Technical Memorandum

SPECTRAL TRANSMISSION OF LIGHT THROUGH SEAWATER

P. M. Moser

15 September 1992

Contract N62269-90-C-0551

Sponsored by

Naval Air Development Center
Warminster, PA 18974

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14. ABSTRACT
Proper design of a lidar system for use in undersea warfare requires knowledge of the spectral transmission characteristics of seawater in the selection of laser wavelengths. In 1968 and in 1974, N. G. Jerlov published spectral transmittance data for ten different types of seawater. In this technical memorandum, Jerlov's data are reworked and converted to graphs of attenuation length and attenuation coefficient as functions of wavelength to permit interpolation of these functions for candidate lidar wavelengths of 455, 486, 517, and 532 nm. For the clearest waters (Jerlov types I, IA, IB, and II) the two shorter wavelengths are preferred. The more turbid waters are somewhat more transparent at the longer wavelengths.

15. SUBJECT TERMS
Seawater, Transmission, Light, Spectral, Jerlov, Undersea Warfare, Detection, Submarine, Mine, Volume Scattering, Water Types, Selective Absorption, Coastal, Transmittance, Laser, Attenuation Length, Attenuation Coefficient, Lidar, Wavelength

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TECHNICAL MEMORANDUM

15 September 1992

SUBJECT: Spectral transmission of light through seawater

REFERENCES

(a) N. G. Jerlov, *Optical Oceanography*, Elsevier Oceanography Series, 5, Elsevier Publishing Company, Amsterdam, 1968

(b) N. G. Jerlov, *Marine Optics*, Elsevier Oceanography Series, 14, Elsevier Science Publishing Company, New York, 1976

(c) M. F. van Norden and S. E. Litts, *The Transparency of Selected U.S. Coastal Waters with Applications to Laser Bathymetry*, Naval Postgraduate School, September 1979

(d) Avco Everett Research Laboratory, Inc., Contract No. 7-35373, *Airborne Hydrography System, Limited Design Report*, prepared for National Ocean Survey, January 1978

BACKGROUND

A scheme for optically classifying ocean waters was propounded by Jerlov in 1951 to enable distinguishing different water types in terms of spectral transmittance of downward irradiance at high solar altitudes. By synthesizing available observational data from surface waters, Jerlov produced three normal transmittance curves representing three different optical water types, I, II, and III.

According to reference (a), several factors combine to permit a simple description of the attenuation process and its change with turbidity. An essential basis for the classification is the observed fact that the shape of the volume scattering function for surface water shows only small variations from one oceanic area to another. It has been demonstrated that particulate matter and "yellow substance," a humus which originates from decaying organic material, are the primary agencies for selective absorption. Nutrient-rich waters in regions of upwelling off the west coasts of continents exhibit selective absorption by yellow substance and particles. On the other hand, nutrient-poor regions, such as the eastern Mediterranean and the Sargasso Sea are highly transparent.

Because a considerable number of ocean spectral transmittances fall between the two basic types I and II, Jerlov, in 1964, added two intermediate types, IA and IB. Jerlov further observed that there were still significant departures from his scheme of five water types. For example, there are instances of Sargasso water being more transparent than type I. There was also evidence that coastal waters which contain a variable amount of terrigeneous material show divergent behavior in the short wavelength part of the spectrum. To classify the coastal waters, Jerlov defined five new water types: 1, 3, 5, 7, and 9. (Apparently his motivation in defining only odd-numbered coastal types was to leave room for other intermediate types, to preclude the embarrassment he must have suffered when he was compelled to invent oceanic types IA and IB.) The coastal types are derived from observations along the coasts of Scandinavia and western North America. The transmittance curve for the clearest coastal water, type 1, coincides with that for the oceanic type III between 500 and 700 nm but tends toward much lower penetration at shorter wavelengths because of the high selective absorption which marks the coastal waters.

In 1976 Jerlov published reference (b), a revised and enlarged edition of reference (a). He cautions that the arrangement of irradiance data into categories is aimed at a regional large-scale classification that distinguishes water masses in only the upper layers, namely, 0 to 10 meters, which are generally homogeneous in the ocean. With highly stratified water, only the top layer can be optically characterized with any certainty.

