ANALYSIS OF TESTBED AIRBORNE MULTISPECTRAL SCANNER DATA FROM SUPERFLUX II

David E. Bowker, Charles A. Hardesty, and Daniel J. Jobson
NASA Langley Research Center

Gilbert S. Bahn
Kentron International, Inc.

SUMMARY

The Langley Test Bed Aircraft Multispectral Scanner (TBAMS) was flown during the James Shelf, Plume Scan, and Chesapeake Bay missions as part of the Superflux II Experiment. Excellent correlations were obtained between water sample measurements of chlorophyll and sediment and TBAMS radiance data. The three-band algorithms used were insensitive to aircraft altitude and varying atmospheric conditions. This was particularly fortunate due to the hazy conditions during most of the experiments. A contour map of sediment, and also chlorophyll, was derived for the Chesapeake Bay plume along the southern Virginia-Carolina coastline. A sediment maximum occurs about 5 nautical miles off the Virginia Beach coast with a chlorophyll maximum slightly shoreward of this. During the James Shelf mission, a thermal anomaly (or front) was encountered about 50 miles from the coast. There was a minor variation in chlorophyll and sediment across the boundary. During the Chesapeake Bay mission, the Sun elevation increased from 50 degrees to over 70 degrees, interfering with the generation of data products.

INTRODUCTION

The Langley Testbed Airborne Multispectral Scanner, abbreviated TBAMS, was flown on three missions during the Superflux II experiment in June of 1980. TBAMS is a conventional rotating mirror scanner designed to be flexible with respect to spectral band location and sensitivity. For the Superflux II experiment, eight visible/near-IR bands, each 20 nanometers wide, were selected as given in figure 1. A thermal IR channel was also available. The two curves in figure 1 represent the normalized spectral response of TBAMS for two different water masses with the sediment and chlorophyll concentrations shown. In general, all of the bands respond to an increase in sediment. However, they also respond to an increase in haze, clouds, and other atmospheric parameters. To minimize this interference, spectral bands can be ratioed. The best ratio for sediment is Band 7/Band 8. This ratio is still sensitive to atmospheric variations, however. A better algorithm for minimizing the atmospheric contribution is the three-band ratio, $(\text{Band } 7)^2/(\text{Band } 6 \times \text{Band } 8)$. This algorithm is equivalent to measuring the angular variation of the normalized response curve about Band 7. For the sediment variations shown, this angular change is about 4^{o}. In a similar manner, the three-band algorithm centered at Band 4 can be used to monitor low levels of chlorophyll.

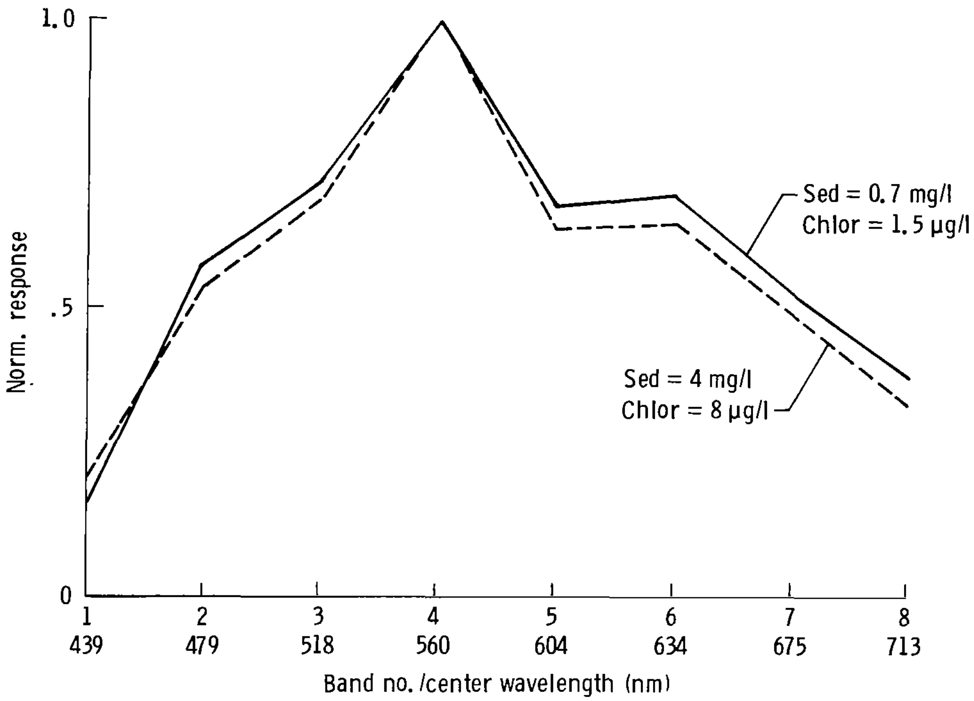

Figure 1. - Normalized response of TBAMS channels.

An indication of the three-band algorithm effectiveness in correcting for atmospheric, or what is more properly termed off-nadir, radiance variations is shown in figure 2. Several scanlines from the end of baseline 4 of the Plume Scan Mission have been averaged to minimize noise and minor variations in the water mass. The radiance variations along each scanline for the three bands shown display the characteristic increase at each end, due primarily to the increased path length from the surface to the sensor. It can be seen that the radiance variation is greatest for Band 6 and least for Band 8. When the three bands are ratioed, the off-nadir variation has essentially been removed while the sediment information has been retained.

