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NOAA Cruise JUL98NAN: Nantucket Shoals Cruise

Ajit Subramaniam[1]
Mary Culver[2]
David Phinney[3]
Douglas Phinney[3]
Jeffery Brown[3]
Brian Schieber[4]
John Brock[5]
David Eslinger[2]
Christopher Brown[6]

[1]REMSA, Inc.
E/RA3, WWBG, Room 711b
5200 Auth Road
Camp Springs, MD 20746-4304

[2]NOAA Coastal Services Center
2234 South Hobson Avenue
Charleston, SC 29405

[3]Bigelow Laboratory for Ocean Sciences
180 McKown Point Road
West Boothbay Harbor, ME 04575

[4]SAIC General Sciences Corp.
SeaWiFS Project
NASA Goddard Space Flight Center
Code 970.2
Greenbelt, MD 20771

[5]Center for Coastal Geology
U.S. Geological Survey
600 4th St.
St. Petersburg, FL 33701

[6]NOAA NESDIS
E/RA3, WWBG, Room 105
5200 Auth Road
Camp Springs, MD 20746-4304

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COASTAL SERVICES CENTER
2234 South Hobson Avenue, Charleston, SC 29405-2413

Abstract

The July 1998 Nantucket Shoals cruise (JUL98NAN) was a cooperative effort among the National Oceanic and Atmospheric Administration's Coastal Service Center's Coastal Remote Sensing Program (NOAA/CSC/CRS), the Bigelow Laboratory for Ocean Sciences and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project Office at National Aeronautics and Space Administration (NASA) Goddard Space Flight Center. Seventeen stations were occupied over five days in Massachusetts Bay, Buzzard's Bay, Nantucket Sound, and Nantucket Shoals.

The standard NASA chlorophyll algorithm consistently overestimates the chlorophyll concentration in Massachusetts Bay by at least a factor of three, while it appears to be reasonably accurate in the Nantucket Shoals region. A regional algorithm needs to be developed for the Massachusetts Bay in order to make SeaWiFS data useful to the coastal managers administering a water body with high anthropogenic impact. There is excellent radiometric agreement at station D2 for the 490, 510, and 555 nm bands, indicating that it is the chlorophyll algorithm and not the atmospheric correction algorithm that is affecting the accuracy of the chlorophyll estimates.

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Acknowledgments

We thank the Captain Paul Pelletier and the crew of the R/V *Gulf Challenger* for assistance provided. A NASA SIMBIOS (Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies) contract to Drs. Christopher Brown and John Brock as well as a NOAA Coastal Ocean Program grant to Dr. Charles Yentsch and David Phinney contributed to this cruise.

I. Introduction

Monitoring the health of U.S. coastal waters is an important goal of the National Oceanic and Atmospheric Administration (NOAA). Satellite ocean color sensors are capable of providing regular synoptic water quality data for the U.S. coast. Algorithms are used to derive products such as chlorophyll biomass from satellite data in order to study short and long term changes in water quality; however, these algorithms need to be evaluated and validated. Satellite ocean color imagery from the Ocean Color Temperature Sensor (OCTS) and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) show extremely high chlorophyll concentrations within Massachusetts Bay, and relatively high chlorophyll concentrations over Nantucket Shoals. It is uncertain how much of this chlorophyll signal detected by the satellite sensors was actually due to phytoplankton biomass and how much was due to other substances in the water such as colored dissolved organic matter and suspended sediments. Knowledge of the validity of the satellite data in these regions is imperative to better understand the true productivity of the Nantucket Shoals region and the impact that the highly urbanized coast around Boston has on the water quality in Massachusetts Bay.

Towards this purpose, scientists from the NOAA Coastal Services Center (CSC) Coastal Remote Sensing (CRS) program, the Bigelow Laboratory for Ocean Sciences and the SeaWiFS Project Office at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center undertook a five-day cruise in Massachusetts Bay, Nantucket Sound, and Nantucket Shoals. This program is funded in part through a NASA Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) contract awarded to CRS and the Ocean Color Program at the NOAA National Environmental Satellite, Data and Information Service (NESDIS) Office of Research and Applications.

II. Objectives

The objectives of this cruise were to obtain sub-surface downwelling irradiance, upwelling radiance, chlorophyll pigment concentration and total suspended sediment concentration in Massachusetts Bay and Nantucket Shoals. The remote sensing reflectance measurements calculated from these samples were used to evaluate and validate the OC2 version 2 (O'Reilly *et al*. 1998) algorithm for the NASA/OrbImage ocean color sensor, SeaWiFS.

III. Methods

A description of the sample collection methods and instruments is detailed in the following sections.

A. Sampling Location

Optical profile measurements were made from July 6, 1998 through July 10, 1998, at a total of 17 stations (Figure 1.). Surface water samples were acquired at these locations for determination of particulate absorption, total suspended solids (TSS) concentration

and for chlorophyll analysis by fluorometric and High-Performance Liquid Chromatography (HPLC) techniques.

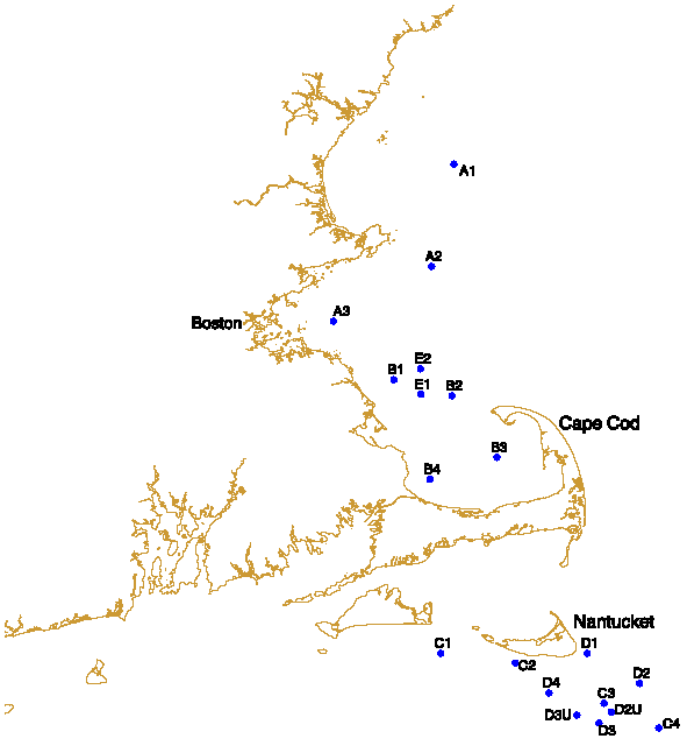

Figure 1. Location of Stations.

B. Sampling Platform

The University of New Hampshire's R/V *Gulf Challenger*, a 50-foot aluminum hull, twin engine ship, was used on this cruise (Figure 2). This boat is capable of travelling at up to 20 knots and thus can be used to sample multiple stations for a single SeaWiFS pass. The SeaWiFS Project office criteria specify that stations should be more than 10 km apart and sampling should be completed within two hours of overpass. This vessel has a draft of 5 feet, and thus was ideal for working in the shallower waters of the Nantucket Shoals. The vessel has a stern "A-frame" which was used to deploy the optical cage. The A-frame put the cage at least 1 m away from the stern of the boat, minimizing ship shadow effects on the SPMR (SeaWiFS Profiling Multichannel Radiometer).

Figure 2. The R/V *Gulf Challenger.*

C. Sample Collection Methods Summary

A Satlantic, Inc. SeaWiFS SPMR and a SeaWiFS multi-channel surface radiometer (SMSR) were used on this cruise. The SMSR is a surface tethered buoy that measures above-water spectral downwelling irradiance and *in-situ* spectral upwelling radiance 75 cm below the surface (Figure 3.). It was floated away from the side of the vessel to avoid ship shadow artifacts in the calculation of water leaving radiance, and data was collected for 5 to 10 minutes. The SPMR is normally used as a free-falling device that measures downwelling irradiance and upwelling radiance, temperature, and salinity. On this cruise, it was fixed inside the optics cage because the water depth may have been inadequate for a free falling instrument. The optics cage contained a Wetlabs AC-9 to measure spectral absorption at nine wavelengths, a Hobilabs Hydroscat to measure spectral backscatter at 6 wavelengths, and a SeaBird CTD to measure *in-situ* temperature, salinity, and density (Figure 4). The AC-9 was rigged with a valve and a 0.2 μm filter cartridge such that it measured total absorption on the downcast and dissolved absorption on the upcast. Niskin bottles were used to obtain water samples from three to five depths at each station for particulate absorption, total suspended solids concentration, and pigment analyses.

Figure 3. Deployment of the SMSR.

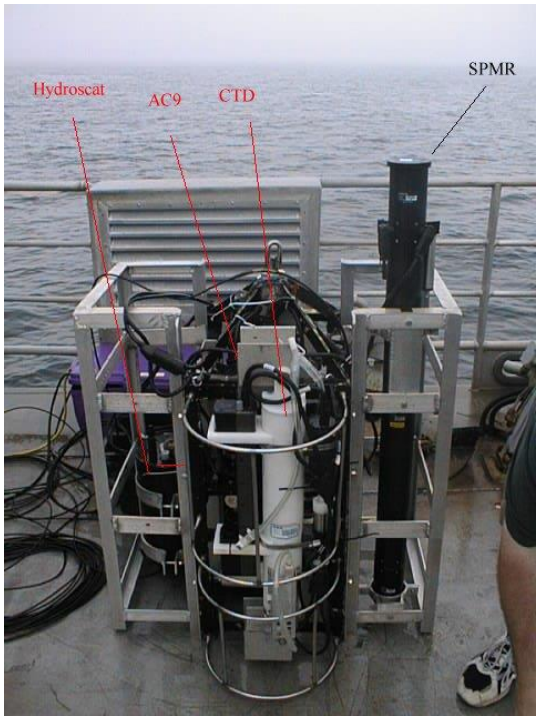

Figure 4. Optical Cage with the SPMR.

