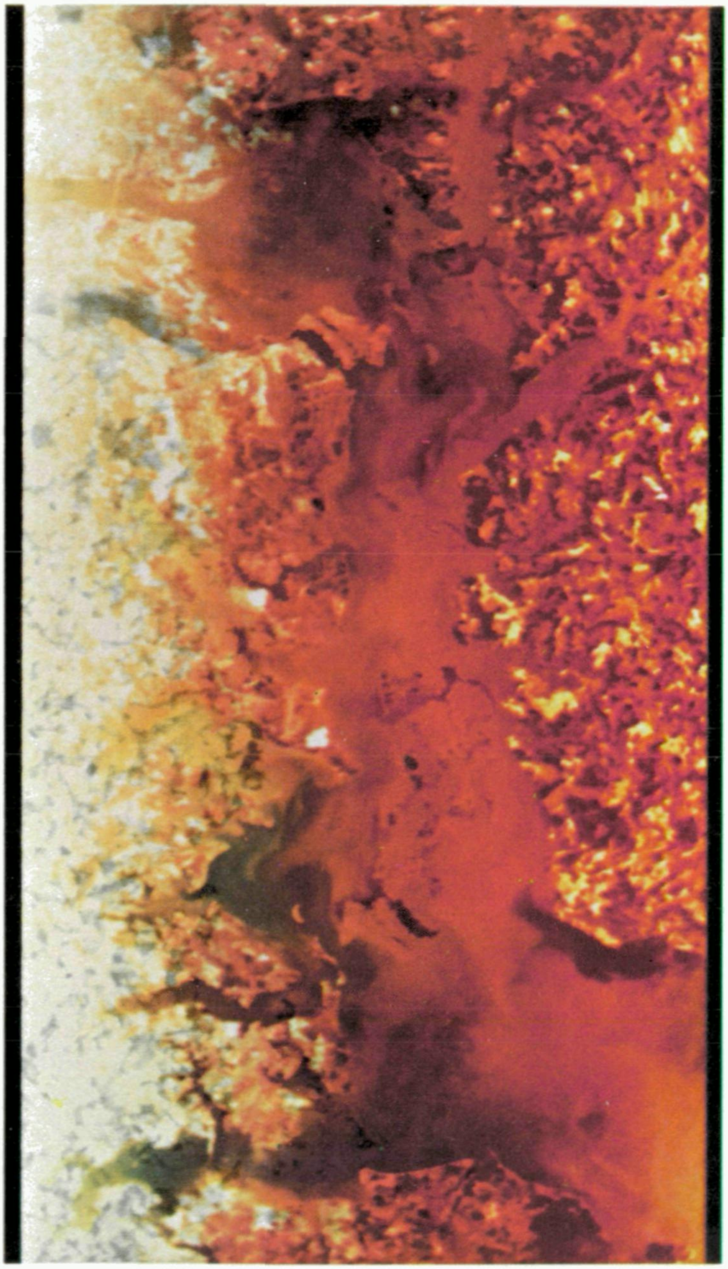
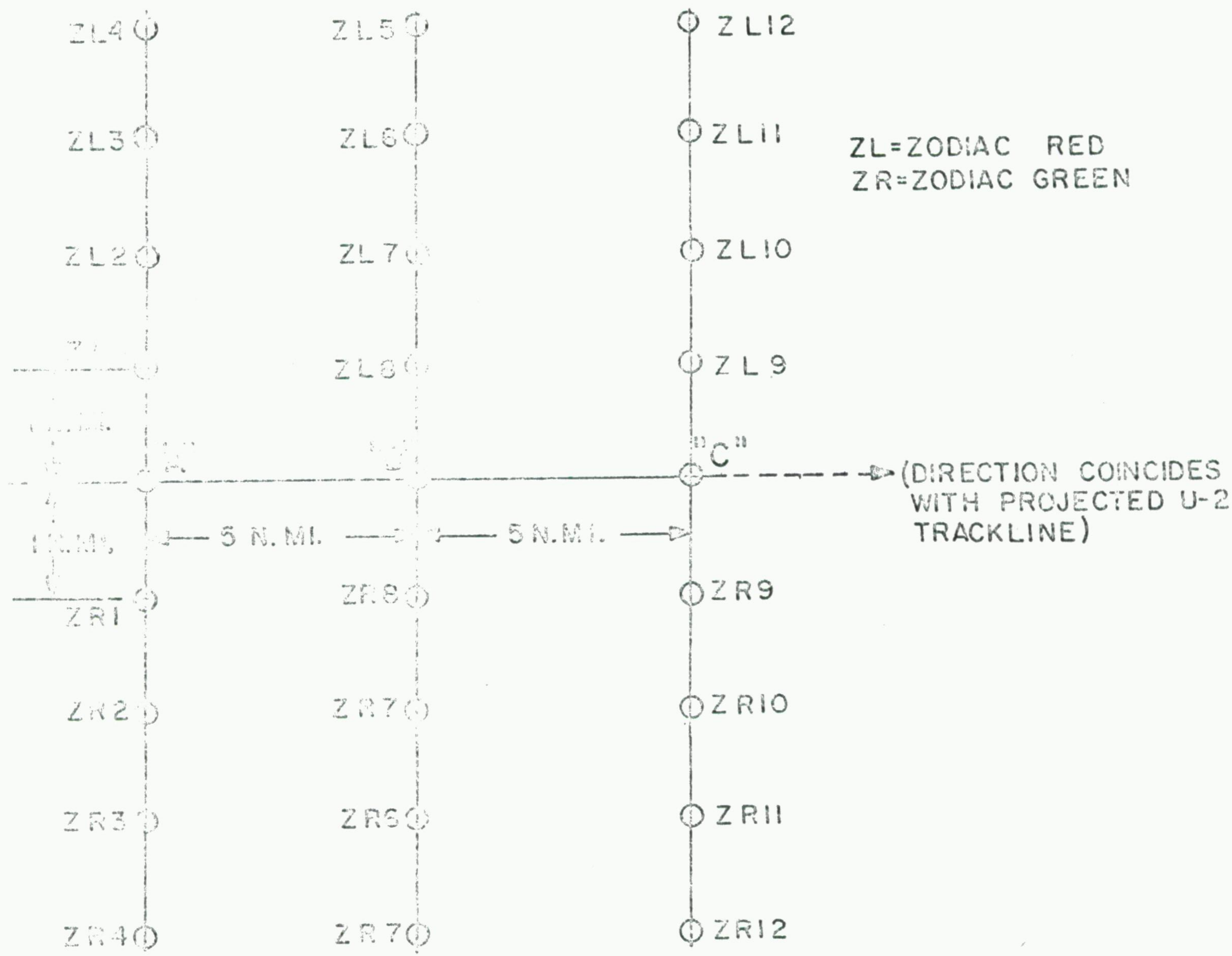