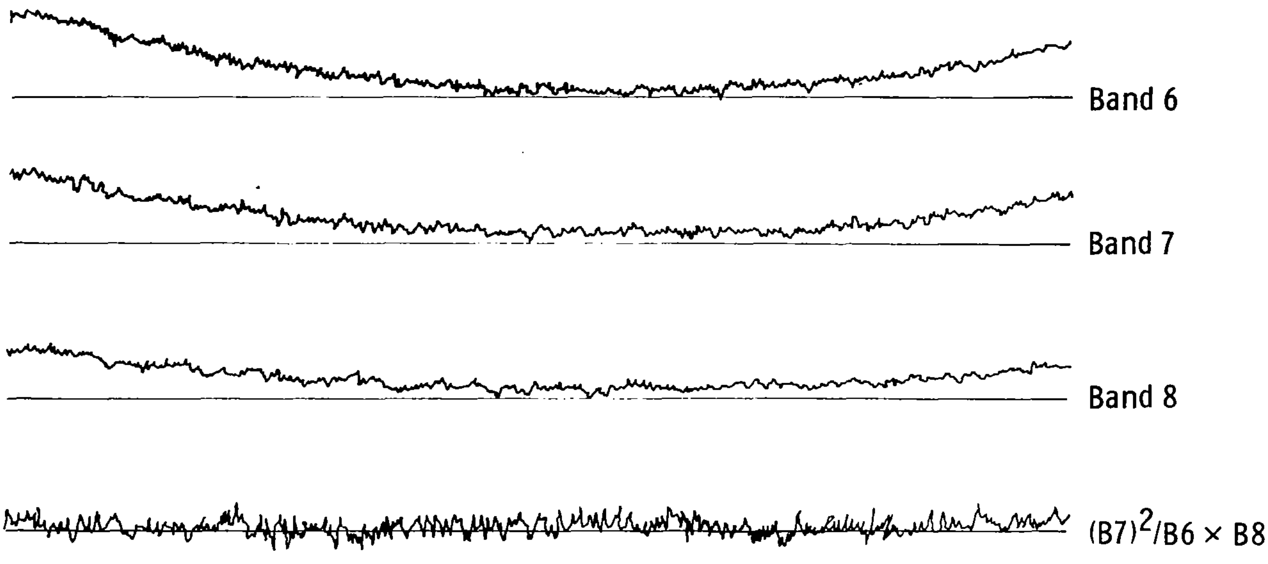

Figure 2. - Relative radiance variation along scan lines.

EXPERIMENT RESULTS

Plume Scan Mission

In order to convert the radiance variations at the sensor into sediment variations within the water column, a calibration curve was established. Ten ship stations located near the Chesapeake Bay entrance were overflown on either June 20 (James Shelf Mission) or June 24 (Plume Scan Mission).

Figure 3 is a plot of the $(\text{Band } 7)^2/(\text{Band } 6 \times \text{Band } 8)$ radiance ratio versus sediment concentration for these stations. Where samples were analyzed from 1m and 3m depths, the two values were averaged to give one value. The aircraft altitude during the overpass of the John Smith on June 20 was 5.3 km, while the altitude for the other stations was 2.3 km. Considering the variations in flight altitude, day of sampling, and haze conditions, this is a good correlation of data for such a small spread in sediment. (On similar experiments in this area during March of 1979, the sediment varied from 1 to 20 mg/1).

Flight lines for the Plume Scan Mission are plotted in figure 4. Originally, the mission was to have been flown at 7 km altitude with the baselines oriented parallel to the coast, but haze forced the aircraft down to 2.3 km and the baselines were oriented essentially perpendicular to the coast whereby the Bay Plume could be contoured. This orientation put the Sun line perpendicular to the scanner direction such that sunglint would

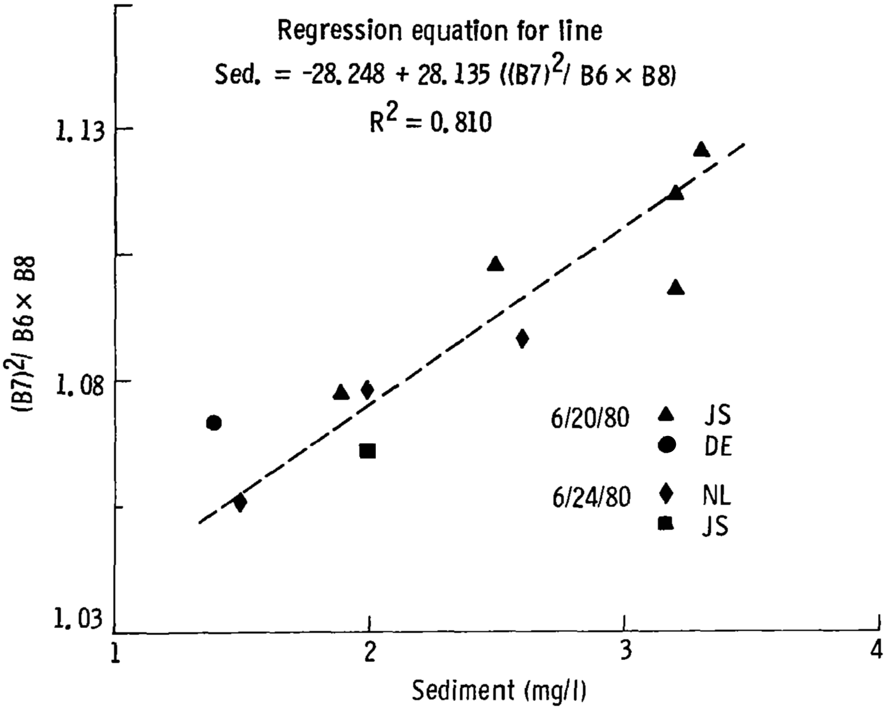

Figure 3. - Regression plot of sediment vs. band 7 algorithm.

