Technical Report 1553
September 1992

Oceanic In Situ Fraunhofer-Line Characteristics (Fraunhofer-Line Underwater eXperiment: FLUX)

M. G. Lovern
M. W. Roberts
S. A. Miller
G. T. Kaye

NRaD

Approved for public release; distribution is unlimited.

Technical Report 1553
September 1992

Oceanic In Situ Fraunhofer-Line Characteristics (Fraunhofer-Line Underwater eXperiment: FLUX)

M .G. Lovern
M. W. Roberts
S. A. Miller
G. T. Kaye

NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER RDT&E DIVISION
San Diego, California 92152−5000

J. D. FONTANA, CAPT, USN
Commanding Officer

R. T. SHEARER
Executive Director

ADMINISTRATIVE INFORMATION

The study covered in this document was performed from August 1989−September 1991. The Fraunhofer-Line Underwater eXperiment (FLUX) field work was sponsored by the Office of Naval Research, Code 12, Arlington, VA; and the data analysis was funded through the Space and Naval Warfare Systems Command, Washington, DC. The task was performed under program element 0603741N, accession no. DN687623, and project no. CM06 by Code 844 of the Naval Command, Control and Ocean Surveillance Center RDT&E Division (NRaD), San Diego, CA 92152−5000.

Released by
R. J. Nies, Head
Electro-Optic
Systems Branch

Under authority of
C. E. Gibbens, Head
Satellite Communications
Division

ACKNOWLEDGMENTS

The following NRaD personnel provided valuable help during the at-sea experiment: Roy Axford and Robert Howarth, Code 844; and George Evanoff, Code 843.

RBT

CONTENTS

1. INTRODUCTION 1
2.. AT-SEA MEASUREMENTS 3
3. ANALYSIS 9
4. CONCLUSIONS 17
5. REFERENCES 19

FIGURES

1. 486-nm Fraunhofer line 3
2. FLUX system, block diagram 4
3. Fraunhofer-line comparison—FLUX versus textbook 5
4. Underwater sensor package 5
5. Typical example of K measurement 6
6. Comparison of submerged (73-m depth) and surface Fraunhofer-line scans 10
7. Comparison of submerged (90-m depth) and surface Fraunhofer-line scans 11
8. Squared coherence function comparisons for 73-m Fraunhofer-line spectral scans 13
9. Comparison of submerged (73-m depth) and surface "long" scans 14

TABLES

1. Fraunhofer-lines investigated 3
2. FLUX K data summary 7

1. INTRODUCTION

Daytime performance of underwater optical communications in the upper ocean is limited by solar background. To enhance performance, numerous researchers have proposed using signal wavelengths within the reduced solar background provided by Fraunhofer lines. The performance improvement (references 1 and 2) gained by operating in a Fraunhofer line can be significant and, at some wavelengths, approaches an order of magnitude in signal-to-noise ratio. However, recent work in optical oceanography suggests the presence of an "additional" light field (references 3–7) in the upper ocean. The effect of an increased light field could significantly reduce (potentially eliminate) the absorption depth of Fraunhofer lines and reduce their solar-rejection benefits to optical communications.

For a number of years, optical oceanographers have measured abnormally low values for oceanic diffuse attenuation coefficients (K); and in certain cases, these values have been lower (references 8–12) than those for molecular water. These abnormally low values of K indicate the presence of more light at depth than for the case of molecular water. The increased light level has been suggested to result from internal-radiant emission caused by an inelastic (Raman) scattering process. This action produces a wavelength-shifted band of light (references 3–7) with a mean frequency shift of 3357 cm^{-1}. In other words, Raman scattering causes solar irradiance from shorter wavelengths to be wavelength-shifted to longer wavelengths, thus increasing ambient light at the longer wavelengths. The result of this process should be more apparent in the "green" spectral region (reference 13) due to the transmission characteristics of seawater.

The Naval Oceanographic and Atmospheric Research Laboratory (NOARL) has recently developed a model (references 3 and 4) that accounts for the additional light field induced by Raman scattering. Their optical model is a Monte Carlo solution of the radiative-transfer equation. Model results indicate the underwater light field becomes increasingly dominated by the Raman-scattered light component as depth increases. The largest unknown in the model (references 3, 4, and 6) is the value of the Raman-scattering coefficient. A range of values for the Raman-scattering coefficient has been determined by using experimental data from both field measurements and laboratory observations. The Raman-scattering coefficient values are bounded by a high estimate and a low estimate. Application of the high estimate in the NOARL model (at 520 nm) indicates that at a depth of 110 m, 50 percent of the total amount of light present is due to direct solar irradiance, and the other 50 percent is due to Raman scattering. However, when the low estimate is used, this same condition occurs at a depth of 160 m. As the depth is increased beyond this point, the underwater light field becomes dominated by the Raman-scattered light.

Since the Raman-scattering process produces a band shift, the total Raman contribution to any narrow wavelength interval should be homogeneous. This would suggest that as the Raman-scattered contribution to the underwater light field increases as depth increases, the Fraunhofer lines would become less defined: The lines would appear to "fill-in" to the continuum level as depth increases.

2. AT-SEA MEASUREMENTS

To investigate the potential effect of reducing the Fraunhofer absorption, an experiment was conducted at sea in August 1989. This experiment, the Fraunhofer Line Underwater eXperiment (FLUX), was conducted approximately 100 miles north of Oahu, Hawaii. FLUX was conducted on the Semi-Submerged Platform (SSP) Kaimalino, operated by the NCCOSC RDT&E Division (Hawaii). The objective of the experiment was to characterize Fraunhofer lines as a function of ocean depth.

Table 1 lists the five Fraunhofer lines characterized. As illustrated in figure 1, the fine structure inherent in the Fraunhofer lines (reference 14) requires narrowband spectral scanning and a high degree of wavelength accuracy. This was accomplished by using a 0.75-m double monochromator with an optical bandwidth of 0.01–0.02 nm. In addition to the five Fraunhofer-line scans, a continuous scan (0.1-nm resolution) from 450 to 550 nm was made at a depth of 73 m.

Table 1. Fraunhofer-lines investigated.