Table 1. Station Locations.

Station	Date	Time On	Time Off	Time GMT	Latitude	Longitude	Total Depth (m)	Secchi Depth	Sky State	Sea State	Wind speed	Measurements	Bottle Depths(m)
A1	06-Jul-98	12:20	13:03	16:30	42.895	-70.373	102.0	7.0	90% Haze, cirrus clouds	flat calm	0-3 knts	1,2,3,5,6,7,8	0,10,20,30,50
A2	06-Jul-98	14:20	15:08	18:30	42.551	-70.448	106.0	8.0	high cirrus, with some clear patches	flat calm	0-3 knts	1,2,3,5,6,7,8,10,11	0,10,20,30,50
A3	06-Jul-98	16:20	16:50	20:30	42.366	-70.779	26.4	7.5	80% Haze, cirrus clouds	flat calm	0-3 knts	1,2,3,5,6,7,8	0,10,20
B1	07-Jul-98	9:25	10:22	13:35	42.170	-70.575	33.4	11.0	clear overhead, 40 %cirrus and thick clouds in horizon	flat calm	5 knts	1,2,3,4,5,6,7,8,10,11	0,10,20,30
B2	07-Jul-98	11:00	11:54	15:05	42.116	-70.380	63.7	10.0	clear overhead, cirrus clouds around	6 in waves	5 knts	1,2,3,4,5,6,7,8,10,11	0,10,20,30,50
B3	07-Jul-98	12:55	13:50	17:00	41.908	-70.228	32.0	11.0	high cirrus, 70% cloud cover	glassy calm	0 knts	1,2,3,4,5,6,7,8,10,11	0,10,20,30
B4	07-Jul-98	14:30	15:00	18:35	41.835	-70.454	23.7	7.0	95% overcast, overcast overhead	6 in waves	5 knts	1,2,3,4,5,6,7,8	0,10,20
C1	08-Jul-98	11:00	12:10	15:05	41.250	-70.417	28.7	8.0	100% overcast	6 in waves	0-3 knts	1,2,3,4,5,7,8,9	0,10,25
C2	08-Jul-98	13:00	13:54	17:05	41.217	-70.166	13.0	6.0	100% overcast, fog bank approaching	6 in waves	0-3 knts	1,2,3,4,5,6,7,8,9	0,10
C3	08-Jul-98	15:00	16:05	19:05	41.082	-69.867	20.5	6.5	100% overcast, light drizzle	1 foot waves	6 knts	1,2,3,4,5,6,7,8,9	0,10,20
C4	08-Jul-98	16:45	17:55	20:50	40.999	-69.683	39.0	8.0	100% overcast, light drizzle	flat calm	0-3 knts	1,2,3,4,5,6,7,8,9	0,10,20,30
D1	09-Jul-98	9:40	10:25	13:45	41.250	-69.923	32.0	5.0	clear overhead, 10% clouds in horizon	1 foot waves	6 knts	1,2,3,4,5,6,7,8,9,10,11	0,10,20,30
D2	09-Jul-98	11:15	12:06	15:20	41.149	-69.748	24.0	7.0	clear overhead, 10% clouds in horizon	glassy calm	0-3 knts	1,2,3,4,5,6,7,8,9,10,11	0,10,20

Station	Date	Time On	Time Off	Time GMT	Latitude	Longitude	Total Depth(m)	Secchi Depth	Sky State	Sea State	Wind speed	Measurements	BottleDepths (m)
D2U	09-Jul-98	12:33	12:40	16:37	41.053	-69.843	13.0		clear overhead, 10% clouds in horizon	6 inch waves	6 knts	1,2,3,10,11	0
D3	09-Jul-98	12:50	13:47	17:35	41.015	-69.884	35.8	7.0	clear overhead, haze in horizon	1 foot waves	5-8 knts	1,2,3,4,5,6,7,8,9,10,11	0,10,20,30
D3U	09-Jul-98	14:05	14:12	18:08	41.042	-69.958	28.5		clear overhead, haze in horizon	1 foot waves	5-8 knts	1,2,3,10,11	0
D4	09-Jul-98	14:40	15:00	18:45	41.117	-70.052	20.7	6.5	clear overhead	1 foot waves	6 knts	1,2,3,4,5,6,7,8,9,10,11	0,10,20
E1	10-Jul-98	11:30	12:07	15:35	42.121	-70.484	51.0	11.0	clear overhead	1 foot waves	5-8 knts	1,2,3,4,5,6,7,8,9,10,11	0,10,20
E2	10-Jul-98	12:37	12:48	16:38	42.207	-70.486	64.0	10.0	clear overhead, 30% overcast	1 foot waves	5-8 knts	1,2,3,4,6,7,8,9,11	0

1-ChlF (Volume filtered=100 mL)
2-Ap (Volume filtered = 1000 mL)
3-TSS (Volume filtered = 1000 mL)
4-HPLC pigments (Volume filtered = 1000 mL)
5-AC9
6-CTD
7-Hydroscat
8-SMSR
9-SPMR
10-SIMBAD
11-Sunphotometer

D. Sampling Gear

The SPMR (Serial No. 024) and the SMSR (Serial No. 024) are multi-spectral radiometers manufactured by Satlantic, Inc. The SPMR is a free-falling instrument that measures 13 wavelengths of downwelling irradiance, 12 wavelengths of upwelling radiance (Table 2.), depth, temperature, conductivity, salinity, tilt, and roll. The SMSR is a surface tethered buoy that measures 13 wavelengths of above-water downwelling irradiance and 13 wavelengths of upwelling radiance at 75 cm below the surface. Both the instruments are designed to be used away from the ship to avoid perturbations of the *in-situ* light field by ship shadow.

Table 2. Center Wavelengths for the SPMR System.

Channel No.	SPMR Downwelling Irradiance	SPMR Upwelling Radiance	SMSR Downwelling Irradiance	SMSR Upwelling Radiance
1	339.3 nm	--	339.2 nm	339.9 nm
2	379.8 nm	379.8 nm	380.1 nm	380.1 nm
3	412.4 nm	411.2 nm	411.2 nm	412.4 nm
4	443.2 nm	443.3 nm	442.0 nm	442.8 nm
5	489.6 nm	490.3 nm	490.4 nm	489.9 nm
6	509.4 nm	510.4 nm	510.5 nm	509.7 nm
7	520.8 nm	519.2 nm	519.3 nm	519.9 nm
8	554.9 nm	554.3 nm	554.9 nm	554.4 nm
9	565.5 nm	565.1 nm	564.9 nm	565.3 nm
10	619.1 nm	619.1 nm	619.2 nm	619.3 nm
11	665.3 nm	665.6 nm	665.4 nm	664.4 nm
12	669.7 nm	670.0 nm	670.1 nm	669.8 nm
13	683.9 nm	683.8 nm	682.2 nm	682.7 nm

E. Bottle Samples

The chlorophyll biomass was determined using a Turner Designs fluorometer (Parsons *et al.* 1984). The Total Suspended Solids (TSS) concentration was measured as described by Parsons *et al.* (1984). Phytoplankton pigment concentrations were determined by HPLC as described in Tester *et al.* (1995). Discrete water samples were obtained for these analyses using Niskin bottles deployed just before the optics cage cast.

F. Optical Data Processing

Data for stations A1 to B4, where only the SMSR was used, were processed using the Satlantic Proview software. The data were binned and averaged. The water leaving radiance was calculated from the measured above surface downwelling irradiance and the radiance at 0.75 m below the surface. The below surface radiance was propagated to the surface using the attenuation coefficient (k) calculated as per Morel (1988). Briefly, the approximate chlorophyll concentration at that location was calculated using the 443/555-

band ratio. The k at 490 nm for that chlorophyll concentration was calculated and then transferred to the other wavelengths using the relationships detailed in Morel (1988).

The normalized water leaving radiance data for stations C1 to E2 were calculated from the SMSR data as detailed above except that the k for each station was calculated from the SPMR measurements. The SPMR data was binned to 0.5 m bins and k was calculated for the top 10 m. This k was then applied to the SMSR radiance measurement 0.75 m below the surface to propagate it to the surface. In both above cases, the radiance was propagated through the air-water interface as detailed in O'Reilly *et al*. (1998).

IV. Results

Results of the study are detailed below.

A. Bottle Samples

The surface chlorophyll concentrations (Chl a) varied from about 0.4 μg/l to 2.0 μg/l (Table 3). Inside Massachusetts Bay, the maximum chlorophyll concentrations were at about 10 m, while on the Nantucket shoals the water column was well mixed with uniform chlorophyll concentrations. The bottle samples showed that the chlorophyll concentrations were higher in the Shoals than inside Massachusetts Bay, even close to the shore. Chlorophyll *a* concentrations at the surface as measured using the HPLC technique varied from 0.1 in Massachusetts Bay to 1.5 μg/l on the Shoals (Tables 4 and 5).

Table 3. Fluorometric Pigment Analyses.

All pigment values in μg/l.