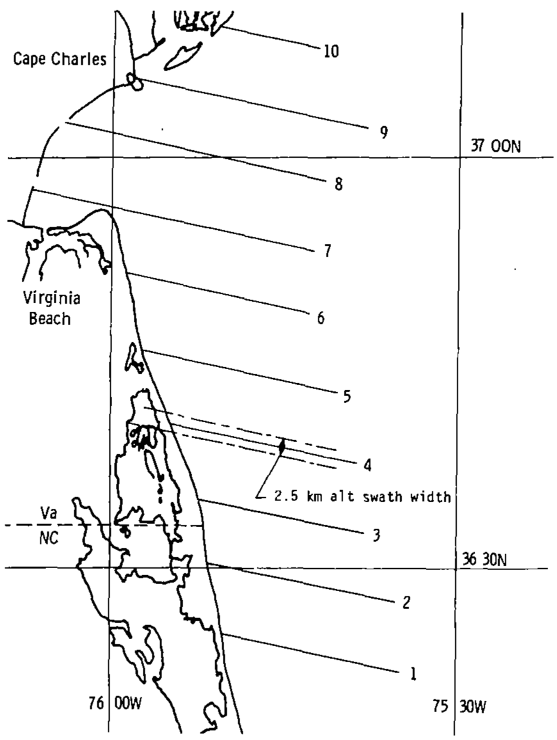

Figure 4. - Plume scan mission flight lines for 6/24/80.

be minimized. At this altitude, the swath width of the scanner is only 1.4 nmi. and two dimensional data products would not be very useful.

Sediment profiles along each baseline were generated using the calibration data from figure 3. Only the 25 scanner pixels at nadir were used in the initial product and then this was smoothed to eliminate the usual electronic and scene noise inherent in high resolution scanner data. The profiles for baselines 6 and 3 are shown in figure 5. In general, there is a high sediment area near the coast and a more pronounced plume reaching a maximum around 6 to 10 nmi. offshore.

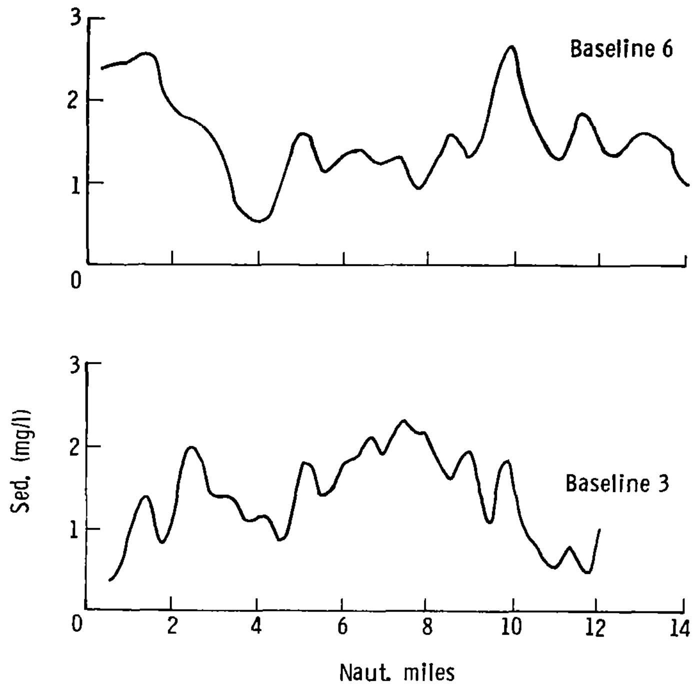

Figure 5. - Plume scan sediment profiles from baselines 3 and 6.

The sediment profiles from the ten baselines were used to construct the contour map presented in figure 6. Only the boundaries of the plume are shown; there were many oscillations about the 2 mg/l contour within the plume, but it was considered distracting to show all of the details on such a small plot. The main feature of the southern portion of the plume is the sediment maximum about 6 nmi. off the Virginia Beach coast. There is a similar maximum northeast of the Bay mouth.

The only ship stations within the scanner field of view are those shown in figure 6. The Warfield, which measured 18 mg/l sediment, was positioned between baselines 6 and 7. To explain this anomaly, we must look at the photography from the high altitude mission on June 20. Figure 7 is a T-11

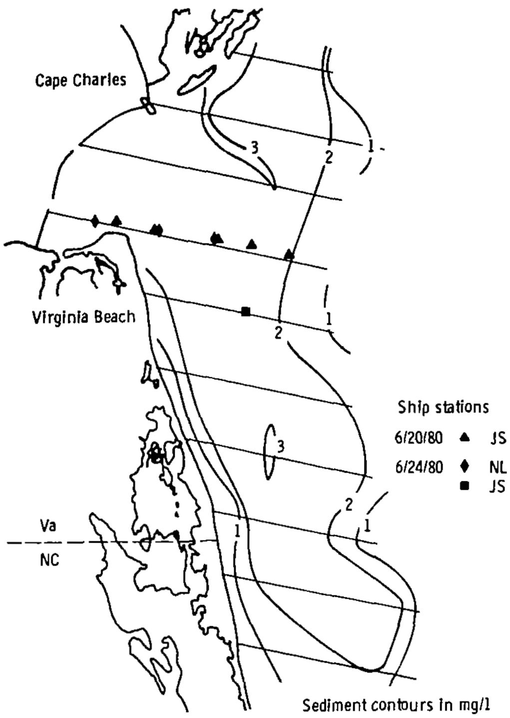

Figure 6. - Chesapeake Bay plume sediment contours for 6/24/80.

		1	2	3	4	5	6
1.	Ch a	1.000					
2.	Ph a	.992	1.000				
3.	Ch + Ph	.999	.990	1.000			
4.	N. Vol.	.024	-.065	.000	1.000		
5.	Vol.	-.380	-.538	-.424	.776	1.000	
6.	Tot. Sed.	.153	.152	.153	.935	.949	1.000

Table 1. - Correlation of ship data from Superflux II.