Center Wavelength (nm)	Scan Parameters (nm)		Scan Width (nm)
	Start	End	
420.18 (Fe)	420.03	420.33	0.30
440.47 (Fe)	440.20	440.70	0.50
486.13 (H)	485.28	487.00	1.72
518.30 (Mg)	517.80	519.00	1.20
532.42 (Fe)	532.15	533.15	2.00

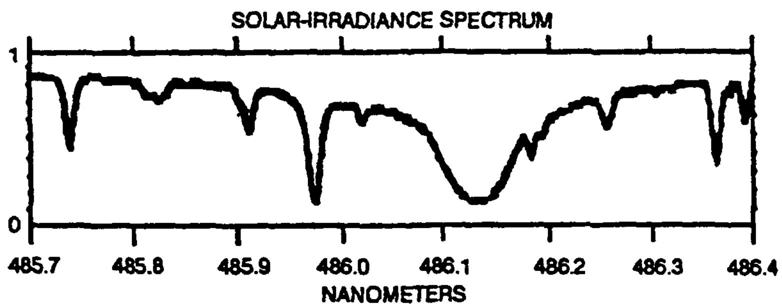


Figure 1. 486-nm Fraunhofer line.

Figure 2 shows the FLUX experimental setup. A custom-built fiber-optic bundle was used to couple the underwater light into the shipborne monochromator. A fiber-optic cable was chosen, since it is difficult to find a high-resolution monochromator capable of being submerged and remotely operated. The fiber-optic bundle was 120 m long and consisted of one-hundred, 210-micron fibers optimized for the visible region. The bundle was carefully shielded to prevent light from leaking into and out of the cable. The fibers were arranged in a circular pattern at the collection end and a 1-by-100 linear array at the exit end. The linear array of fibers at the exit end was designed to be compatible with the linear input slit of the monochromator. To increase the coupling efficiency of the fiber-to-monochromator interface, a relay lens system was used to image the output of the fiber array onto the input slit of the monochromator. The monochromator had a linear drive motor attached to the wavelength scanner to scan the wavelength at a constant speed. A photomultiplier tube (PMT) was attached to the output slit of the monochromator with the anode connected to a photon counter. The spectral scans were recorded by interfacing a computer to the photon counter. The computer recorded the number of photoelectron counts as a function of time which in turn translates to counts versus wavelength.

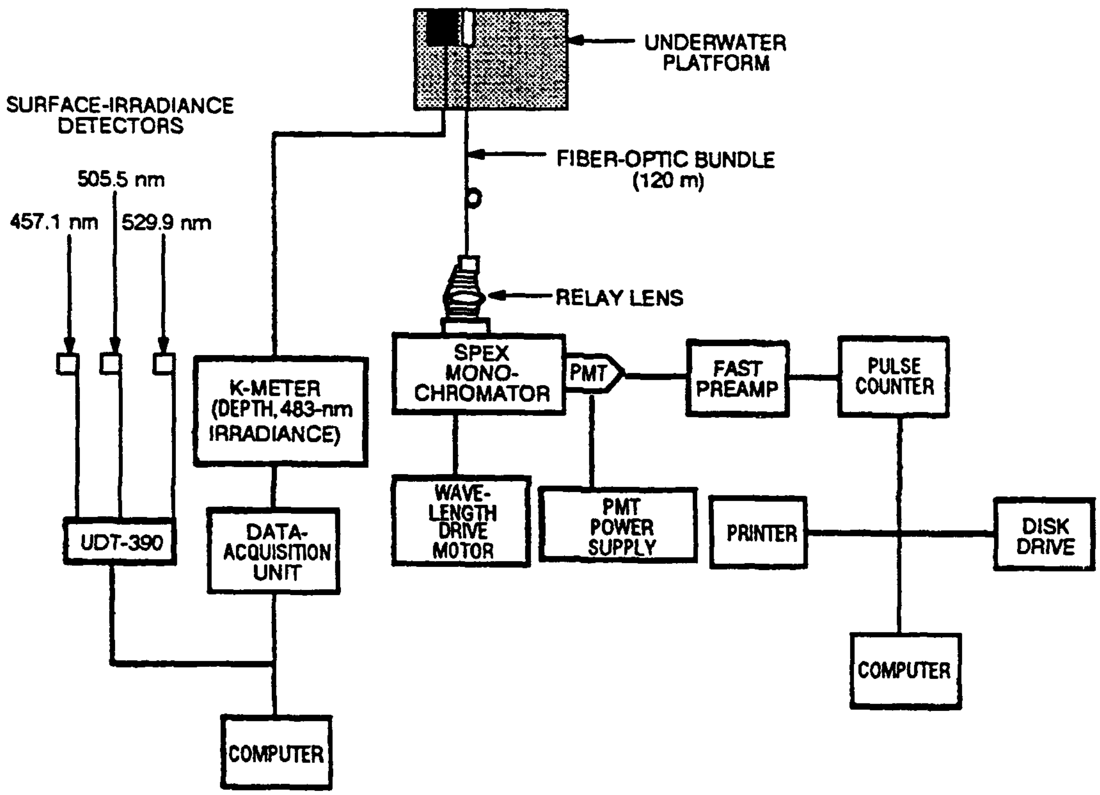


Figure 2. FLUX system, block diagram.

The wavelength of each of the five Fraunhofer lines was scanned at four discrete depths: 25, 50, 73, and 90 m. Scans were also conducted at the surface, both to check the system and to serve as a reference. Figure 3 shows a comparison between a textbook scan and one the FLUX equipment recorded for the 486-nm Fraunhofer line. (Note: the rough appearance of the two figures is caused by the optical scanner used to read them into the computer for this report.) The scans are vertically offset to allow a better comparison, with the textbook scan positioned on the top. The strong similarity indicates no statistically significant differences and ensured that the in-situ characterizations are correct. During the final day, we added a broadband spectral scan from 450 nm to 550 nm (0.1-nm resolution).