Station	Depth (m)	Avg Chl a	Avg Pheo	Avg Chl a+Pheo
A1	S	0.657	0.125	0.782
A1	10	1.175	0.436	1.610
A1	20	0.759	0.434	1.193
A1	30	0.148	0.611	0.760
A1	50	0.081	0.390	0.471
A2	S	0.651	0.131	0.782
A2	10	1.211	0.320	1.531
A2	20	0.542	0.286	0.828
A2	30	0.286	0.307	0.592
A2	50	0.145	0.217	0.362
A3	S	0.771	0.137	0.908
A3	10	2.115	0.530	2.644
A3	20	0.349	0.539	0.888
B1	S	0.482	0.121	0.603
B1	10	1.229	0.362	1.591
B1	20	1.030	0.183	1.213
B1	30	0.249	0.367	0.616
B2	S	0.566	0.090	0.656
B2	10	1.301	0.210	1.511
B2	20	2.802	0.598	3.400
B2	30	2.042	0.622	2.664
B2	50	0.217	0.320	0.537

Station	Depth (m)	Avg Chl a	Avg Pheo	Avg Chl a+Pheo
B3	S	0.476	0.087	0.563
B3	10	0.813	0.161	0.974
B3	20	0.759	0.288	1.047
B3	30	0.518	0.237	0.756
B4	S	1.139	0.233	1.372
B4	10	1.410	0.459	1.869
B4	20	0.633	0.401	1.034
C1	S	0.777	0.270	1.047
C1	10	2.603	0.618	3.221
C1	25	4.013	0.998	5.010
C2	S	1.229	0.421	1.650
C2	10	1.699	0.408	2.108
C3	S	1.482	0.745	2.227
C3	10	1.500	0.786	2.286
C3	20	1.482	0.804	2.286
C4	S	1.518	0.868	2.386
C4	10	1.247	0.920	2.167
C4	20	1.392	0.795	2.187
C4	30	1.374	0.793	2.167
D1	S	1.988	0.457	2.446
D1	10	1.808	0.698	2.505
D1	20	1.898	0.568	2.465
D1	30	1.898	0.746	2.644
D2	S	1.609	0.578	2.187
D2	10	1.952	0.672	2.624
D2	20	1.916	0.709	2.624
UD2	S	1.645	0.363	2.008
D3	S	1.374	0.197	1.571
D3	10	1.464	0.524	1.988
D3	20	1.862	0.445	2.306
D3	30	2.097	0.528	2.624
UD3	S	1.374	0.296	1.670
D4	S	1.392	0.298	1.690
D4	10	1.934	0.452	2.386
D4	20	2.097	0.607	2.704
E1	S	0.398	0.076	0.473
E1	10	2.368	0.396	2.764
E1	20	0.759	0.235	0.994
E2	S	0.434	0.131	0.565

Table 4. HPLC Pigment Abbreviations.

Pigment	Abbreviation	Pigment	Abbreviation
Chlorophyll *a*	Chl *a*	19'-Butanoyloxyfucoxanthin	19-But
Sum of Chlorophyll a isomers	Sum Chl *a*	Fucoxanthin	Fucox
Chlorophyll *b*	Chl *b*	19'-Hexanoyloxyfucoxanthin	19-Hex
Chlorophyll *c1 + c2*	Chl *c1 + 2*	Diadinoxanthin	Diadin
Chlorophyll *c3*	Chl *c3*	Alloxanthin	Allox
PheophorbideDi	Ph-ide	Diatoxanthin	Diat
Pheophytin	Ph-tin	Lutein	Lutein
Peridinin	Perid	Zeaxanthin	Zeax

Table 5. HPLC Pigment Analysis Results.

All pigment values in μg/l.

Station	Chl a	Sum Chl a	Chl b	Chl c3	Chl c1+2	Ph-ide	Ph-tin	Perid	19-But	Fucox	19-Hex	Diadin	Allox	Diat	Lutein	Zeax
B1	0.119	0.266	0.000	0.014	0.040	0.000	0.006	0.022	0.025	0.102	0.302	0.049	0.015	0.021	0.000	0.025
B2	0.144	0.247	0.000	0.016	0.043	0.014	0.009	0.022	0.027	0.106	0.532	0.074	0.021	0.024	0.010	0.018
B3	0.189	0.261	0.032	0.015	0.037	0.000	0.000	0.024	0.024	0.079	0.503	0.063	0.018	0.022	0.009	0.024
B4	0.126	0.289	0.000	0.028	0.092	0.032	0.008	0.050	0.024	0.231	0.519	0.110	0.039	0.037	0.028	0.000
C1	0.173	0.343	0.027	0.035	0.080	0.006	0.006	0.030	0.036	0.232	0.538	0.114	0.023	0.048	0.013	0.028
C2	0.276	0.595	0.091	0.040	0.122	0.008	0.000	0.036	0.038	0.388	0.560	0.115	0.037	0.034	0.018	0.042
C3	1.452	1.579	0.302	0.061	0.168	0.035	0.054	0.042	0.041	0.521	0.821	0.111	0.033	0.038	0.012	0.034
C4	1.222	1.451	0.366	0.052	0.150	0.060	0.041	0.072	0.029	0.342	0.627	0.078	0.037	0.024	0.011	0.048
D1	1.300	1.558	0.213	0.077	0.192	0.058	0.057	0.062	0.033	0.618	0.355	0.130	0.037	0.037	0.013	0.028
D2	1.038	1.269	0.181	0.061	0.164	0.059	0.046	0.038	0.025	0.513	0.393	0.134	0.030	0.038	0.012	0.028
D3	0.865	1.040	0.183	0.055	0.127	0.023	0.038	0.035	0.033	0.350	0.589	0.099	0.029	0.039	0.012	0.028
D4	1.086	1.300	0.276	0.055	0.138	0.012	0.028	0.042	0.031	0.389	0.490	0.122	0.046	0.043	0.019	0.043
E1	0.237	0.312	0.039	0.025	0.049	0.002	0.011	0.026	0.027	0.099	0.432	0.075	0.019	0.038	0.011	0.028
E2	0.251	0.334	0.030	0.027	0.051	0.000	0.005	0.028	0.026	0.103	0.534	0.072	0.019	0.033	0.010	0.029

B. Optical Data

The underwater SPMR unit was not available for the first two days, so only the surface SMSR was used at stations A1 to B4. This made no difference to the measurements at these stations as they were very similar to those made with both the SPMR and SMSR on the return leg in the same water body (stations E1 and E2, Fig 5.). The low reflectance spectra from Massachusetts Bay waters clearly show the influence of colored dissolved organic matter absorption. The higher reflectance in Nantucket Shoals, especially at 670 nm suggest that they may be influenced by higher sediment content.

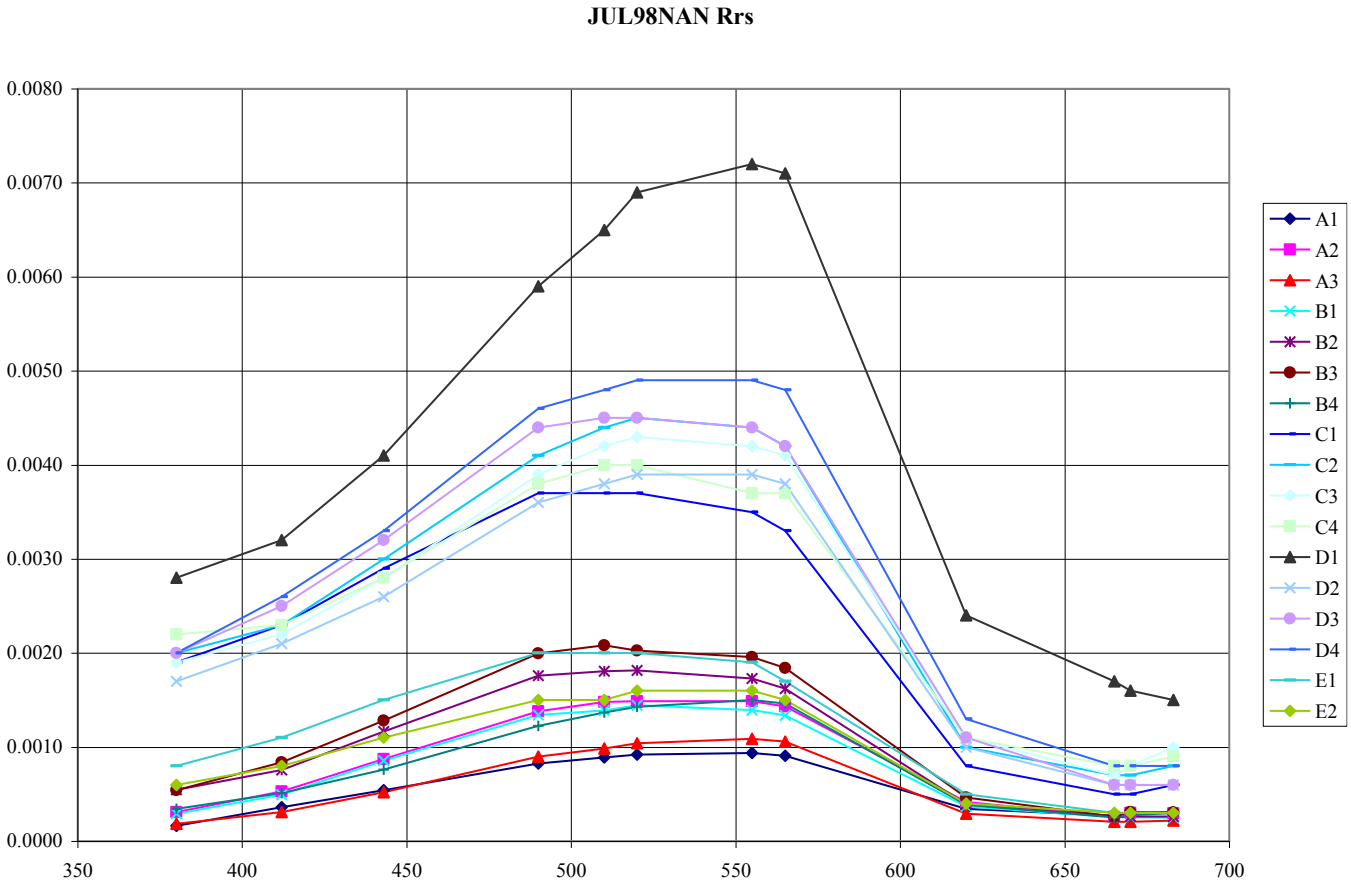

Figure 5. Remote Sensing Reflectance Spectra.