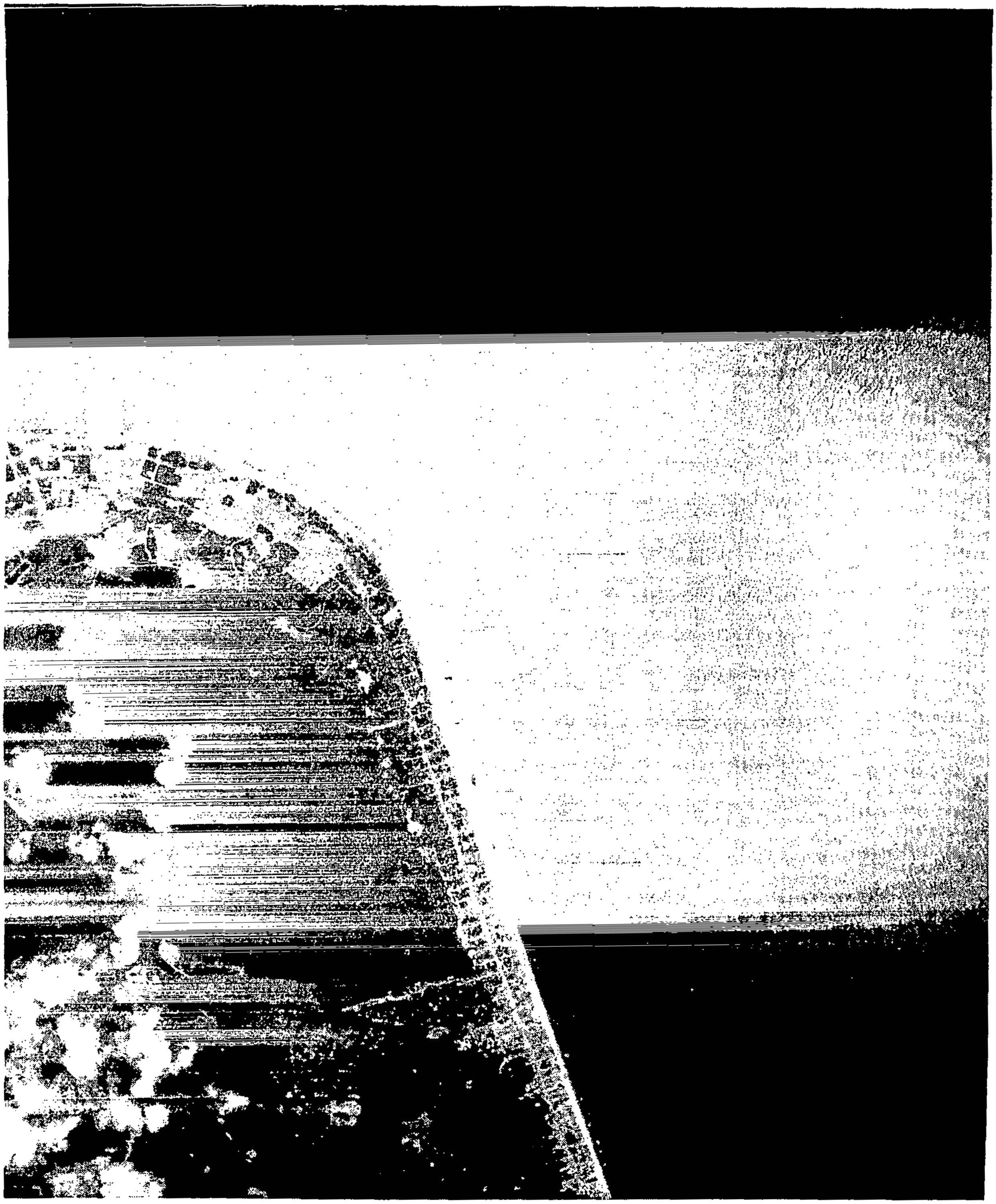

Figure 7.- Photo of Cape Henry area taken on 6/20/80 showing sediment plume.

image taken at 7 km over the Cape Henry area. A sediment plume is seen to follow the coast around Cape Henry and then spread into a front that curves from the Virginia Beach coast toward the northeast. A similar feature was probably present on June 24, in which case the baselines were not optimally located to monitor this important portion of the plume.

Chlorophyll also correlated with TBAMS radiance data, but it is necessary to investigate the relation between chlorophyll and total sediment to determine their degree of independence in the regression data. Table 1 gives the correlation between Ch a, Ph a, non-volatile, and volatile sediment components for the ship data used in the Superflux II data analysis. There were 24 chlorophyll and 17 sediment analyses and 4 volatile/non-volatile separations. The Ch a and Ph a measurements correlate well with each other and with their sum. Since both components influence the upwelled radiance spectra, the sum will be used in the correlation analysis, and where samples were taken at both 1m and 3m depths, an average of the two measurements was made. The low correlations in Table 1 between total sediment and the chlorophyll parameters are somewhat unusual in that these two parameters have generally been found to vary together in this same area. This is fortunate, however, since a regression between chlorophyll and radiances will be independent of sediment variations.

The three-band algorithm centered on Band 4 has been used in the chlorophyll regression analysis. The data are plotted in figure 8 where it is seen that there is an excellent correlation ($R^2 = 0.94$). Again, it should be noted that the radiance data were collected on two different days at two different altitudes; thus, the algorithm has done an excellent job of normalizing the atmospheric influence.