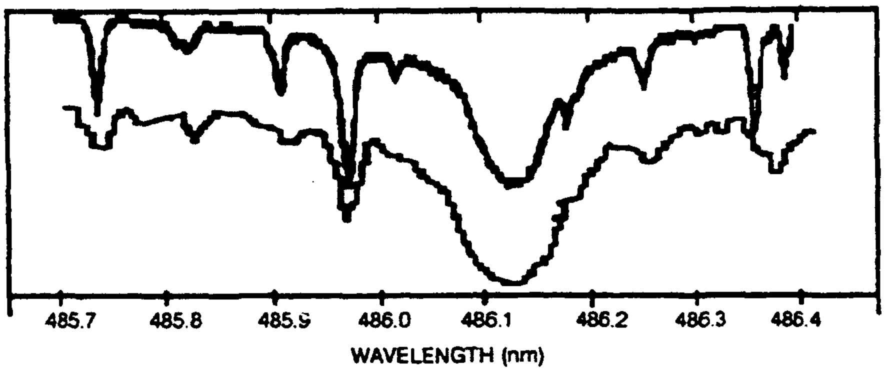


Figure 3. Fraunhofer-line comparison—FLUX versus textbook.

Concurrent irradiance measurements were made during the FLUX scans to normalize solar-irradiance fluctuations due to the presence of clouds, wave focusing, and other underwater optical disturbances. These irradiance measurements were made simultaneously at the surface and underwater (when possible). Underwater irradiance measurements were made with an irradiance meter (K-meter) included in the underwater sensor package as illustrated in figure 4. The K-meter contains a PMT that was spectrally filtered at 483.5 nm with a 10-nm bandpass and a depth sensor. Cable length limited the K-meter to a maximum depth of 73 m. For scans at depths greater than 73 m, the K-meter was removed from the underwater sensor package, and irradiance normalizations were obtained using the surface irradiance data. The fiber-optic bundle was marked at regular intervals (from the 73-m point at 5-m increments), and depth was then determined from these physical markings.

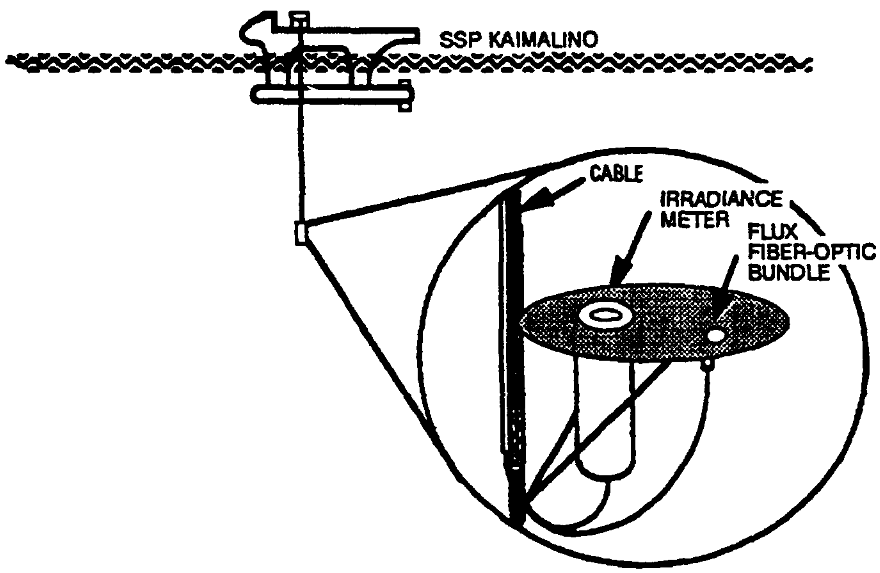


Figure 4. Underwater sensor package.

The K-meter was also used for measuring the diffuse attenuation coefficient (K) before and after each FLUX sensor deployment. A measurement of K was made by recording the irradiance as a function of depth. Once these data were plotted, integrated K was determined by calculating the slope of a linear fit to the data. Figure 5 is a typical example of a K measurement from the FLUX experiment

$$K = \frac{-Ln\left[\frac{E_z}{E_0}\right]}{z}$$

where K is the diffuse attenuation coefficient (m^{-1}), z is the depth in meters, E_z is the irradiance at depth, and E_0 is the surface irradiance.

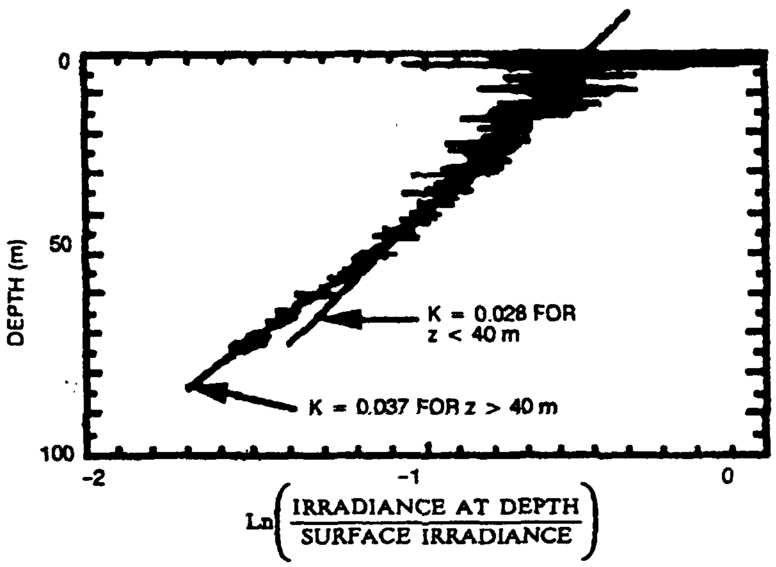


Figure 5. Typical example of K measurement.

The FLUX K profiles had two distinctive slopes intersecting at an approximate depth of 40–50 m and were concurrent with the location of a thermocline. These multiple slopes have the effect of creating a change in the value of integrated K used, depending upon the operating-depth zone. Table 2 is a summary of the FLUX K measurements.

Table 2. FLUX K data summary.

Date	Time	Depth Range (m)	K (483.5 nm)
8/7/89	1437	60–73	0.025
8/7/89	1643	30–73	0.048
8/7/89	1643	0–50	0.040
8/8/89	1138	40–70	0.037
8/8/89	1138	0–40	0.028
8/8/89	1309	50–70	0.029
8/8/89	1413	22–45	0.043
8/9/89	1008	0–55	0.031
8/9/89	1008	55–71	0.042
8/9/89	1200	50–73	0.040
8/9/89	1300	25–40	0.032
8/9/89	1400	0–25	0.034
8/10/89	0910	38–73	0.041
8/10/89	0910	0–38	0.033
8/10/89	1101	47–73	0.037
8/10/89	1101	0–47	0.027

3. ANALYSIS

The majority of the individual spectral scans—referred to as "short scans"—encompassed a wavelength range of approximately 1 nanometer. The start and end wavelengths of each scan were selected so the primary Fraunhofer line was centered within the scan. Additional criteria were that the scan should contain an adequate "continuum" level as well as nearby secondary lines. The continuum level is defined as the level at which the solar irradiance is at maximum. For the short scans, each data point is the photoelectron count accumulated during a 2.5-second integration time. The wavelength scan rate was set for 0.1 nm per minute, and the spectral resolution was approximately 0.01 nm.