C. Algorithm Evaluation

The OC2 algorithm (O'Reilly *et al.* 1998) consistently overestimates the chlorophyll concentration in Massachusetts Bay by a factor of 4 to 5, but appears to do better in the Nantucket Shoals region with an over-estimate factor of about 1.5 (Table 6.). There was no relationship between chlorophyll concentration and the extent of overestimation.

Table 6. Algorithm Evaluation.

Station	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3
Date	7/6/98	7/6/98	7/6/98	7/7/98	7/7/98	7/7/98	7/7/98	7/8/98	7/8/98	7/8/98
TimeGMT	16:30	18:30	20:30	13:35	15:05	17:00	18:35	11:05	17:05	19:05
Latitude	42.895	42.551	42.366	42.170	42.116	41.908	41.835	41.250	41.217	41.082
Longitude	-70.373	-70.448	-70.779	-70.575	-70.380	-70.228	-70.454	-70.417	-70.166	-69.867
ChlF	0.657	0.651	0.771	0.482	0.566	0.476	1.139	0.777	1.229	1.482
Chla	-999	-999	-999	0.119	0.144	0.189	0.126	0.173	0.276	1.452
Es380	54.990	58.910	20.920	49.190	65.800	63.980	33.150	25.455	15.736	11.424
Es412	97.440	106.800	37.020	90.360	121.820	118.910	59.090	44.444	27.077	19.506
Es443	111.180	118.980	40.020	100.050	134.500	130.270	64.240	47.418	28.657	20.596
Es490	121.300	130.290	43.200	111.750	145.380	138.740	69.500	50.565	30.743	22.133
Es510	122.500	128.970	43.680	112.750	146.300	140.120	69.860	50.239	30.119	21.504
Es520	114.010	120.460	40.470	103.500	137.750	132.030	65.110	46.797	28.133	20.154
Es555	113.230	121.170	40.210	104.640	137.110	130.740	65.070	46.172	27.589	19.645
Es565	112.930	121.090	39.970	104.320	136.270	131.530	64.910	45.592	26.955	19.056
Es619	104.410	109.150	36.430	97.270	126.130	120.310	59.440	41.255	24.415	17.283
Es664	96.670	104.800	33.230	90.750	117.270	111.100	54.960	37.980	22.472	16.068
Es670	96.400	96.930	33.930	90.550	116.390	110.960	54.850	37.933	22.551	16.131
Es683	95.760	99.840	34.100	91.480	116.360	109.320	54.990	37.799	22.259	15.848
ku380	-999	-999	-999	-999	-999	-999	-999	0.456	0.471	0.468
ku412	-999	-999	-999	-999	-999	-999	-999	0.390	0.311	0.354
ku443	-999	-999	-999	-999	-999	-999	-999	0.314	0.188	0.264
ku490	-999	-999	-999	-999	-999	-999	-999	0.220	0.083	0.168
ku510	-999	-999	-999	-999	-999	-999	-999	0.198	0.060	0.149
ku520	-999	-999	-999	-999	-999	-999	-999	0.195	0.054	0.148
ku555	-999	-999	-999	-999	-999	-999	-999	0.168	0.021	0.131
ku565	-999	-999	-999	-999	-999	-999	-999	0.159	0.013	0.131
ku619	-999	-999	-999	-999	-999	-999	-999	0.304	0.143	0.356
ku664	-999	-999	-999	-999	-999	-999	-999	0.207	0.262	0.367
ku670	-999	-999	-999	-999	-999	-999	-999	0.192	0.218	0.314
ku683	-999	-999	-999	-999	-999	-999	-999	0.182	0.252	0.284
Lw380	0.009	0.018	0.004	0.014	0.036	0.035	0.011	0.048	0.031	0.022
Lw412	0.035	0.056	0.011	0.045	0.092	0.100	0.030	0.101	0.062	0.043
Lw443	0.060	0.104	0.021	0.085	0.157	0.167	0.049	0.137	0.085	0.058
Lw490	0.100	0.180	0.039	0.150	0.256	0.277	0.085	0.186	0.127	0.087
Lw510	0.109	0.191	0.043	0.157	0.265	0.292	0.096	0.186	0.132	0.090
Lw520	0.105	0.180	0.042	0.150	0.250	0.267	0.093	0.175	0.127	0.087
Lw555	0.106	0.181	0.044	0.146	0.237	0.256	0.098	0.160	0.121	0.083
Lw565	0.103	0.173	0.042	0.139	0.221	0.243	0.095	0.149	0.114	0.078
Lw619	0.036	0.046	0.011	0.036	0.049	0.056	0.023	0.034	0.024	0.019
Lw664	0.026	0.027	0.007	0.023	0.030	0.029	0.014	0.019	0.016	0.012
Lw670	0.028	0.029	0.007	0.023	0.030	0.034	0.015	0.020	0.017	0.013
Lw683	0.030	0.029	0.008	0.023	0.030	0.033	0.017	0.021	0.018	0.015
nLw380	0.017	0.033	0.020	0.031	0.058	0.058	0.037	0.203	0.210	0.207
nLw412	0.063	0.092	0.054	0.086	0.131	0.146	0.089	0.392	0.397	0.384
nLw443	0.101	0.163	0.097	0.160	0.218	0.239	0.142	0.538	0.552	0.522
nLw490	0.156	0.262	0.170	0.255	0.333	0.378	0.232	0.697	0.779	0.741
nLw510	0.172	0.286	0.190	0.268	0.349	0.402	0.264	0.716	0.847	0.807
nLw520	0.168	0.272	0.190	0.264	0.331	0.369	0.260	0.681	0.821	0.784
nLw555	0.175	0.277	0.202	0.259	0.322	0.365	0.279	0.643	0.819	0.790

Station	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3
nLw565	0.168	0.264	0.195	0.247	0.299	0.340	0.270	0.601	0.781	0.759
nLw619	0.058	0.071	0.050	0.063	0.067	0.079	0.066	0.141	0.168	0.190
nLw664	0.042	0.040	0.032	0.039	0.040	0.041	0.039	0.077	0.109	0.116
nLw670	0.045	0.046	0.032	0.039	0.040	0.047	0.042	0.081	0.113	0.124
nLw683	0.046	0.044	0.033	0.037	0.039	0.045	0.045	0.082	0.123	0.141
Rrs380	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.002	0.002	0.002
Rrs412	0.000	0.001	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002
Rrs443	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.003	0.003
Rrs490	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.004	0.004	0.004
Rrs510	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.004	0.004	0.004
Rrs520	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.004	0.005	0.004
Rrs555	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.004
Rrs565	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.003	0.004	0.004
Rrs619	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
Rrs664	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
Rrs670	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
Rrs683	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
kd490	-999	-999	-999	-999	-999	-999	-999	0.183	0.195	0.175
X	-0.056	-0.033	-0.082	-0.015	0.008	0.008	-0.088	0.024	-0.031	-0.032
Expov2	0.425	0.372	0.488	0.332	0.280	0.279	0.500	0.244	0.367	0.370
OC2v2	2.569	2.263	2.981	2.054	1.814	1.806	3.072	1.660	2.235	2.254
MeasChlF	0.657	0.651	0.771	0.482	0.566	0.476	1.139	0.777	1.229	1.482
sat/meas	3.9	3.5	3.9	4.3	3.2	3.8	2.7	2.1	1.8	1.5

Station	C4	D1	D2	D2U	D3	D3U	D4	E1	E2
Date	7/8/98	7/9/98	7/9/98	7/9/98	7/9/98	7/9/98	7/9/98	7/10/98	7/10/98
TimeGMT	20:50	13:45	15:20	16:37	17:35	18:08	18:45	15:35	16:38
Latitude	40.999	41.250	41.149	41.053	41.015	41.042	41.117	42.121	42.207
Longitude	-69.683	-69.923	-69.748	-69.843	-69.884	-69.958	-70.052	-70.484	-70.486
ChlF	1.518	1.988	1.609	1.645	1.374	1.374	1.392	0.398	0.434
Chla	1.222	1.300	1.038	-999	0.865	-999	1.086	0.237	0.251
Es380	13.473	55.070	69.096	-999	68.745	-999	60.382	62.751	66.657
Es412	23.230	99.988	126.854	-999	127.028	-999	109.340	111.680	120.823
Es443	24.856	110.439	139.289	-999	139.693	-999	119.729	124.228	132.139
Es490	27.043	122.757	151.119	-999	151.380	-999	130.944	137.225	145.401
Es510	26.531	122.658	151.234	-999	151.461	-999	131.451	137.824	147.543
Es520	24.739	112.790	140.940	-999	142.006	-999	121.506	128.262	135.650
Es555	24.286	114.087	140.939	-999	141.353	-999	121.889	125.699	134.144
Es565	23.771	113.672	141.776	-999	141.448	-999	120.809	127.162	136.505
Es619	21.789	105.470	129.897	-999	130.522	-999	112.781	119.585	127.359
Es664	20.323	97.549	119.844	-999	120.884	-999	104.124	110.340	119.445
Es670	20.463	97.720	119.654	-999	120.171	-999	103.299	110.745	119.000
Es683	20.265	98.088	118.204	-999	118.782	-999	104.057	110.070	116.437
ku380	0.568	0.855	0.336	-999	0.369	-999	0.406	0.490	0.922
ku412	0.420	0.635	0.321	-999	0.366	-999	0.374	0.371	0.586
ku443	0.308	0.483	0.227	-999	0.287	-999	0.280	0.260	0.366
ku490	0.197	0.325	0.111	-999	0.201	-999	0.175	0.168	0.205
ku510	0.179	0.291	0.088	-999	0.184	-999	0.151	0.156	0.180
ku520	0.178	0.287	0.084	-999	0.183	-999	0.147	0.156	0.177
ku555	0.165	0.253	0.056	-999	0.167	-999	0.119	0.142	0.152
ku565	0.162	0.248	0.050	-999	0.165	-999	0.114	0.140	0.148