In reference (b), Jerlov made use of additional data accumulated during the 1970s in the Mediterranean and off the west coast of Africa to revise his transmittance curves and tables of data. Jerlov's figure 69 and tables XXVI and XXVII, which are reproduced in this memorandum as figure 1 and tables 1 and 2, respectively, are probably the most basic summaries of Jerlov's work on this subject. Figure 1 is a family of curves of percent transmittance per meter of downward irradiance in the surface layer for eight of the water types. (Strangely, Jerlov did not include curves for types IA and IB, perhaps out of resentment because they symbolized his earlier lack of foresight.) Table 1 comprises two sub-tables of percent irradiance transmittance for surface waters of ten different types, one covering data for the depth interval 0 to 1 meter and the other covering 0 to 10 meters. Data are presented for 16 values of wavelength, mostly in increments of 25 nm, over the range of 310 to 700 nm. Table 2 gives values of the downward irradiance attenuation coefficient K_d for the depth interval of 0 to 10 meters for 10 water types and 16 wavelengths. Reference (b) does not include the curves of K_d as a function of wavelength which are frequently attributed to that book.

The data of table 2 were plotted by use of *Harvard Graphics* as the family of ten curves shown in figure 2. It is seen that the curves represent a fairly good fit to Jerlov's data points; however, for the clearer waters, there are obvious departures at wavelengths of 475, 575, and 600 nm. If one needs secondary data (e.g., at some specific wavelengths or over a range corresponding to wavelength intervals of 1 nm) that match Jerlov's data precisely, perhaps the best approach would be to use the computer to plot only the data points for each curve separately and then to draw each curve manually. Next, one would use a scanner to read out values of K_d as a function of wavelength that would include Jerlov's input values. The secondary data could then serve as a standard for all future calculations.

The transmittance curves in reference (b) are very similar to those in reference (a). The principal changes were a decrease in the reported transmittance of coastal water types 1, 3, and 5 in the range of roughly 350 to 500 nm (for example, the transmittance of coastal type 1 water at 400 nm over a 1-m path dropped to 60% from 69%) and, for the oceanic water types, the downward slope in transmittance that previously occurred at about 625 nm became more abrupt and shifted to about 580 nm.

Figure 3, which is a reproduction of Jerlov's figure 72, is map showing the regional distribution of optical water types.

Some of the points of the foregoing discussion are as follows: Jerlov's data do not represent specific measurements but are a synthesis of data from many sources (including Jerlov himself) that he massaged into a number of smooth curves. The data apply only over large regions to homogeneous, surface waters and not to specific sites and deep, stratified water. The data should serve as a useful tool for designing lidars for world-wide use in detecting mines and submarines.

ANALYSIS

To apply the Jerlov data to specific lidar design problems it is instructive to note that, for oceanic water types I, IA, IB and II, tables 1 and 2 show the maximum transmittance occurring at 475 nm. As one goes from oceanic type III, with its broad maximum occurring at 500 nm, through the coastal types, the peak broadens even more and shifts to 575 nm for type 9.

Because Jerlov provides curves for only eight of his ten water types and presents data in tabular form at wavelength increments of 25 nm, the user who needs data at specific laser wavelengths for all ten water types is required to plot Jerlov's data or to use some other interpolation scheme. Reference (c) includes a plot of irradiance attenuation coefficient for all ten water types which it attributes to reference (d); this family of curves is reproduced here as figure 4.

It was desired to obtain values of attenuation coefficient and attenuation length for all ten Jerlov optical water types for lidar wavelengths of 455, 486, 517 and 532 nm. The approach taken was to enlarge figures 1 and 4, read off values of irradiance transmittance and attenuation coefficient, respectively, and calculate values of attenuation length. The resulting values are given in table 3. In general, there is reasonable agreement between the two sets of values. In figure 4, average values of the two data sets are plotted. It is seen that a cross-over occurs at about oceanic water type III; the clearer water types are significantly more transparent to light of wavelengths 455 and 486 nm and the more turbid waters are somewhat more transparent at wavelengths 517 and 532 nm. For the clearer waters, the 455- and 486-nm curves nearly coincide because they are about equally spaced on each side of the peak at 475 nm. Figure 6 shows the variation in attenuation coefficient as a function of water type for the same four wavelengths. Numerical values corresponding to figures 5 and 6 are given in table 4.