Chlorophyll profiles were generated along each baseline using the relation given in figure 8. A contour plot of this data is shown in figure 9. In the Bay mouth region, there is a minor extension of the contours seaward, but along the coast, the chlorophyll concentration falls off more rapidly. There is a major anomaly on baseline 4, similar to the sediment anomaly, but it is displaced toward the coast about 1.5 km or more. The Chesapeake Bay plume is therefore evident in the sediment map, but not in the chlorophyll distribution.

James Shelf Mission

The flight lines for the James Shelf Mission and the Chesapeake Bay Mission are shown in figure 10. Baseline 7 of the James Shelf Mission was initially flown at an altitude of 5.3 km, but clouds were encountered just beyond the Chesapeake Bay tower and the aircraft had to drop to 2.3 km. The return flight along baseline 8 began about 60 nmi. at sea at 2.3 km altitude. The temperature, sediment, and chlorophyll profiles from baseline 8 are shown in figure 11. Only the initial 25 nmi. of data are given, plotted in a west to east direction. The profiles represent nadir data smoothed in the same way as the previous data. The temperature plot indicates a major anomaly of approximately 1.4° C. which might be the Gulf

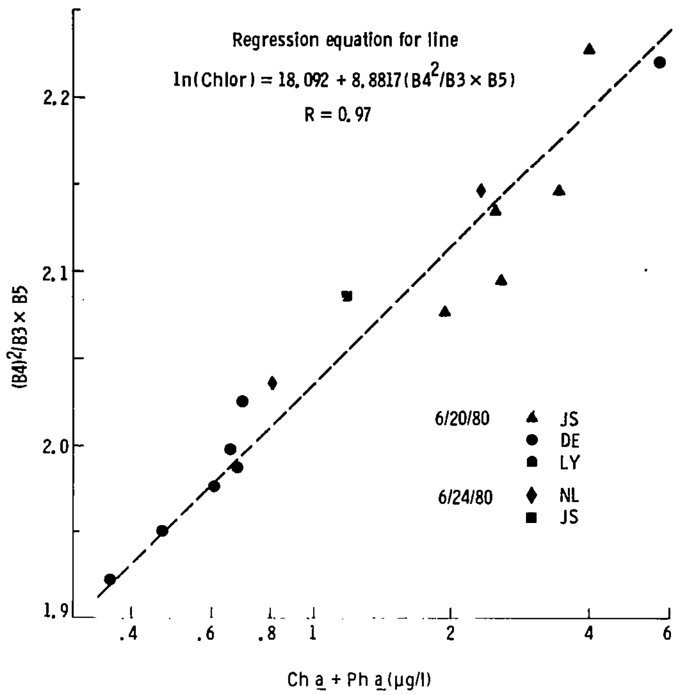

Figure 8. - Regression plot of Ch a + Ph a vs. band 4 algorithm.

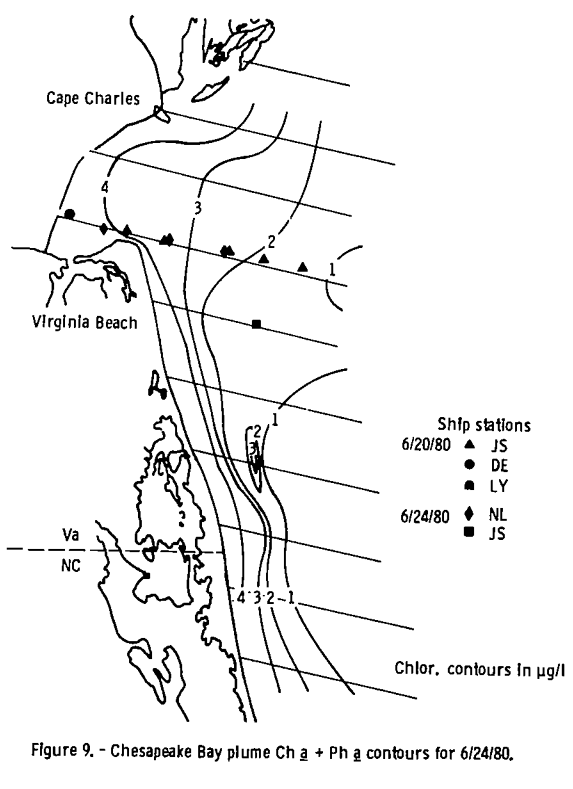

Figure 9. - Chesapeake Bay plume Ch a + Ph a contours for 6/24/80.

Figure 10. - Chesapeake Bay and James-shelf flight lines for 6/19/80 and 6/20/80.

Stream boundary. The sediment and chlorophyll data show only minor variations across this boundary; the data smoothing process would tend to minimize such effects. Baseline 7 profiles for sediment and chlorophyll shown in figure 12 are similar to those taken 4 days later during the plume scan mission.

Chesapeake Bay Mission

The calibration data for the Chesapeake Bay Mission are given in figure 13. There was not sufficient variation in the chlorophyll measurements to establish an adequate calibration. Note that the three-band algorithm centered on Band 5 has been used due to the higher values. The decrease in the radiance values with increasing chlorophyll at the lower end of the scale is real; this algorithm goes negative while the Band 4 algorithm goes positive below 8 to 10 μg/l. Another factor influencing the calibration was sunglint. The flight lines for this mission were basically oriented perpendicular to the Sun direction whereby the scanner looked into the Sun's reflection as it scanned off nadir. This may account for the negative shift in calibration for both parameters.