Station	C4	D1	D2	D2U	D3	D3U	D4	E1	E2
ku619	0.450	0.536	0.228	-999	0.308	-999	0.319	0.263	0.352
ku664	0.528	0.665	0.186	-999	0.229	-999	0.294	0.191	0.393
ku670	0.468	0.612	0.154	-999	0.218	-999	0.246	0.151	0.351
ku683	0.435	0.569	0.178	-999	0.221	-999	0.248	0.108	0.314
Lw380	0.030	0.155	0.120	-999	0.139	-999	0.123	0.049	0.043
Lw412	0.054	0.317	0.260	-999	0.313	-999	0.282	0.119	0.094
Lw443	0.070	0.458	0.358	-999	0.442	-999	0.397	0.183	0.145
Lw490	0.104	0.727	0.547	-999	0.663	-999	0.599	0.279	0.222
Lw510	0.106	0.793	0.577	-999	0.688	-999	0.636	0.281	0.227
Lw520	0.100	0.778	0.557	-999	0.644	-999	0.598	0.258	0.218
Lw555	0.091	0.822	0.556	-999	0.624	-999	0.597	0.237	0.209
Lw565	0.087	0.806	0.538	-999	0.598	-999	0.577	0.221	0.198
Lw619	0.023	0.248	0.128	-999	0.137	-999	0.149	0.054	0.055
Lw664	0.016	0.164	0.071	-999	0.075	-999	0.085	0.030	0.037
Lw670	0.017	0.152	0.071	-999	0.077	-999	0.087	0.031	0.033
Lw683	0.019	0.143	0.071	-999	0.075	-999	0.085	0.029	0.032
nLw380	0.238	0.301	0.185	-999	0.216	-999	0.218	0.084	0.068
nLw412	0.402	0.550	0.356	-999	0.428	-999	0.447	0.185	0.136
nLw443	0.528	0.775	0.480	-999	0.591	-999	0.620	0.275	0.205
nLw490	0.727	1.122	0.686	-999	0.830	-999	0.866	0.384	0.289
nLw510	0.768	1.247	0.736	-999	0.876	-999	0.934	0.393	0.297
nLw520	0.735	1.258	0.720	-999	0.827	-999	0.898	0.367	0.293
nLw555	0.697	1.341	0.734	-999	0.822	-999	0.911	0.351	0.290
nLw565	0.673	1.308	0.700	-999	0.779	-999	0.881	0.321	0.268
nLw619	0.182	0.400	0.167	-999	0.179	-999	0.225	0.077	0.074
nLw664	0.120	0.262	0.093	-999	0.097	-999	0.127	0.042	0.048
nLw670	0.125	0.238	0.091	-999	0.099	-999	0.130	0.043	0.042
nLw683	0.141	0.217	0.090	-999	0.094	-999	0.121	0.039	0.041
Rrs380	0.002	0.003	0.002	-999	0.002	-999	0.002	0.001	0.001
Rrs412	0.002	0.003	0.002	-999	0.003	-999	0.003	0.001	0.001
Rrs443	0.003	0.004	0.003	-999	0.003	-999	0.003	0.002	0.001
Rrs490	0.004	0.006	0.004	-999	0.004	-999	0.005	0.002	0.002
Rrs510	0.004	0.007	0.004	-999	0.005	-999	0.005	0.002	0.002
Rrs520	0.004	0.007	0.004	-999	0.005	-999	0.005	0.002	0.002
Rrs555	0.004	0.007	0.004	-999	0.004	-999	0.005	0.002	0.002
Rrs565	0.004	0.007	0.004	-999	0.004	-999	0.005	0.002	0.002
Rrs619	0.001	0.002	0.001	-999	0.001	-999	0.001	0.001	0.000
Rrs664	0.001	0.002	0.001	-999	0.001	-999	0.001	0.000	0.000
Rrs670	0.001	0.002	0.001	-999	0.001	-999	0.001	0.000	0.000
Rrs683	0.001	0.002	0.001	-999	0.001	-999	0.001	0.000	0.000
kd490	0.263	0.345	0.118	-999	0.195	-999	0.218	0.142	0.184
X	0.012	-0.086	-0.035	-999	0.000	-999	-0.027	0.022	-0.028
Expov2	0.272	0.498	0.376	-999	0.297	-999	0.360	0.248	0.361
OC2v2	1.776	3.052	2.286	-999	1.890	-999	2.196	1.677	2.203
MeasChlF	1.518	1.988	1.609	1.645	1.374	1.374	1.392	0.398	0.434
sat/meas	1.2	1.5	1.4	-999	1.4	-999	1.6	4.2	5.1

D. Satellite Data

The skies were partly cloudy or completely overcast July 6, 7, and 8 so no matching SeaWiFS imagery are available for these days. July 9 was a clear day with a good overpass (Figure 6.) and additional stations (D2u and D3u) were sampled for chlorophyll only. The standard stations (D1, D2, D3, D4) were spaced 12 km apart, while D2u and D3u were approximately midway, about 6 km from D3. Stations D2 and D3 were sampled within two hours of the overpass, with D3 directly coincident with the overpass, and thus can be used to validate the normalized water leaving values. All stations on July 9 were occupied within six hours of the overpass and can be used to validate the OC2 chlorophyll algorithm.

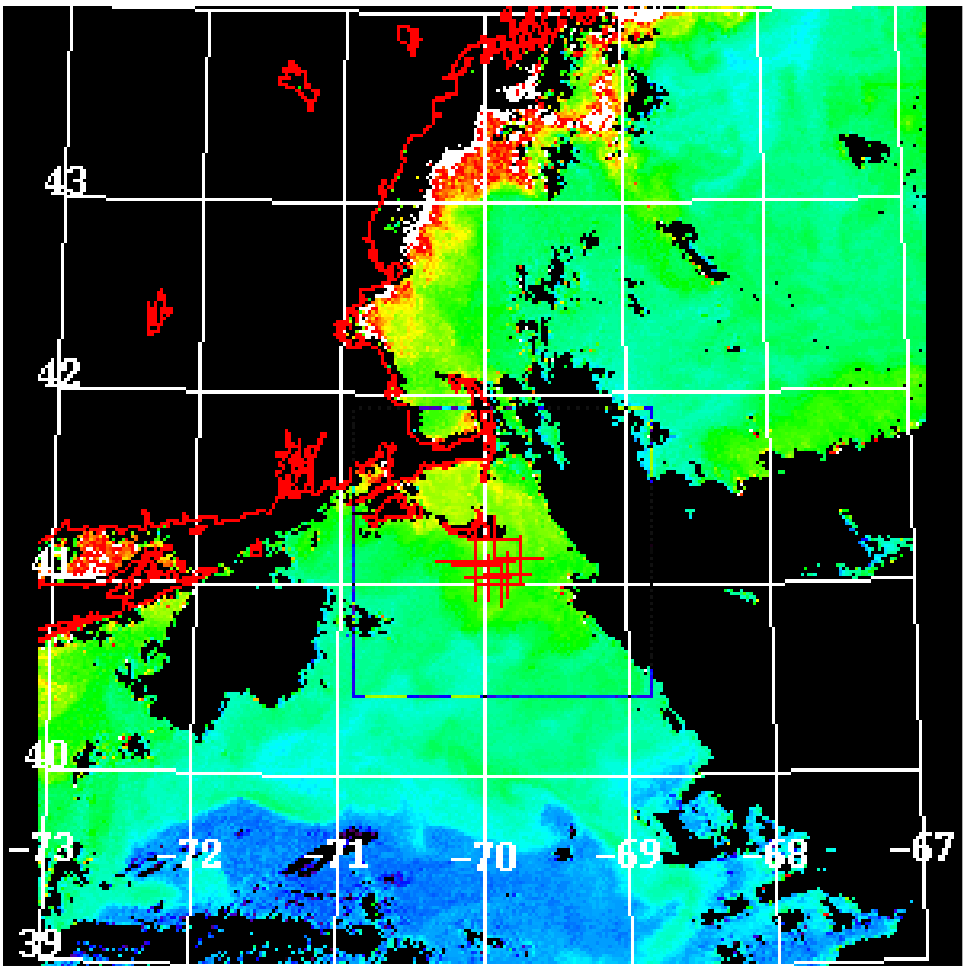

Figure 6 SeaWiFS Chlorophyll Data for July 9, 1998 with Stations D1-D4 Marked.

Comparison of the chlorophyll products derived from the satellite and the *in-situ* optical measurement using the OC2 algorithm and fluorometrically determined in the lab show that the algorithm overestimates the actual chlorophyll concentrations by a factor of 1.5 (Figure 7.). While there was a relatively large difference between the satellite and *in-situ* measurements of normalized water leaving radiance for the blue wavelengths (412 and

443 nm), the difference is quite small for the 490, 510 and 555 nm bands, especially at station D2 (<3%) (Figure 8.).

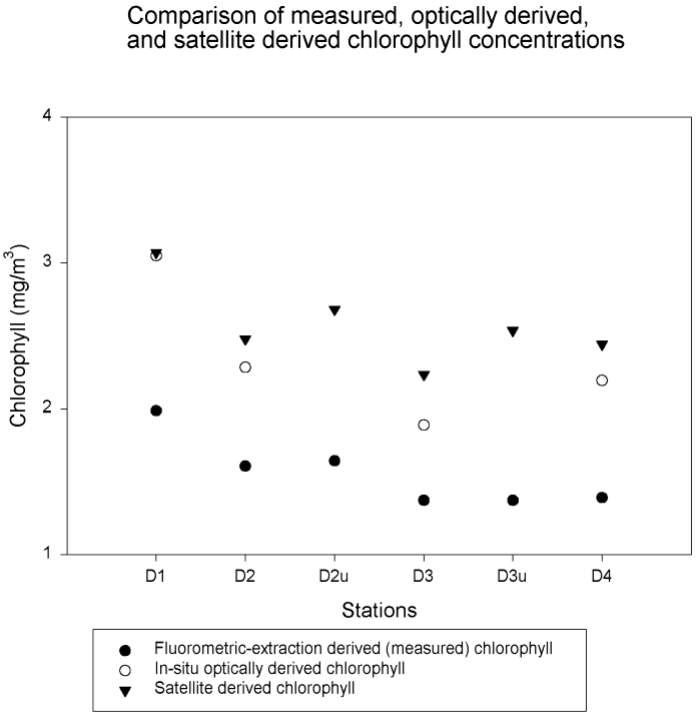

Figure 7. Chlorophyll Product Determined Three Different Ways.