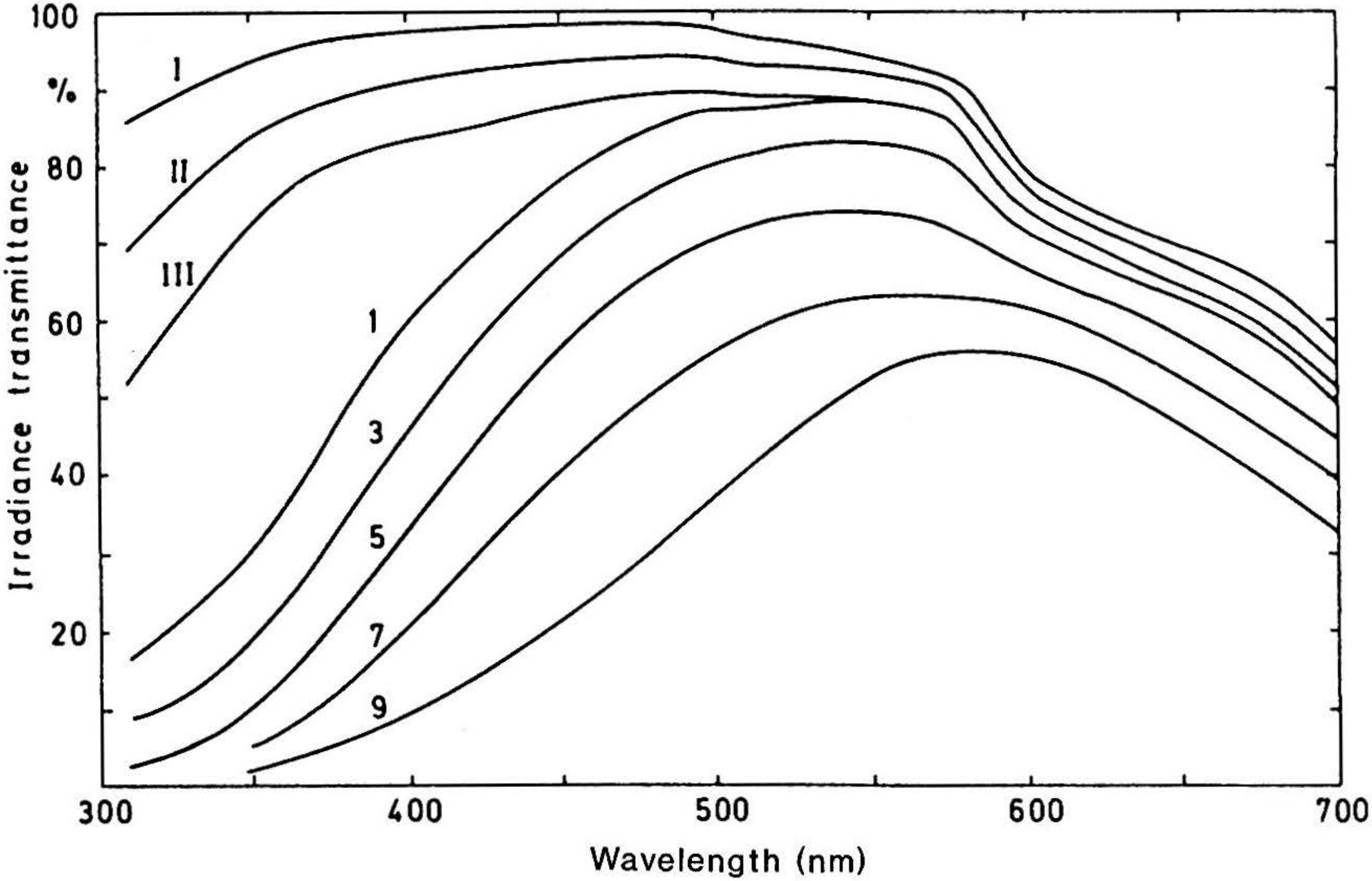

Figure 1. Transmittance per meter of downward irradiance in the seawater surface layer for oceanic types I, II, and III and coastal types 1, 3, 5, 7, and 9. [Jerlov (1976)]