Two submerged "long" scans were also performed over the continuous wavelength range from 450 to 550 nm. The scan rate during the "long" scans was 0.6 nm per minute, integration time was 0.6 seconds, and spectral resolution was approximately 0.1 nm.

During each scan, the operator periodically entered wavelength-counter readings. These counter readings were automatically "time-tagged" by the computer and stored with the data. The settings of all pertinent equipment parameters were also stored in the data file during the scan.

Each scan contained "zero-level" measurements made prior to starting the scan and also at the end of the scan. These are measurements of the dark-noise count and were obtained by blocking the entrance slit of the monochromator and recording several data points at the same sample rate as for the spectral scans. The shutter located between the exit slit and the PMT was left open during these zero-level measurements. Zero-level measurements quantified both the PMT dark noise and any ambient light entering the monochromator.

Two principal "noise" sources producing irradiance fluctuations were noted during the experiment. The sources were caused by wave-focusing and clouds passing overhead. Wave-focusing produced significant fluctuations at 25- and 50-m depths, but had little effect at 73 and 90 m. Irradiance dropout due to clouds was occasionally quite large and was noticeable at all depths.

Since the purpose of the experiment was to determine to what extent various Fraunhofer lines "filled-in," the analysis centered on comparing the Fraunhofer spectra collected at depth against the same Fraunhofer spectra collected at the surface. Each data scan was zero-level corrected and then normalized. The submerged scans were also corrected for gross-temporal irradiance fluctuations by using data from the underwater irradiance meter. Minor higher frequency random noise observed in the raw data was removed by spectral processing (treating the scan as a time series) by using a discrete fast fourier transform (FFT) algorithm.

Comparisons between submerged and surface "short" spectral scans are shown in figures 6 and 7. These figures contain examples of the spectral plots for all five of the Fraunhofer lines that were investigated at depths of 73 and 90 m respectively. For each wavelength, the plot of the underwater scan (solid line) has been normalized and processed using the techniques just described. Along with the underwater plot is a normalized plot of the associated surface scan (dotted line). To within experimental accuracy, the line shapes and the ratios between line depth and continuum level remained constant for all observed wavelength ranges at all depths.

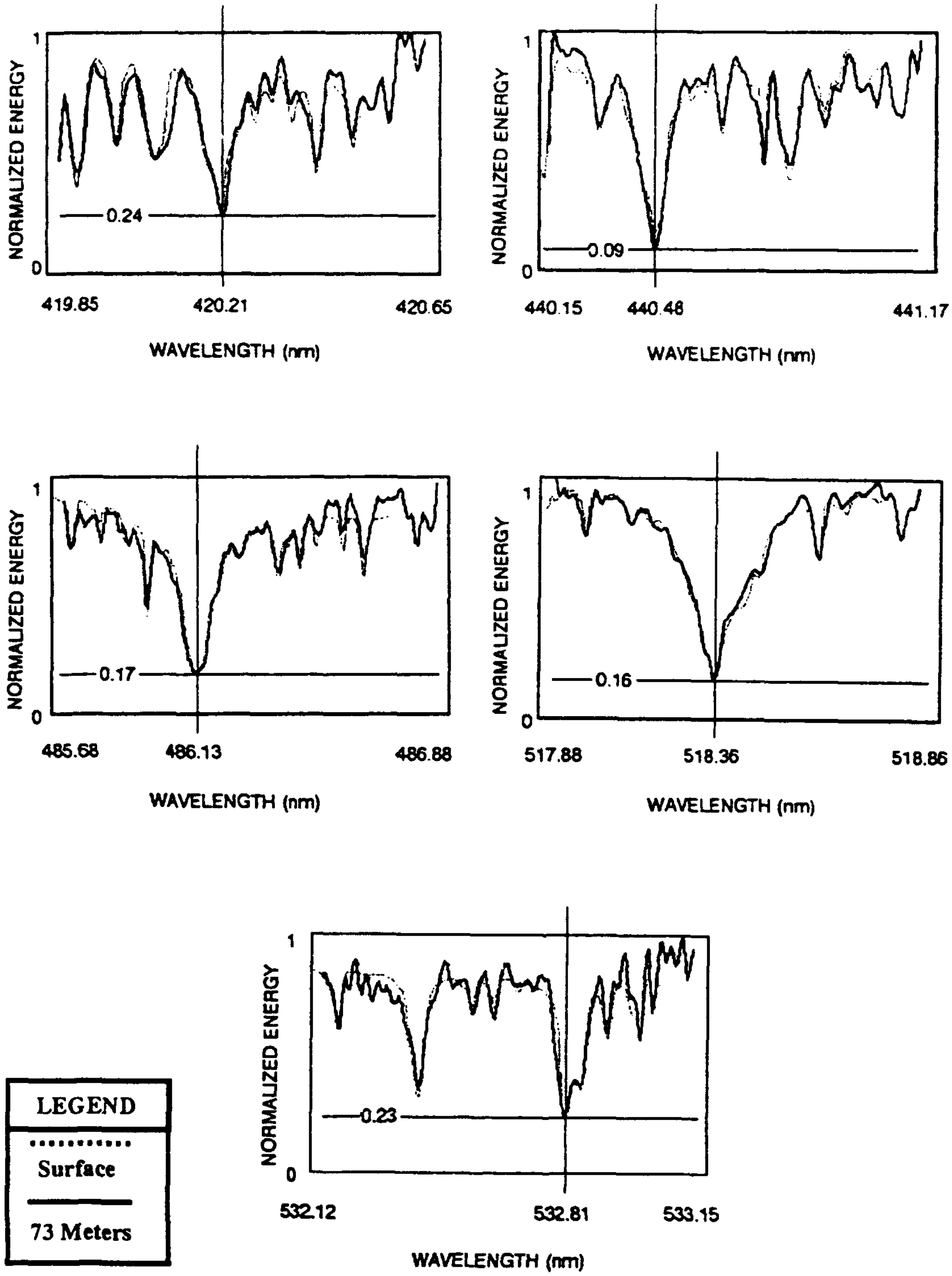


Figure 6. Comparison of submerged (73-m depth) and surface Fraunhofer-line scans.