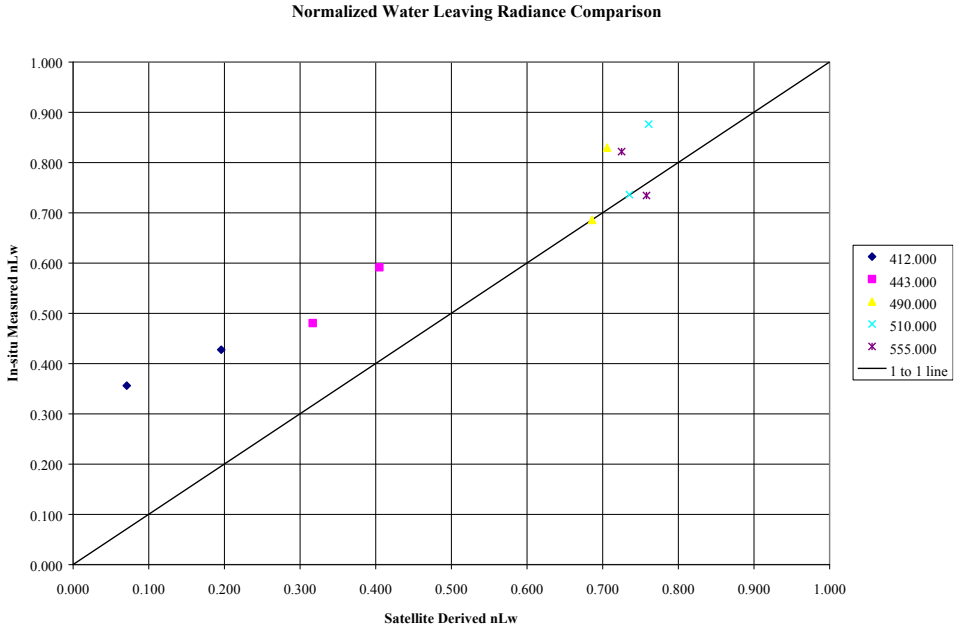

Figure 8. Satellite Derived and *In-situ* Measured Normalized Water Leaving Radiance for July 9, 1998.

V. Summary

A regional algorithm needs to be developed for the Massachusetts Bay in order to make SeaWiFS data useful to the coastal managers administering a water body with high anthropogenic impact. On the other hand, the OC2 algorithm tested using the *in-situ* data appears to work better in the Nantucket Shoals region, although it still overestimates chlorophyll by a factor of 1.5. There is excellent radiometric agreement at station D2 for the 490, 510, and 555 nm bands, indicating that it is the OC2 algorithm and not the atmospheric correction algorithm is affecting the accuracy of the chlorophyll estimates.

VI. References

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VII. Metadata

Identification Information:

Citation:

Citation Information:

Originator: Ajit Subramaniam, REMSA, NOAA/NESDIS
Originator: Mary Culver, TPMC, NOAA Coastal Services Center
Originator: David Phinney, Bigelow Laboratory for Ocean Sciences
Originator: Douglas Phinney, Bigelow Laboratory for Ocean Sciences
Originator: Jeffery Brown, Bigelow Laboratory for Ocean Sciences
Originator: Brian Scheiber, SeaWiFS Project Office, NASA GSFC
Originator: John C. Brock, Center for Coastal Geology, USGS
Originator: David Eslinger, NOAA Coastal Services Center
Originator: Chrisropher Brown, NOAA/NESDIS
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Purpose: See objectives on page 1.

Time Period of Content:

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Range of Dates/Times:
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Progress: Complete
Maintenance and Update Frequency: Unknown

Spatial Domain:

Bounding Coordinates:

West Bounding Coordinate: -70.779
East Bounding Coordinate: -69.748
North Bounding Coordinate: 42.895
South Bounding Coordinate: 40.999

Keywords:

Theme:

Theme Keyword Thesaurus: None
Theme Keyword: oceanography
Theme Keyword: bio-optical

Theme Keyword: turbidity
Theme Keyword: water clarity
Theme Keyword: algal blooms
Theme Keyword: coastal water optics
Theme Keyword: case II algorithms
Theme Keyword: light attenuation
Theme Keyword: reflectance difference
Theme Keyword: in-situ optical profiling
Theme Keyword: ocean color satellites
Theme Keyword: coastal ocean algorithm development
Theme Keyword: river plumes
Theme Keyword: AVHRR
Theme Keyword: downwelling irradiance
Theme Keyword: upwelling radiance
Theme Keyword: temperature
Theme Keyword: chlorophyll
Theme Keyword: particulate absorption
Theme Keyword: colored dissolved organic matter
Theme Keyword: salinity
Theme Keyword: spectral attenuation
Theme Keyword: spectral absorption
Theme Keyword: beam attenuation
Theme Keyword: scalar quantum irradiance
Theme Keyword: light scattering
Theme Keyword: fluorescence

Place:

Place Keyword Thesaurus: None
Place Keyword: Massachusetts Bay
Place Keyword: Nantucket Shoals
Place Keyword: Massachusetts
Place Keyword: United States

Temporal:

Temporal Keyword Thesaurus: None
Temporal Keyword: Summer
Temporal Keyword: July, 1998

Access Constraints: None

Use Constraints: This data was acquired for scientific research and is applicable for algorithm validation purposes. Knowledge of in-water optics is expected of users for interpretation of the data. Users of this data are required to provide appropriate attribution in the form of co-authorship for any publications that use this data, unless formal permission to do otherwise is granted by NOAA/CSC.

Point of Contact:

Contact Information:

Contact Organization Primary:
Contact Organization: NOAA Coastal Services Center

Contact Address:
Address Type: mailing and physical address
Address: 2234 Hobson Avenue
City: Charleston
State or Province: South Carolina
Postal Code: 29405-2413
Country: USA
Contact Voice Telephone: (843) 740-1200
Contact Facsimile Telephone: (843) 740-1224
Contact Electronic Mail Address: csc@csc.noaa.gov
Hours of Service: 8AM-5PM, M-F

Data Set Credit: Captain Paul Pelletier and the crew of the R/V *Gulf Challenger*. A NASA SIMBIOS contract to Dr. Chris Brown and John Brock as well as a NOAA Coastal Ocean Program grant to Dr. Charles Yentsch and David Phinney contributed to this cruise.

Data Quality Information:

Attribute Accuracy:

Attribute Accuracy Report: Refer to the Process Step section for specific calibration information. The primary instrumentation on the cruise are sent to the respective manufacturers for calibration at least once per year. Calibration certificates for the relevant instrumentation are available in the full written report. Secondary instrumentation were calibrated only upon purchase. Calibration of the WetStar *in situ* Fluorometer is conducted during the cruise by comparing the fluorescence reading of a series of samples placed in the instrument with the measured chlorophyll concentration measured by extracting the samples for laboratory analysis. Laboratory calibrations of the Turner Designs fluorometer and the HPLC are conducted as needed using known concentrations of purified photosynthetic pigment extracts (measured using a spectophotometer) purchased commercially or isolated from algal cultures.

Logical Consistency Report: The HydroScat-6 data were processed using IDL software. A calibrated data file was created using software provided by HOBI Labs, Inc. Data less than the dark threshold was replaced by -9.9×10^{35}. The data were despiked, in two passes, with a difference threshold. A moving average was calculated for these channels. The data were separated into upcast and downcast profiles and then binned to 0.5-m bins.

Completeness Report: Refer to the separate sections of Logical Consistency, Methodology, and Process Steps for descriptions of completeness of the data.

Lineage:

Methodology:

Methodology Type: Shipboard Deployments and sample and data collection and laboratory analyses..

Methodology Description: See Methods section pages 1-8.

Process Step:

Process Description: Calibration of the Hydroscat6 in situ Backscattering Sensor.

Process Date: 19970527

Process Contact:
Contact Information:
Contact Organization Primary:
Contact Organization: HOBI Labs
Contact Address:
Address Type: mailing and physical address
Address: 55 Penny Lane, Suite 104
City: Watsonville
State or Province: California
Postal Code: 95076-6017
Country: USA
Contact Voice Telephone: (408) 768-0680

Process Step:
Process Description: Calibration of the SeaCat CTD.
Process Date: 19951012
Process Contact:
Contact Information:
Contact Organization Primary:
Contact Organization: Sea-Bird Electronics, Inc.
Contact Address:
Address Type: mailing and physical address
Address: 1808 136th Place NE
City: Bellevue
State or Province: Washington
Postal Code: 98005
Country: USA
Contact Voice Telephone: (206) 643-9866

Process Step:
Process Description: Calibration of the AC-9 Spectral Absorption and Attenuation meter.
Process Date: 19960821
Process Contact:
Contact Information:
Contact Organization Primary:
Contact Organization: WET Labs, Inc.
Contact Address:
Address Type: mailing and physical address
Address: 620 Applegate Street
City: Philomath
State or Province: Oregon
Postal Code: 97370
Country: USA
Contact Voice Telephone: (541) 929-5650

Process Step:
Process Description: Calibration of the Microtops II Sun Photometer
Process Date: 19980129

Process Contact:
Contact Information:
Contact Organization Primary:
Contact Organization: NASA/GSFC Code 970.2
Contact Person: Tom Riley, SIMBIOS Project
Contact Address:
Address Type: mailing and physical address
Address: Building 28, Room W108
City: Greenbelt
State or Province: Maryland
Postal Code: 20771
Country: USA
Contact Voice Telephone:

Process Step:
Process Description: Calibration of Satlantic SPMR (SeaWiFS Profiling Multichannel Radiometer). See also Appendix C.
Process Date: 19980310
Process Contact:
Contact Information:
Contact Organization Primary:
Contact Organization: Satlantic, Inc.
Contact Address:
Address Type: mailing and physical address
Address: 3295 Barrington Street
City: Halifax
State or Province: Nova Scotia
Postal Code: B3K 5X8
Country: Canada
Contact Voice Telephone: (902) 492-4780

Process Step:
Process Description: Calibration of SIMBAD
Process Date: 19980301
Process Contact:
Contact Information:
Contact Organization Primary:
Contact Organization: NASA/GSFC Code 970.2
Contact Person: Tom Riley, SIMBIOS Project
Contact Address:
Address Type: mailing and physical address
Address: Building 28, Room W108
City: Greenbelt
State or Province: Maryland
Postal Code: 20771
Country: USA
Contact Voice Telephone:

Spatial Data Organization Information:

Indirect Spatial Reference: Nantucket Shoals, Gulf of Maine, Maine, USA.