Figure 14 is a T-11 camera image taken from baseline 3 near Annapolis, Maryland. The vertical line indicates the flight direction, with north at the top. The horizontal line is what the scanner senses when it sweeps from right to left. Although the Sun's orientation is not exactly perpendicular to the flight line, it is evident that sunglint is dominating the scanner data in the right half of the scene. To illustrate this effect, the first

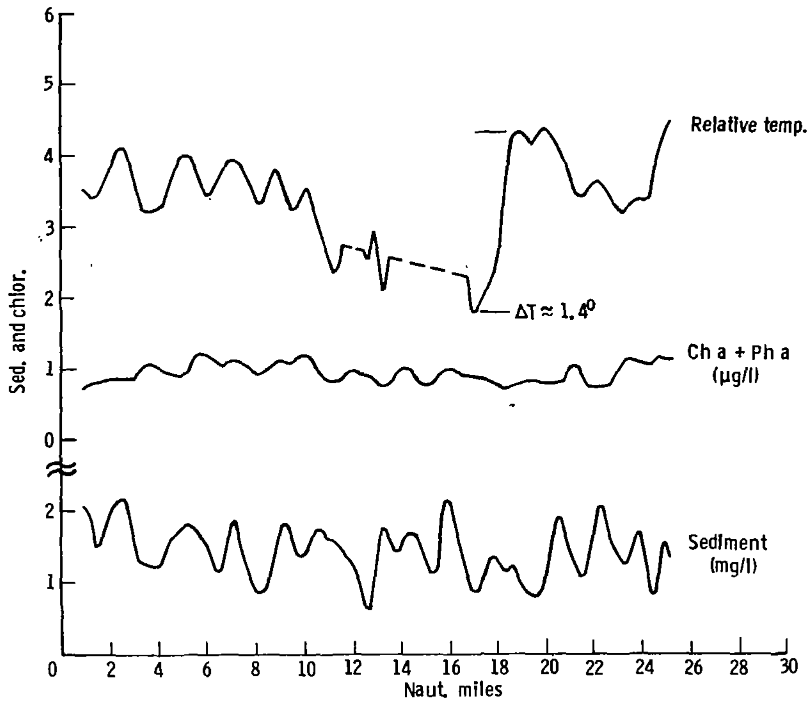

Figure 11. - James - shelf mission baseline 8 profiles.

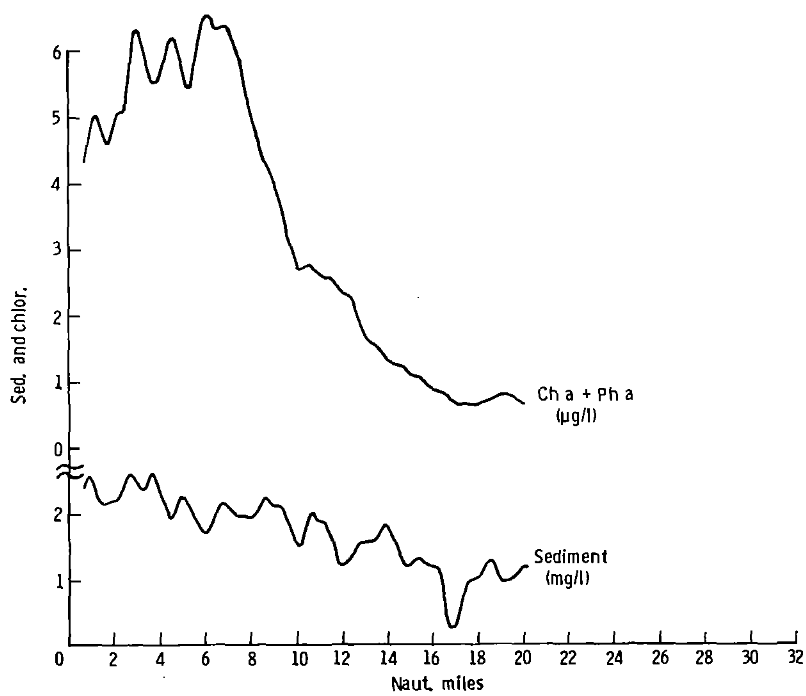

Figure 12. - James - shelf mission baseline 7 profiles.

1,000 scan lines from baseline 3, which contain no land data, were averaged to minimize the influence of sediment variations within the scene. The radiance variation in Band 4, along with the relative variations of the two sediment algorithms, is plotted in figure 15. The large spike in Band 4 is, of course, due to sunglint. The three-band sediment algorithm, which is a ten times enhancement about the value one, indicates a sediment variation from about 1.5 mg/l to 2.5 mg/l, according to the calibration curve in figure 13. By comparison, the Band 7/Band 8 algorithm seems to be more strongly influenced by the sunglint.

Although the three-band algorithm centered on Band 7 appears to normalize the sunglint within the data, it is apparent that the algorithm is not responding solely to subsurface sediment variations. The minimum value in the Band 4 scan has been displaced from nadir, which is at pixel number 350, to beyond pixel 450. Thus, sunglint is dominating most of the data and making it less useful for subsurface information. Surface effects are very pronounced, however, as is evident from figure 14, and operating the scanner in this mode could be beneficial for investigating parameters such as oil slicks.

The Sun elevation was about 50° when the mission started at baseline 1 and by the time the aircraft reached the Delaware Bay, the Sun was over 70°. The image in figure 16 is from baseline 6 near the mouth of the Bay. The aircraft was flying into the Sun and sunglint is evident at the center of the photo. Without subsurface calibration samples for this area, the TBAMS radiance data, which was taken along the vertical line in the photo, would not be effective for generating end products, such as contour maps.