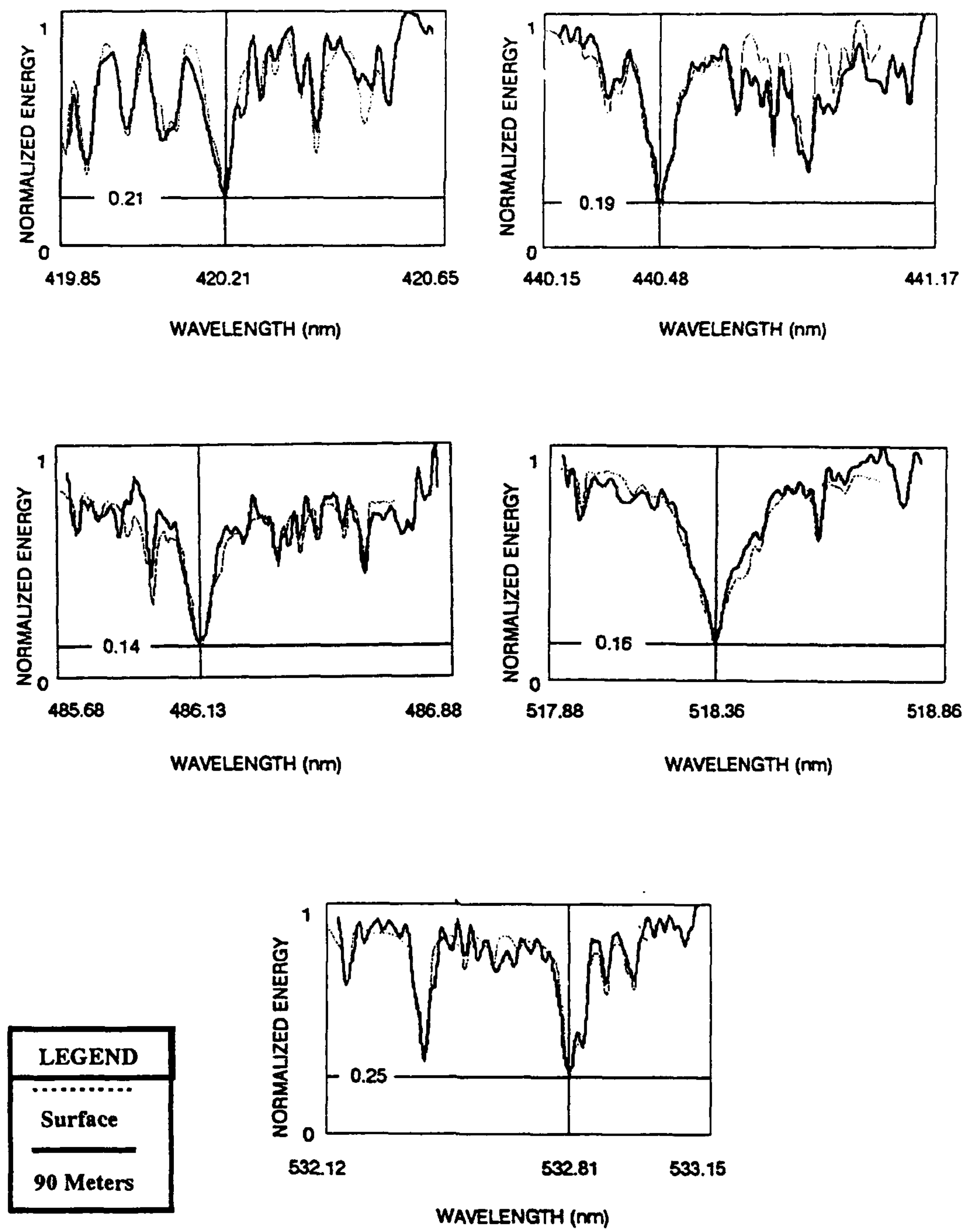
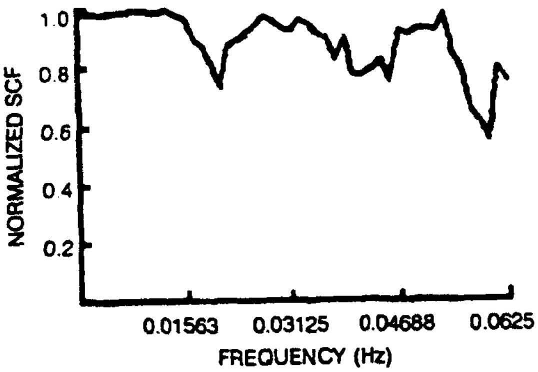


Figure 7. Comparison of submerged (90-m depth) and surface Fraunhofer-line scans.

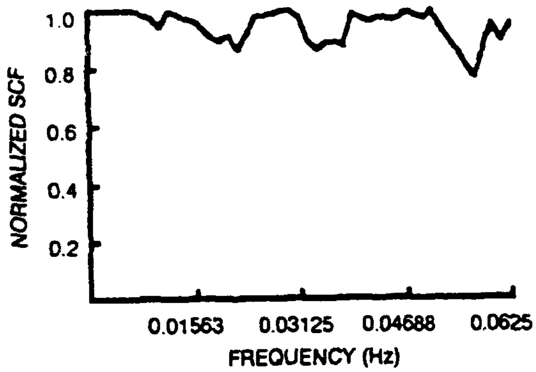
Some minor differences in the wavelength scale may be seen; however, this can be attributed to the slight variability in the wavelength drive motor for the monochromator. The much narrower absorption lines surrounding the main Fraunhofer line have not, in any of the scans, degraded in absorption depth or width. If interwavelength scattering had occurred, the narrowest lines would simply have disappeared and the absorption peak for the main line would have been reduced in depth. Further, a comparison between the 73- and 90-m scans reveals no detectable difference. Had there been interwavelength scattering, a noticeable difference should have occurred between the scans of different depths, particularly at 518 and 532 nm. Thus, these observations reveal no obvious reduction ("filling-in") of the Fraunhofer-line structure.