Distribution Information:

Distributor:

Contact Information:

Contact Organization Primary:
Contact Organization: NOAA Coastal Services Center
Contact Address:
Address Type: mailing and physical address
Address: 2234 Hobson Avenue
City: Charleston
State or Province: South Carolina
Postal Code: 29405-2413
Country: USA
Contact Voice Telephone: (843) 740-1200
Contact Facsimile Telephone: (843) 740-1224
Contact Electronic Mail Address: csc@csc.noaa.gov
Hours of Service: 8AM-5PM, M-F

Resource Description: NOAA CSC 99043-PUB: JUL98NAN Cruise Report

Distribution Liability: None

Custom Order Process: Contact the distributor for a paper copy of the technical report, or the data can be accessed on-line at http://www.csc.noaa.gov/crs/cruises/jul98nan/.

Metadata Reference Information:

Metadata Date: 19990312

Metadata Review Date: 19990312

Metadata Contact:

Contact Information:
Contact Organization Primary:
Contact Organization: NOAA, Coastal Services Center
Contact Position: Metadata Specialist
Contact Address:
Address Type: mailing and physical address
Address: 2234 Hobson Avenue
City: Charleston
State or Province: South Carolina
Postal Code: 29405-2413
Country: USA
Contact Voice Telephone: (843) 740-1200
Contact Facsimile Telephone: (843) 740-1224
Contact Electronic Mail Address: crs@csc.noaa.gov
Hours of Service: 8AM-5PM, M-F

Metadata Standard Name: Content Standard for National Biological Information Infrastructure Metadata.

Metadata Standard Version: December 1995

VIII. Appendix A - Water Column Profile Data Figures

IX. Appendix B - Example Header Information

Example Binned Surface Reference File Header

```
SATHDR CREATIONDATE 02-Oct-1998
SATHDR PROSOFT V5.0d
SATHDR INVESTIGATOR Ajit_Subramaniam
SATHDR AFFILIATION Chesapeake_Biological_Laboratory
SATHDR STATIONID StaA1
SATHDR CRUISEID JUL98NAN
SATHDR CAST CASTA
SATHDR DATE 187
SATHDR YEAR 1998
SATHDR RATE  6
SATHDR ZONE  0.0
SATHDR LATITUDE 42.895000
SATHDR LONGITUDE 70.372917
SATHDR STARTTIME 12.546389
SATHDR PROCLVL 3A
SATHDR NUM_ANCIL 17
SATHDR PROSTAT OFF
SATHDR REFSTAT WET
SATHDR REFCAL Ref024c.cal
SATHDR REFID SATREF0024
SATHDR REFDARK CAL
SATHDR REF_LS_DIST 0.000
SATHDR REF_ES_DIST 0.000
SATHDR REF_EU_DIST 0.000
SATHDR LSWAVES 339.0 380.1 412.4 442.8 489.9 509.7 519.9
554.4 565.3 619.3 664.4 669.8 682.7
SATHDR EVWAVES  0.0
SATHDR ESWAVES 339.2 380.1 411.2 442.0 490.4 510.5 519.3
554.9 564.9 619.2 665.4 670.1 682.2
```

Example Binned Profiler File Header

```
SATHDR CREATIONDATE 14-Sep-1998
SATHDR PROSOFT V5.0d
SATHDR INVESTIGATOR Ajit_Subramaniam
SATHDR AFFILIATION Chesapeake_Biological_Laboratory
SATHDR STATIONID StaC1b
SATHDR CRUISEID JUL98NAN
SATHDR CAST CASTB
SATHDR DATE 189
SATHDR YEAR 1998
SATHDR RATE  6
SATHDR ZONE  0.0
SATHDR LATITUDE 41.249717
```

```
SATHDR LONGITUDE 70.417133
SATHDR STARTTIME 15.942315
SATHDR PROCLVL 3C
SATHDR NUM_ANCIL 17
SATHDR REFCORPRO OFF
SATHDR PROSTAT WET
SATHDR PROCAL Pro024c.cal
SATHDR PROID SATPRO0024
SATHDR PRODARK CAL
SATHDR PRO_LU_DIST 1.142
SATHDR PRO_EU_DIST 0.000
SATHDR EUWAVES  0.0
SATHDR LUWAVES 379.8 411.2 443.3 490.3 510.4 519.2 554.3
565.1 619.1 665.6 670.0 683.8
SATHDR EDWAVES 339.3 379.8 412.4 443.2 489.6 509.4 520.8
554.9 565.5 619.1 665.3 669.7 683.9
SATHDR REFSTAT OFF
SATHDR COMMENTS profiler only
SATHDR MAX_DEPTH  -20
SATHDR START_TIME  15.942361[LOCAL]
SATHDR START_DATE 1998JUL08
SATHDR END_TIME  16.042970[LOCAL]
SATHDR END_DATE 1998JUL08
```

Example Lwn File Header

```
SATHDR CREATIONDATE 02-Oct-1998
SATHDR PROSOFT V5.0d
SATHDR INVESTIGATOR Ajit_Subramaniam
SATHDR AFFILIATION Chesapeake_Biological_Laboratory
SATHDR CRUISEID JUL98NAN
SATHDR STATIONID StaC1b
SATHDR CAST CASTB
SATHDR DATE 189.000000
SATHDR STARTTIME 15.942361
SATHDR LAT 41.249717
SATHDR LON 70.417133
SATHDR REF_ES_DIST 0.000000
SATHDR REF_LS_DIST 0.000000
SATHDR PROCAL Pro024c.cal
SATHDR REFCAL
SATHDR COMMENTS profiler only
SATHDR LWN_ALGORITHM I
SATHDR NUM_K_BINS 4.000000
# rho(lambda,theta) = 0.021
# refractive index seawater = 1.3450
# surface albedo = 0.043
# LWN processing using CASE I algorithms
```

```
# First Profile BIN depth =     0.0
# REFERENCE data not available - using Ed to estimate Es
# Ls sensor data not avaliable - Ls values set to zero
# Warning Kd565.5nm (0.3079/m) is less than pure water
(0.3088/m)
# Warning Kd669.7nm (0.4628/m) is less than pure water
(0.4653/m)
#AP = Lwn computed using Austin-Petzold/Morel method
#
```