FIGURE 6

False Color Image, Upper Chesapeake Bay, April 27, 1974
Sediment Pattern, Susquehanna River Inflow



GROUND TRUTH-SAMPLING GRID

FIGURE 7

2000

2001

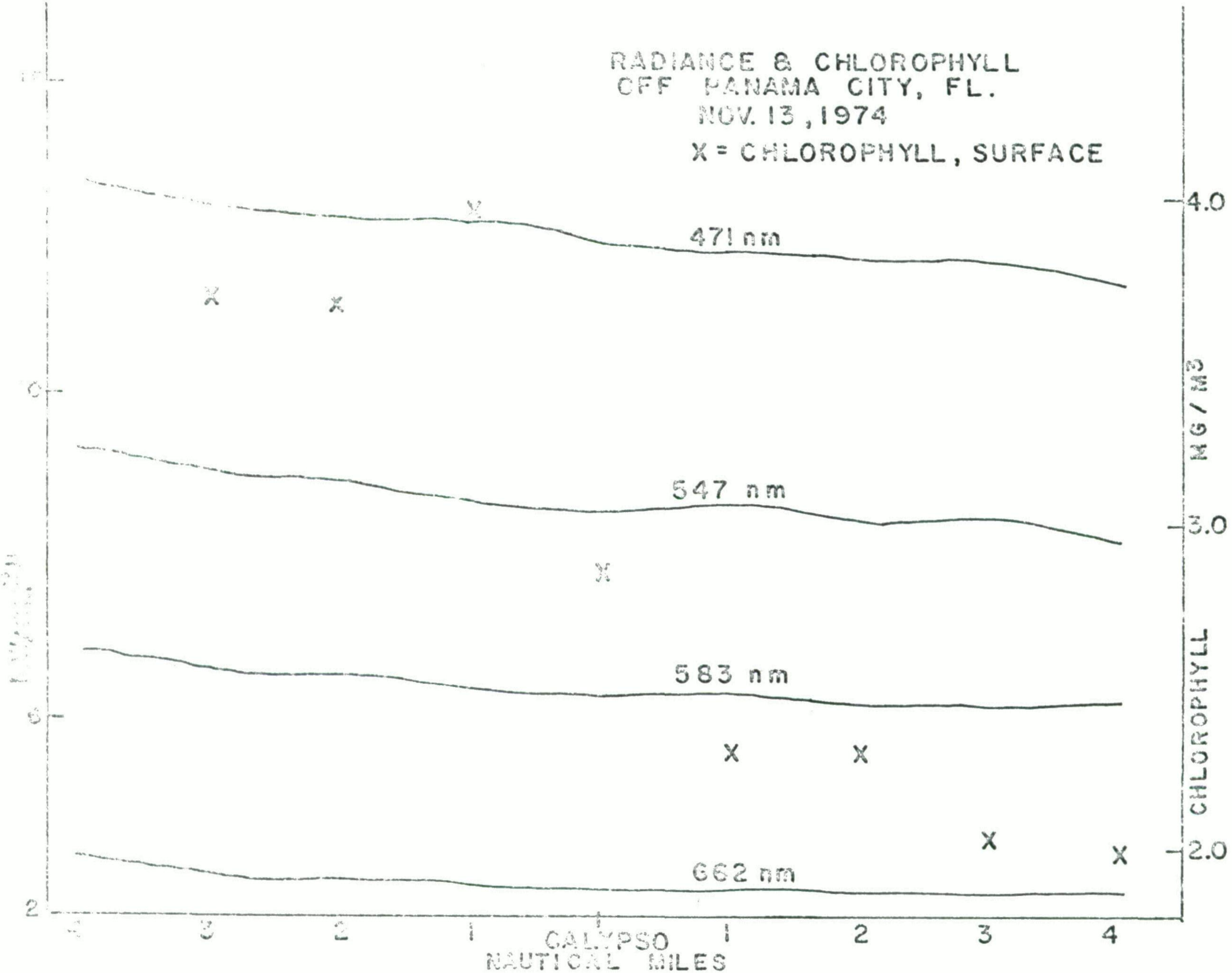