Conclusions based upon the observations just made were further corroborated by calculations of the squared coherence function (SCF) for the surface and underwater data. Figure 8 is a plot of the SCF between the surface and underwater data for the scans shown in figure 6. The value of the SCF never falls below 0.6 and is usually close to 1.0 for the frequency region between 0 and 0.03125 Hz, which contains nearly all of the energy in each scan. This strongly indicates the level of agreement between the surface and underwater scans. Had any interwavelength scattering occurred, the SCF value would have been much lower, particularly at the higher frequencies. Higher frequencies represent the narrower Fraunhofer lines, which are more susceptible to change due to interwavelength scattering. (Since they are narrow in line width, a smaller increase in light level within the absorption band is more readily detected.) Therefore, if the underwater light level had increased and the Fraunhofer line had begun to "fill-in," one would expect the SCF values to fall off toward 0 at higher spatial frequencies. However, this clearly does not occur.

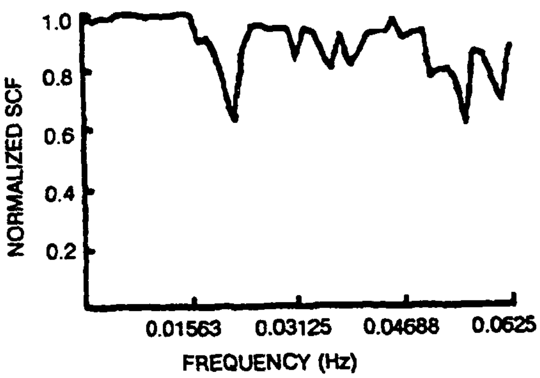
A comparison between submerged and surface "long" scans is presented in figure 9. Figure 9(a) is the complete scan from 450 to 550 nm, whereas figures 9(b) and (c) are expanded views of the 486- and 518-nm Fraunhofer lines taken from the "long" scans. Both scans have been zero-level corrected and normalized. Additionally, each scan was corrected for the dispersion in the fiber-optic bundle using post-field spectral calibration data. The underwater scan was also corrected for temporal irradiance fluctuations.



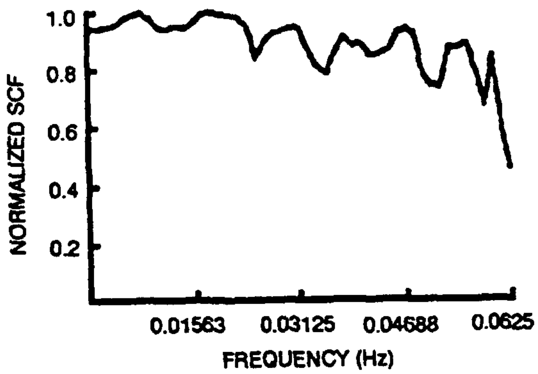
a. 486.13-nm FRAUNHOFER LINE



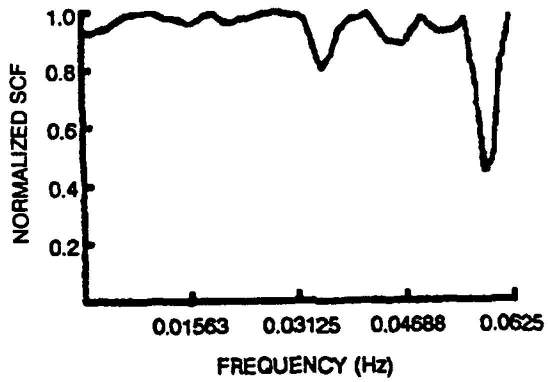
b. 518.36-nm FRAUNHOFER LINE



c. 532.42-nm FRAUNHOFER LINE



d. 440.48-nm FRAUNHOFER LINE



e. 420.18-nm FRAUNHOFER LINE

Figure 8. Squared coherence function comparisons for 73-m Fraunhofer-line spectral scans.