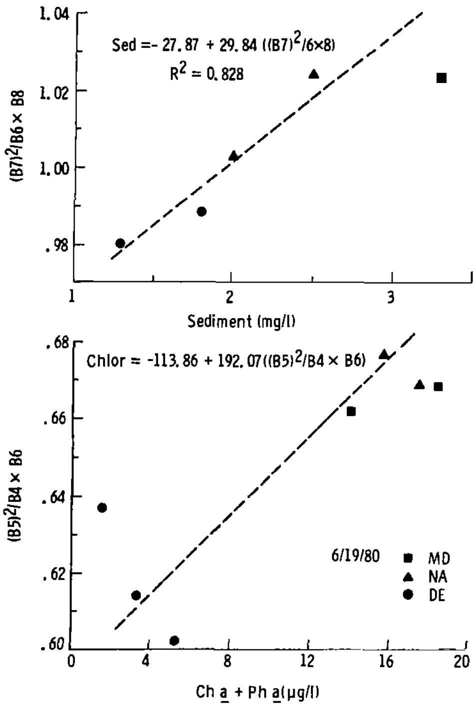

Figure 13. - Regression plots for sediment and chlorophyll from Chesapeake Bay mission.

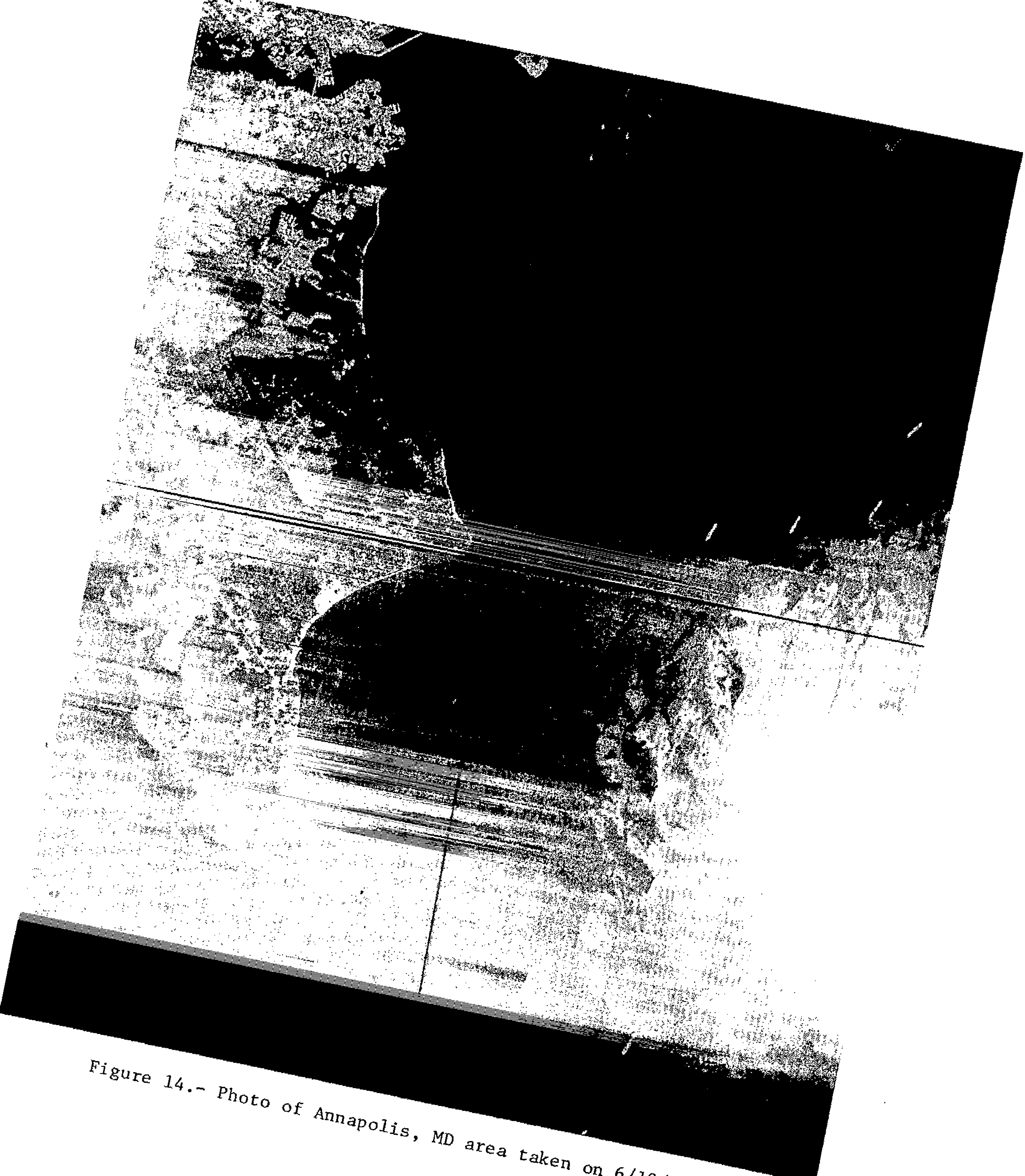

Figure 14.- Photo of Annapolis, MD area taken on 6/19/80.