FIGURE 8

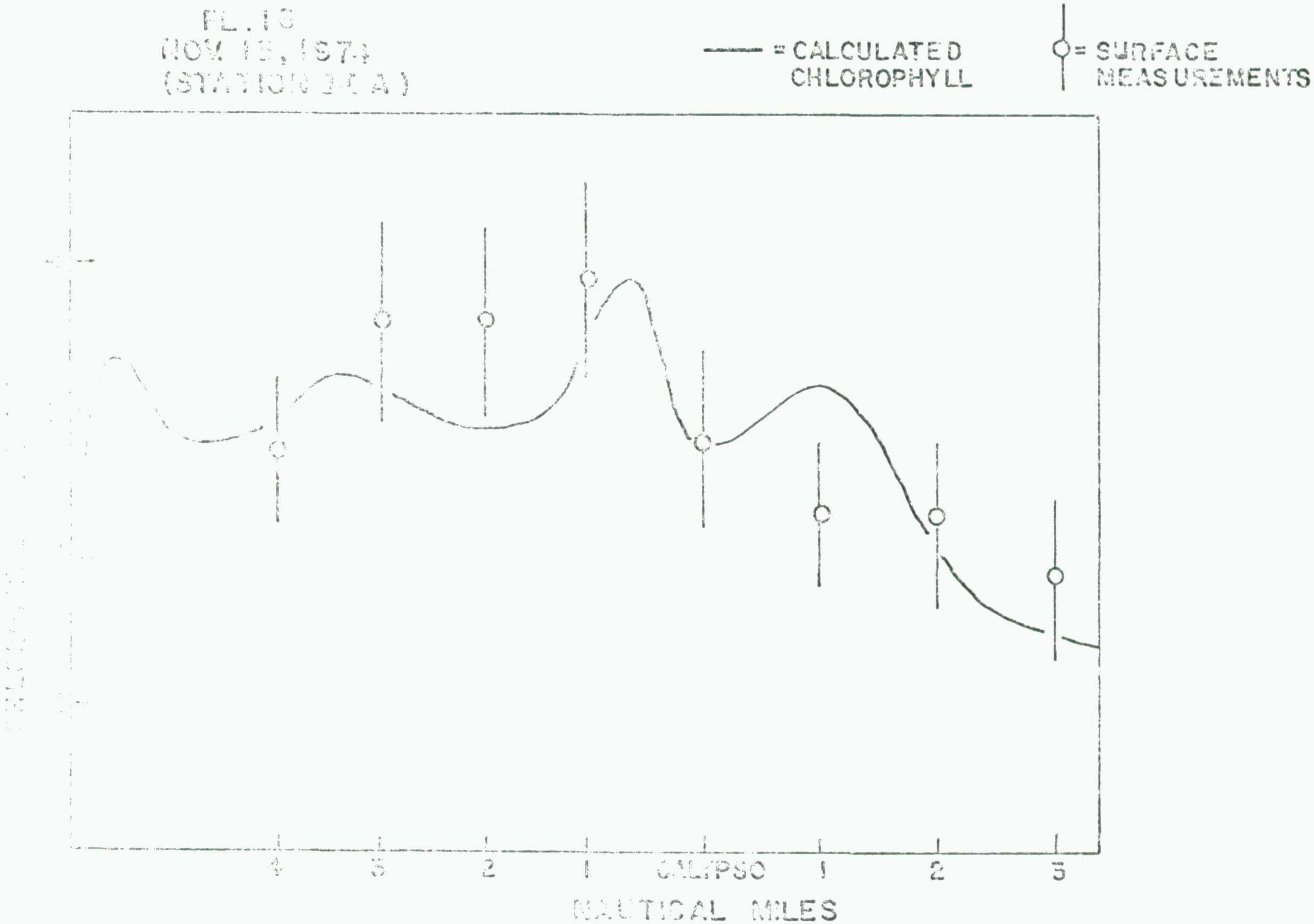


FIGURE 9
Calculated vs Measured Chlorophyll
Off Panama City, Florida

FIGURE 10

Algorithm Enhanced Image of Chlorophyll
Off Panama City, Florida