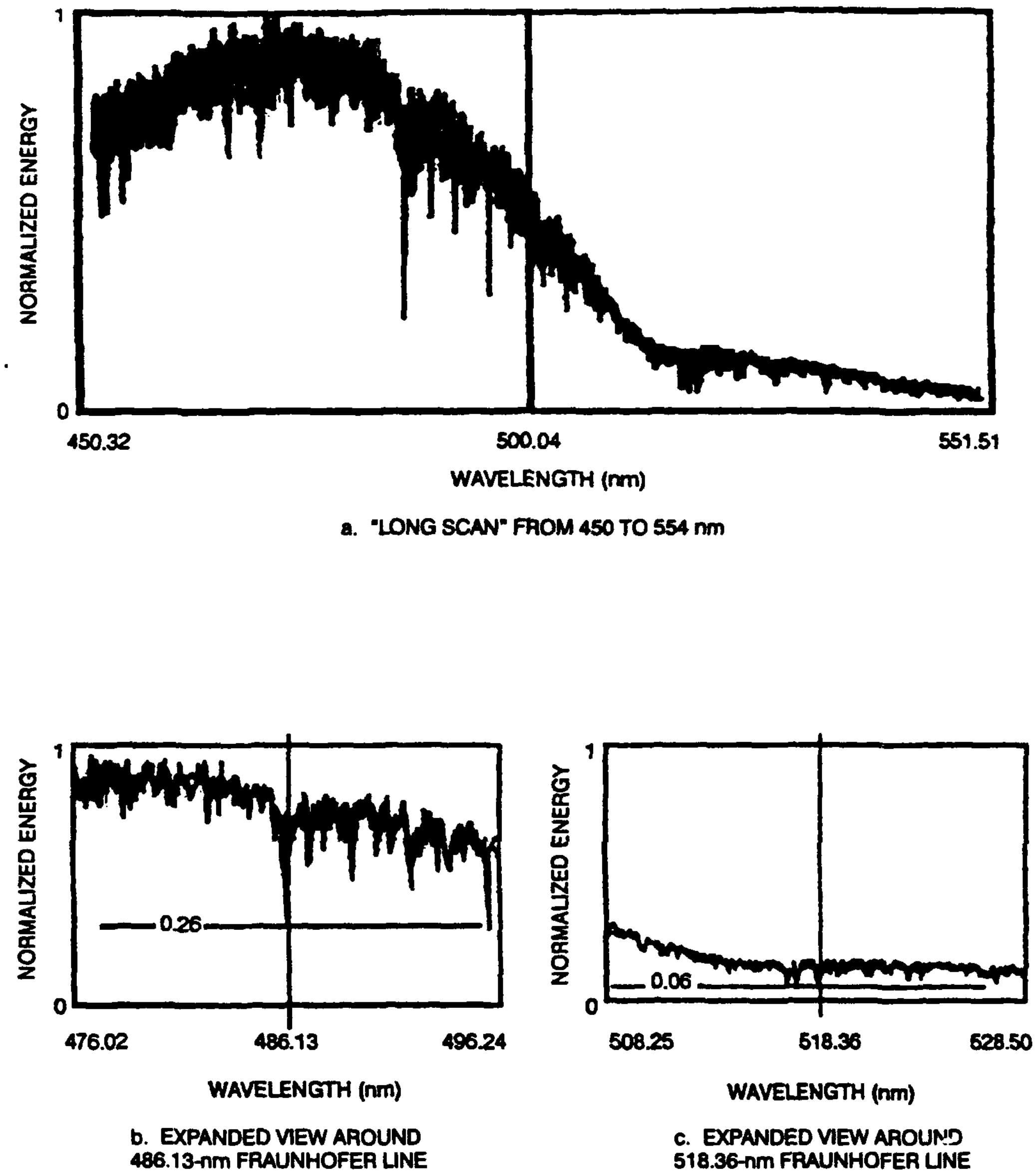


Figure 9. Comparison of submerged (73-m depth) and surface "long" scans.

The surface "long" scan has been altered to appear as it would at a depth of 73 m. This was done by applying the Austin/Petzold water model (reference 15). Using this model, knowing the value of the diffuse attenuation coefficient at any wavelength in the range from 400 to 700 nm allows calculation of K at any other wavelength within the range. During the experiment, measurements of K (483.5 nm) were made at the beginning and end of a FLUX sensor deployment. The mean of these measurements was 0.035. This value was used in the water model to correct the surface "long" scan data for the relative dispersive attenuation of the ocean to a depth of 73 m. Although distinguishing between the two curves in figure 9 is difficult, they illustrate how much agreement exists between the surface and underwater scans. Had there been interwavelength scattering, the underwater scan would have fallen away from the surface scan as wavelength increased from 450 to 550 nm. Furthermore, the fine structure in the underwater scan would have disappeared. The expanded views of the 486- and 518-nm lines clearly indicate the level of agreement between the two scans.

4. CONCLUSIONS

The ONR-sponsored Fraunhofer-Line Underwater eXperiment (FLUX) was successfully conducted off the coast of Hawaii in August 1989. This experiment obtained the first-known characterizations of Fraunhofer lines underwater. These characterizations verified the presence of the blue-green spectrum Fraunhofer lines to a depth of 90 m with no measurable change in the line structure.

According to the current Raman scattering model, use of the high-estimate scattering coefficient yields a prediction that a significant amount of Raman scattered light should have been present at the FLUX measurement depth of 90 m. The model predicts the Raman scattered contribution in the "blue" (420, 440, and 486 nm) Fraunhofer lines was potentially too small to resolve. It also predicts that an observable change should have occurred in the "green" (518 and 532 nm) Fraunhofer lines. The Raman scattering effect should also have been observable in the "long" scan. The results of the FLUX experiment indicate that the high estimate of the Raman scattering coefficient may be discontinued.

These results demonstrate the need for additional experimental investigation to quantify the Raman scattering coefficient. While, clearly, Fraunhofer lines may be used in an SLC system down to 90 m without degrading their solar rejection characteristics, further experiments should be conducted at depths greater than those achieved during FLUX. These experiments should include upwelling and side-looking irradiance measurements, since these measurements would contain dominating amounts of scattered light.

5. REFERENCES

1. Kerr, E. L. 1989. "Fraunhofer Filters to Reduce Solar Background for Optical Communications," *Opt. Eng. 28(9)*, pp. 963–968.

2. Anderson, R. D., R. R. James, and J. W. Rockway. 1989. "Optical Communications Receivers for Satellite Laser Communications (SLC) and Tactical Airborne Laser Communications (TALC)." NOSC TR 1291 (April). Naval Ocean Systems Center, San Diego, CA.

3. Stavn, R. H., and A. D. Weidemann. 1988. "Raman Scattering Effects in Ocean Optics," in *Ocean Optics IX*, M. A. Blizard, ed., *Proc. Soc. Photo-Opt. Instrum. Eng. 925*, pp. 131–139.

4. Stavn, R. H., and A. D. Weidemann. 1988. "Optical Modeling of Clear Ocean Light Fields: Raman-Scattering Effects," *Appl. Opt. 27*, pp. 4002–4010.

5. Marshall, B. R. 1989. "Raman-Scattering in Ocean Water," M. S. thesis. Department of Geography, University of California, Santa Barbara; Santa Barbara, California.

6. Marshall, B. R., and R. C. Smith. 1990. "Raman Scattering and In-Water Optical Properties," *Appl. Opt. 29*, pp. 71–84.

7. Sugihara, S., M. Kishino, and M. Okami. 1984. "Contribution of Raman Scattering to Upward Irradiance in the Sea," *J. Oceanogr. Soc. Jpn. 40*, pp. 397–404.

8. Siegel, D. A., and T. D. Dickey. 1988. "Characterization of Downwelling Spectral Irradiance Fluctuations," in *Ocean Optics IX*, M. A. Blizard, ed., *Proc. Soc. Photo-Opt. Instrum. Eng. 925*, pp. 67–74.

9. Siegel, D. A., and T. D. Dickey. 1987. "Observations of the Vertical Structure of the Diffuse Attenuation Coefficient Spectrum," *Deep Sea Res. 34A*, pp. 547–563.

10. Prieur, L., and S. Sathyendranath. 1981. "An Optical Classification of Coastal and Oceanic Waters Based on the Specific Spectral Absorption Curves of Phytoplankton Pigments, Dissolved Organic Matter, and Other Particulate Materials," *Limnol. Oceanogr. 26*, pp. 671–689.

11. Kitchen, J. C., and H. Pak. 1987. "Observations of Natural Fluorescence with an Underwater Radiometer," *J. Oceanogr. Soc. Jpn. 43*, pp. 356–362.