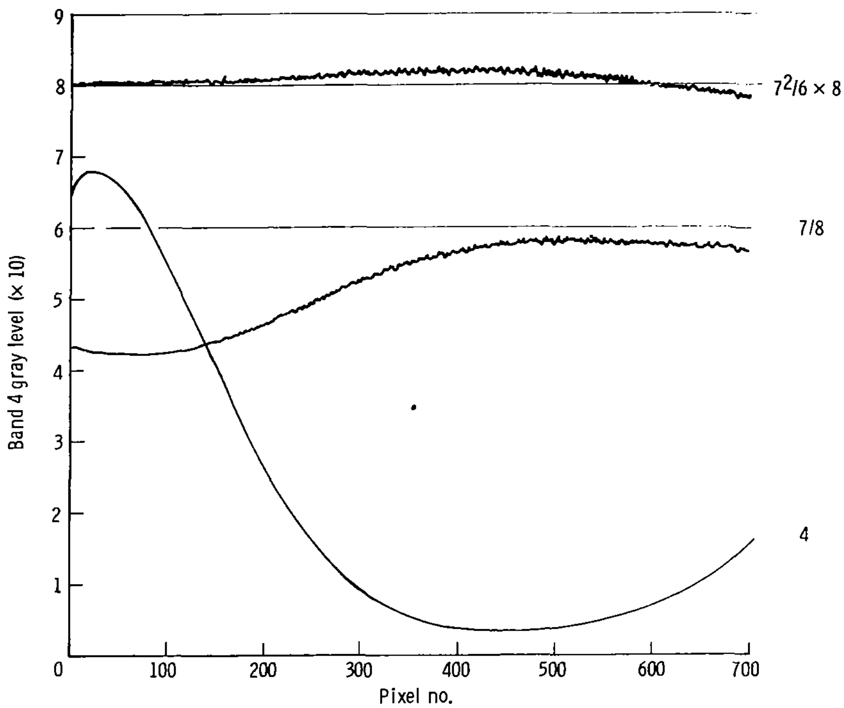

Figure 15. - Radiances from average of 1,000 scanlines beginning of baseline 3 Chesapeake Bay mission.

CONCLUSION

In summary, TBAMS has been successful in fulfilling its objectives during the Superflux II experiment. In particular, three highlights of the missions should be mentioned. First, an algorithm was demonstrated that monitored sediment and chlorophyll and was essentially insensitive to off-nadir radiance variations. Second, the Chesapeake Bay plume was successfully mapped when the sediment and chlorophyll variations were probably at a historic low. And third, it was found that sunglint did not interfere with the mapping mission, although it meant that the sensor was responding to surface reflections and not subsurface upwelling.

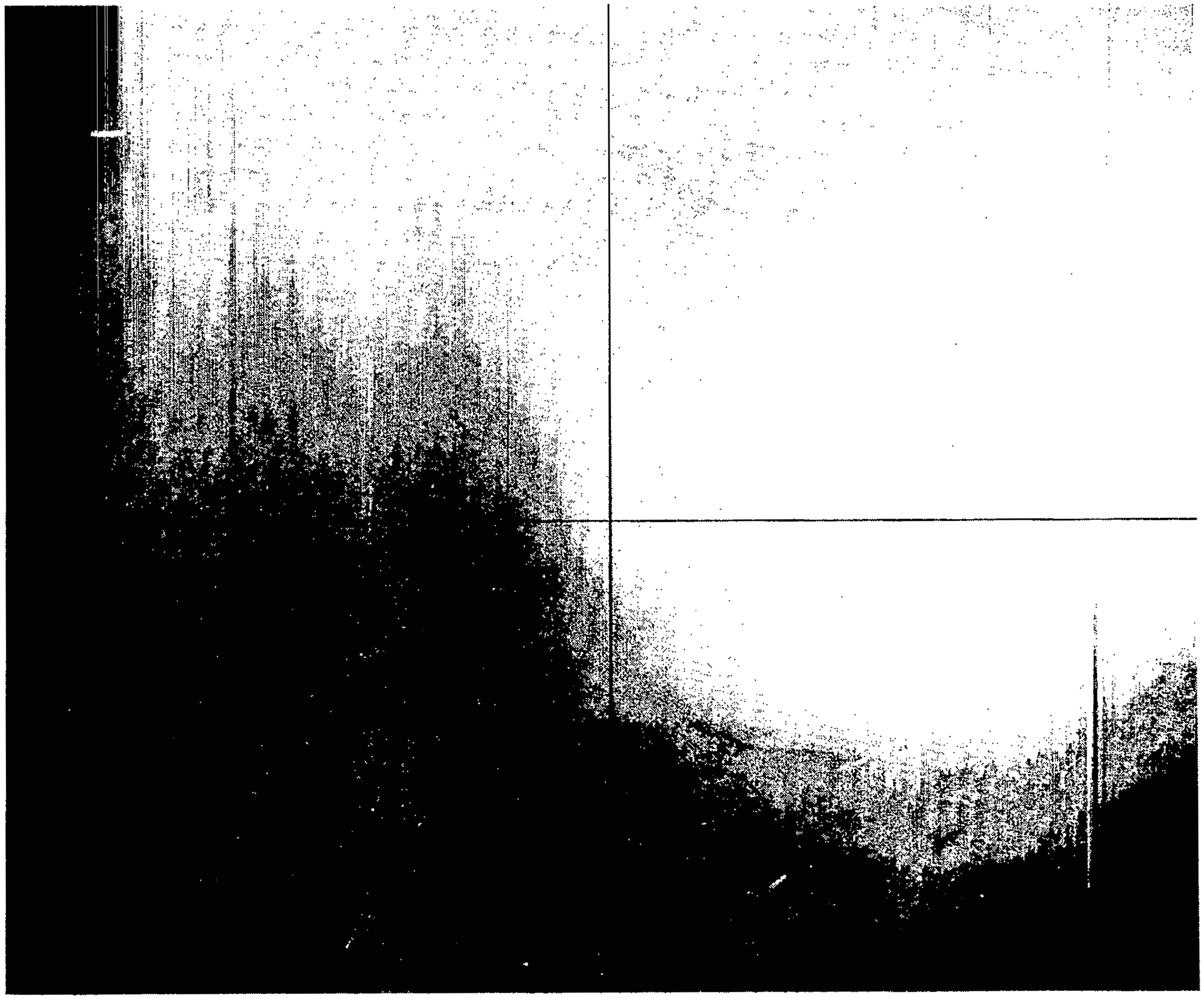

Figure 16.- Photo of Delaware Bay area taken on 6/20/80.