X. Appendix C - Calibration Certificates

SPMR Calibration File

```
#
#SATPRO0024
#
# SPMR 024 / Maryland 97129
#
# cal file valid 10 March, 1998
#

INSTRUMENT SATPRO '' 6 AS 0 NONE
SN 0024 '' 4 AI 0 COUNT
RATE 6 'Hz' 0 BU 0 NONE

#LU sensor OCR-1000 S/N 036 calibrated for LO GAIN in IN
SEAWATER
# by HEIKE on TUE MAR 10, 1998 at 10:24:27
# LO GAIN calibration LAMP: F497 TARGET: T13172G at DIST:
130.0cm
#LU sensor OCR-1000 S/N 036 calibrated for HI GAIN in IN
SEAWATER
# by HEIKE on TUE MAR 10, 1998 at 10:42:01
# HI GAIN calibration LAMP: F497 TARGET: T13172G at DIST:
230.0cm
LU NONE '' 3 BU 0 NONE
LU 411.2 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389636.0 1.3617e-006  1.76
 8389468.6 1.3668e-007  1.76
LU 379.8 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389363.6 1.4029e-006  1.77
 8388788.0 1.3744e-007  1.77
LU 443.3 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389726.2 1.4399e-006  1.75
 8389643.3 1.3768e-007  1.75
LU 519.2 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389625.4 1.4671e-006  1.74
 8389475.2 1.3896e-007  1.74
LU 490.3 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389544.6 1.3311e-006  1.75
 8389582.8 1.3766e-007  1.75
LU 510.4 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389508.8 1.2653e-006  1.74
 8389384.8 1.3844e-007  1.74
LU 565.1 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389568.8 1.3868e-006  1.74
 8389441.8 1.3848e-007  1.74
```

```
LU 554.3 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388710.5 1.3581e-006  1.74
 8388586.7 1.3584e-007  1.74
LU 619.1 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388528.9 7.0767e-007  1.73
 8389121.1 3.4410e-008  1.73
LU 665.6 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388720.5 7.0357e-007  1.73
 8388519.4 3.3878e-008  1.73
LU 683.8 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388752.8 7.1725e-007  1.73
 8391485.1 3.4738e-008  1.73
LU 670.0 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388669.4 7.2828e-007  1.73
 8390558.6 3.4145e-008  1.73
LU DARK 'COUNTS' 3 BU 0 COUNT

#ED sensor OCI-1000 S/N 051 calibrated for LO GAIN in IN
SEAWATER
# by HEIKE on FRI MAR 6, 1998 at 19:45:38
# LO GAIN calibration LAMP: F497 at DIST: 50.0cm
#ED sensor OCI-1000 S/N 051 calibrated for HI GAIN in IN
SEAWATER
# by HEIKE on FRI MAR 6, 1998 at 19:50:44
# HI GAIN calibration LAMP: F497 at DIST: 110.0cm
ED 339.3 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8387669.8 2.8436e-005  1.36
 8386995.9 1.3937e-005  1.36
ED 412.4 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388672.0 2.3524e-005  1.52
 8388345.8 1.5840e-006  1.52
ED 379.8 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389084.6 2.5118e-005  1.42
 8386149.5 6.1361e-006  1.42
ED 443.2 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388945.4 2.6061e-005  1.44
 8388731.6 1.6618e-006  1.44
ED 520.8 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389160.5 2.6408e-005  1.42
 8389041.4 1.6880e-006  1.42
ED 489.6 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8390161.4 2.6146e-005  1.43
 8390494.3 1.6845e-006  1.43
ED 509.4 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389329.6 2.4565e-005  1.42
 8389726.3 1.6821e-006  1.42
ED 565.5 'uW/cm^2/nm' 3 BU 2 OPTIC1
```

```
 8389057.1 2.7728e-005  1.39
 8391088.2 1.7589e-006  1.39
ED 554.9 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388831.4 2.3869e-005  1.39
 8388739.6 1.6988e-006  1.39
ED 619.1 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388581.8 1.6543e-005  1.40
 8389299.4 4.2972e-007  1.40
ED 665.3 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388542.6 1.7915e-005  1.40
 8388166.6 4.2322e-007  1.40
ED 683.9 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388439.4 1.7025e-005  1.38
 8389407.1 4.3603e-007  1.38
ED 669.7 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388505.4 1.5738e-005  1.40
 8388976.0 4.3234e-007  1.40
ED DARK 'COUNTS' 3 BU 0 COUNT

#
# Ancillary sensors
#
#Tilts calibrated Feb 24, 1998 by Darrell and Heike
# Tiltx Coeff
TILT X 'deg' 2 BU 1 POLYU
-8.4506634e+001   2.5696849e-003   2.7117824e-011

# Tilty Coeff
TILT Y 'deg' 2 BU 1 POLYU
-8.1487576e+001   2.5188603e-003   -3.2515903e-010

#
# SATCAL THERMAL (SATPRO0024)
# Bath run: SATCAL AT=10:48:10 1998-03-07, Jason MacFadyen
# Analysis: SATANL AT=09:30:55 1998-03-08, Jason MacFadyen
#
T i 'C' 2 BU 1 POLYU
-8.859455921e+000 1.170369024e-003 -1.823527569e-008
4.259527991e-013 -6.102609730e-018 5.228366850e-023 -
1.614164093e-028

T r 'C' 2 BU 1 POLYU
-9.658634982e+000 1.273903354e-003 -2.592815753e-008
7.528743094e-013 -1.371316865e-017 1.433271313e-022 -
5.961479868e-028

T w 'C' 2 BU 1 POLYU
```

```
-1.484749725e+001 1.382353307e-003 -2.491509161e-008
7.105451410e-013 -1.307112921e-017 1.427792586e-022 -
6.131730331e-028



# Viatran 500 psi transducer 2224AU2AAE10 s/n 251396
Pres none 'm' 2 BU 1 POLYF
0.010853711  32685

#
#COND024B.cal
#Ocean Sensors CT probe s/n 379 calibrated March 5, 1998 by
Darrell
#
COND NONE 'mmho/cm' 2 BU 1 POLYU
3.5010449236e+0 7.5044785486e-4 3.9190291424e-8 -
1.3476666126e-12 2.2512104196e-17 -1.3920027126e-22


# USE IF NO CONDUCTIVITY PROBE
#Aux2 none '' 2 BU 0 NONE

Aux3 none '' 2 BU 0 NONE
FRAME none '' 1 BU 0 COUNT

#
#  padding for optional Paroscientific sensor
#
PAD none '' 17 AS 0 NONE
```

SMSR Calibration File

```
#
# SATREF0024
#
# SMSR 024 / Maryland 97129
#
# cal file valid 9 March, 1998
#

INSTRUMENT SATREF '' 6 AS 0 NONE
SN 0024 '' 4 AI 0 COUNT
RATE 6 'Hz' 0 BU 0 NONE

#LS sensor OCR-1000 S/N 037 calibrated for LO GAIN in IN
SEAWATER
# by HEIKE on MON FEB 23, 1998 at 19:33:16
# LO GAIN calibration LAMP: F497 TARGET: T13172G at DIST:
130.0cm
#LS sensor OCR-1000 S/N 037 calibrated for HI GAIN in IN
SEAWATER
# by HEIKE on MON FEB 23, 1998 at 19:38:36
# HI GAIN calibration LAMP: F497 TARGET: T13172G at DIST:
230.0cm
LS 339.0 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8390314.3 1.3631e-006  1.78
 8391280.3 1.6356e-007  1.78
LS 412.4 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388756.1 1.4487e-006  1.76
 8388848.7 1.4219e-007  1.76
LS 380.1 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389727.9 1.4641e-006  1.77
 8391490.5 1.4272e-007  1.77
LS 442.8 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389093.0 1.3754e-006  1.75
 8388986.8 1.4204e-007  1.75
LS 519.9 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389446.4 1.5161e-006  1.74
 8389414.6 1.3511e-007  1.74
LS 489.9 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388784.7 1.3648e-006  1.75
 8388697.2 1.3792e-007  1.75
LS 509.7 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8389320.3 1.3816e-006  1.74
 8389271.1 1.4086e-007  1.74
LS 565.3 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388786.8 1.3988e-006  1.74
 8388719.6 1.4266e-007  1.74
```

```
LS 554.4 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388735.4 1.4423e-006  1.74
 8388765.5 1.4008e-007  1.74
LS 619.3 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388814.3 7.0402e-007  1.73
 8388800.9 3.3583e-008  1.73
LS 664.4 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388423.7 7.2085e-007  1.73
 8388414.0 3.4940e-008  1.73
LS 682.7 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388815.6 7.2432e-007  1.73
 8388952.3 3.5161e-008  1.73
LS 669.8 'uW/cm^2/nm/sr' 3 BU 2 OPTIC1
 8388173.8 7.2753e-007  1.73
 8388205.1 3.4713e-008  1.73
LS DARK 'COUNTS' 3 BU 0 COUNT

#ES sensor OCI-1000 S/N 052 calibrated for LO GAIN in IN
AIR
# by HEIKE on MON MAR 9, 1998 at 17:56:47
# LO GAIN calibration LAMP: F497 at DIST: 50.0cm
#ES sensor OCI-1000 S/N 052 calibrated for HI GAIN in IN
AIR
# by HEIKE on MON MAR 9, 1998 at 18:01:16
# HI GAIN calibration LAMP: F497 at DIST: 50.0cm
ES 339.2 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388787.8 3.4965e-005  1.00
 8385732.1 4.5416e-006  1.00
ES 411.2 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389313.1 3.5822e-005  1.00
 8389278.1 2.4194e-006  1.00
ES 380.1 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389362.7 3.4385e-005  1.00
 8387451.0 2.5411e-006  1.00
ES 442.0 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389889.9 3.7767e-005  1.00
 8389839.3 2.4958e-006  1.00
ES 519.3 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389583.3 3.6962e-005  1.00
 8389524.9 2.3948e-006  1.00
ES 490.4 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389367.0 3.7985e-005  1.00
 8389385.9 2.4542e-006  1.00
ES 510.5 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8389469.7 3.7817e-005  1.00
 8389421.5 2.4185e-006  1.00
ES 564.9 'uW/cm^2/nm' 3 BU 2 OPTIC1
```

```
 8388961.8 3.9324e-005  1.00
 8388960.6 2.4324e-006  1.00
ES 554.9 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388663.1 3.5851e-005  1.00
 8388624.3 2.4201e-006  1.00
ES 619.2 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388150.4 3.4395e-005  1.00
 8388140.2 2.4216e-006  1.00
ES 665.4 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388536.1 3.8642e-005  1.00
 8388511.9 2.4044e-006  1.00
ES 682.2 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388205.2 3.8207e-005  1.00
 8388313.2 2.4679e-006  1.00
ES 670.1 'uW/cm^2/nm' 3 BU 2 OPTIC1
 8388033.0 3.8312e-005  1.00
 8388036.1 2.4081e-006  1.00
ES DARK 'COUNTS' 3 BU 0 COUNT

#
# Ancillary sensors
#
#Tilts calibrated Feb 23 1998 by Darrell and Heike
# Tiltx Coeff
TILT X 'deg' 2 BU 1 POLYU
8.1434267e+001   -2.4903728e-003   9.0977616e-011

# Tilty Coeff
TILT Y 'deg' 2 BU 1 POLYU
8.2598038e+001   -2.4998651e-003   -2.8631035e-010

#
# SATCAL THERMAL (SATREF0024)
# Bath run: SATCAL AT=17:01:17 1998-02-26, Vern, Darrell &
Jason
# Analysis: SATANL AT=09:50:04 1998-02-27, Jason & Darrell
#
T i 'C' 2 BU 1 POLYU
-8.966624303e+0 1.178159189e-3 -1.859307444e-8
4.448179627e-13 -6.638994363e-18 5.971746755e-23 -
2.000428162e-28

T r 'C' 2 BU 1 POLYU
-9.574832669e+0 1.214497515e-3 -1.949485280e-8
4.360412326e-13 -5.706579775e-18 4.289859677e-23 -
1.016340157e-28
```

```
Aux2 none '' 2 BU 0 NONE
Aux3 none '' 2 BU 0 NONE
Aux4 none '' 2 BU 0 NONE
Aux5 none '' 2 BU 0 NONE

FRAME none '' 1 BU 0 COUNT

#
# padding for optional Paroscientific sensor
#
PAD none '' 17 AS 0 NONE
```