12. Topliss, B. J. 1985. "Optical Measurements in the Sargasso Sea: Solar-Stimulated Chlorophyll Fluorescence," *Oceanol. Actra. 8*, pp. 263–270.

13. Jerlov, N. G. 1976. *Marine Optics*. Elsevier, Amsterdam.

14. Kurucz, R. L., et al. 1984. "Solar Flux Atlas from 296 to 1300 nm," *National Solar Observatory Atlas No. 1*, (June) p. 26.

15. Austin, R. W., and T. J. Petzold. 1986. "Spectral Dependence of the Diffuse Attenuation Coefficient of Light in Ocean Waters," *Optical Engineering 25(3)*, (March) pp. 471–479.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1992

3. REPORT TYPE AND DATES COVERED
Final: FY89–FY91

4. TITLE AND SUBTITLE
OCEANIC IN SITU FRAUNHOFER-LINE CHARACTERISTICS
(FRAUNHOFER-LINE UNDERWATER EXPERIMENT: FLUX)

5. FUNDING NUMBERS
PE: 0603741N
ACCESS NO.: DN687623
PR: CM06

6. AUTHOR(S)
M. G. Lovern, M. W. Roberts, S. A. Miller, and G. T. Kaye

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER
TR 1553

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Arlington, VA 22217–5000

Space and Naval Warfare Systems Command
Washington, DC 20363–5100

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Interest in making use of the existence of Fraunhofer lines to reduce solar background noise for the Satellite Laser Communications (SLC) program prompted the requirement for making underwater in situ characterizations of five Fraunhofer lines in the blue-green spectrum. Recent papers that discuss and attempt to explain frequent occurrences of high measured values for underwater irradiance raised concerns about the persistence of Fraunhofer lines. The effect of an increased light field could significantly reduce (potentially eliminate) the absorption depth of Fraunhofer lines and reduce their solar-rejection benefits to optical communications. These characterizations were made from a surface ship off the coast of Hawaii in August 1989. Fraunhofer lines at 420, 440, 486, 518, and 532 nm were characterized at the surface and at four discrete depths to a maximum depth of 90 m. These are the first known characterizations of Fraunhofer lines underwater. A high resolution scan from 450 to 550 nm was also made at a depth of 73 m. The results from this experiment showed no differences between the surface and underwater scans, suggesting the effects of interwavelength scattering is less than originally proposed.

14. SUBJECT TERMS

15. NUMBER OF PAGES
23

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1992	Final: FY89–FY91

4. TITLE AND SUBTITLE

OCEANIC IN SITU FRAUNHOFER-LINE CHARACTERISTICS (FRAUNHOFER-LINE UNDERWATER EXPERIMENT: FLUX)

5. FUNDING NUMBERS

PE: 0603741N
ACCESS NO.: DN687623
PR: CM06

6. AUTHOR(S)

M. G. Lovern, M. W. Roberts, S. A. Miller, and G. T. Kaye

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

TR 1553

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Arlington, VA 22217–5000

Space and Naval Warfare Systems Command
Washington, DC 20363–5100

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Interest in making use of the existence of Fraunhofer lines to reduce solar background noise for the Satellite Laser Communications (SLC) program prompted the requirement for making underwater in situ characterizations of five Fraunhofer lines in the blue-green spectrum. Recent papers that discuss and attempt to explain frequent occurrences of high measured values for underwater irradiance raised concerns about the persistence of Fraunhofer lines. The effect of an increased light field could significantly reduce (potentially eliminate) the absorption depth of Fraunhofer lines and reduce their solar-rejection benefits to optical communications. These characterizations were made from a surface ship off the coast of Hawaii in August 1989. Fraunhofer lines at 420, 440, 486, 518, and 532 nm were characterized at the surface and at four discrete depths to a maximum depth of 90 m. These are the first known characterizations of Fraunhofer lines underwater. A high resolution scan from 450 to 550 nm was also made at a depth of 73 m. The results from this experiment showed no differences between the surface and underwater scans, suggesting the effects of interwavelength scattering is less than originally proposed.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
	23	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

UNCLASSIFIED

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE (include Area Code)	21c. OFFICE SYMBOL
M. G. Lovern	(619) 553-3724	Code 844

NSN 7540-01-280-5500

Standard form 298 (BACK)

UNCLASSIFIED

INITIAL DISTRIBUTION

Code 0012	Patent Counsel	(1)
Code 02712	Archive/Stock	(6)
Code 0274B	Library	(2)
Code 555	S. A. Miller	(1)
Code 804	E. Munn	(1)
Code 804	G. W. Beaghler	(1)
Code 804	E. Schimitischek	(1)
Code 804	V. N. Smiley	(1)
Code 805	M. S. Kvigne	(1)
Code 84	C. E. Gibbens	(1)
Code 843	D. A. Gookin	(1)
Code 843	G. L. Adams	(1)
Code 843	G. A. Evanoff	(1)
Code 843	F. E. Hanson	(1)
Code 843	R. F. Howarth	(1)
Code 843	M. G. Lovern	(20)
Code 844	R. J. Nies	(1)
Code 844	R. A. Axford	(1)
Code 844	R. James	(1)
Code 844	J. F. Parsons	(1)

Defense Technical Information Center
Alexandria, VA 22304–6145 (4)

NCCOSC Washington Liaison Office
Washington, DC 20363–5100

Center for Naval Analyses
Alexandria, VA 22302–0268

Navy Acquisition, Research and Development
Information Center (NARDIC)
Washington, DC 20360–5000

GIDEP Operations Center
Corona, CA 91718–8000

NCCOSC Division Detachment
Warminster, PA 18974–5000

Office of Naval Research
Detachment, Boston
Boston, MA 02210–2109 (2)

Advanced Research Projects Agency
Arlington, VA 22203–1714

Naval Oceanographic Atmospheric Research
Laboratory (NOARL)
Stennis Space Center, MS 39529–5004

Naval Air Warfare Center
Warminster, PA 18974–5000

Texas A&M University
College Station, TX 77843–4242

University of North Carolina
Greensboro, NC 27412

University of Miami
Coral Gables, FL 33124

EOO, Inc.
Palo Alto, CA 94301

SAIC
San Diego, CA 92121