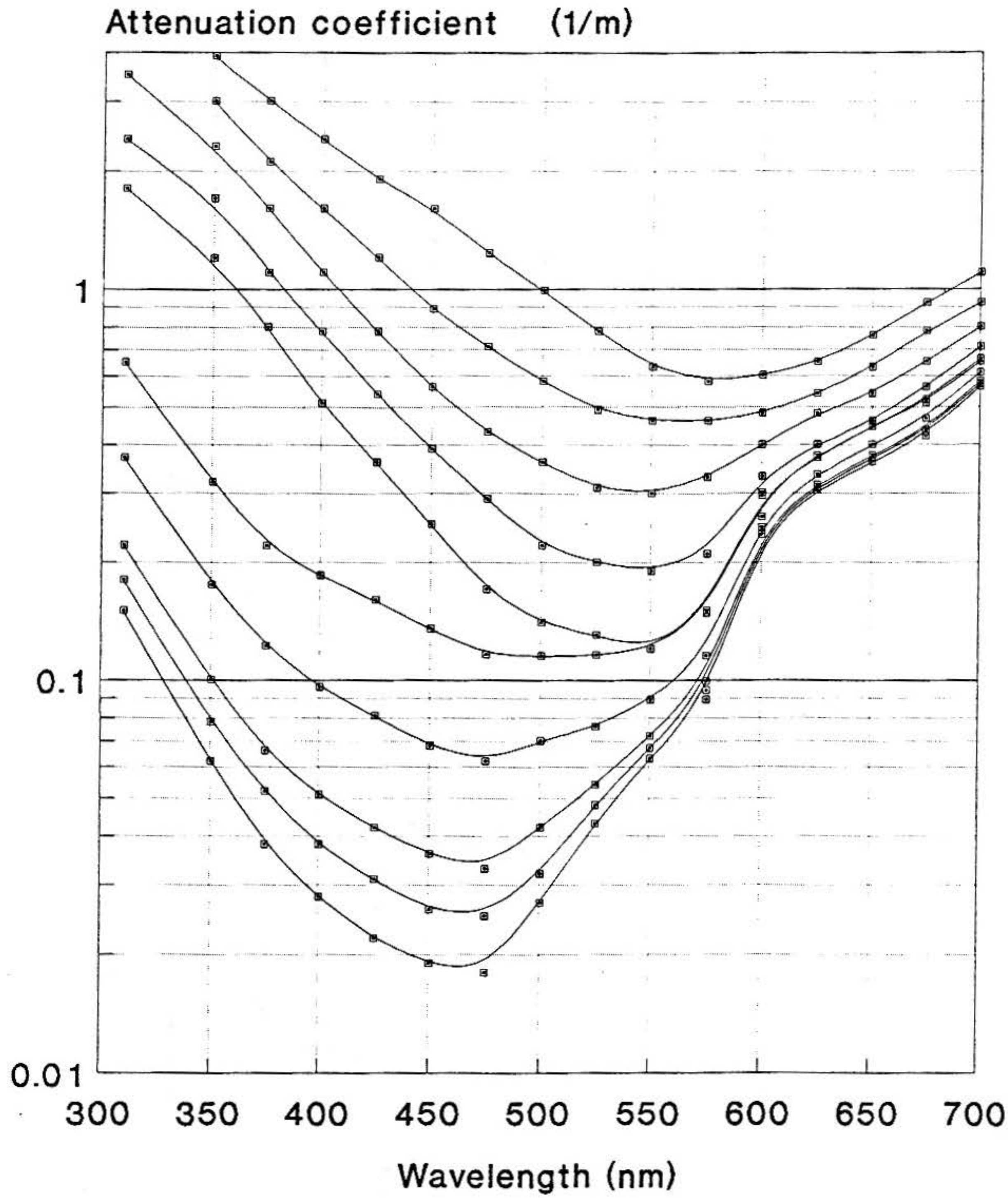

Figure 2. Attenuation coefficient K_d as a function of wavelength for (from bottom to top) oceanic types I, IA, IB, II, and III and coastal types 1, 3, 5, 7, and 9.

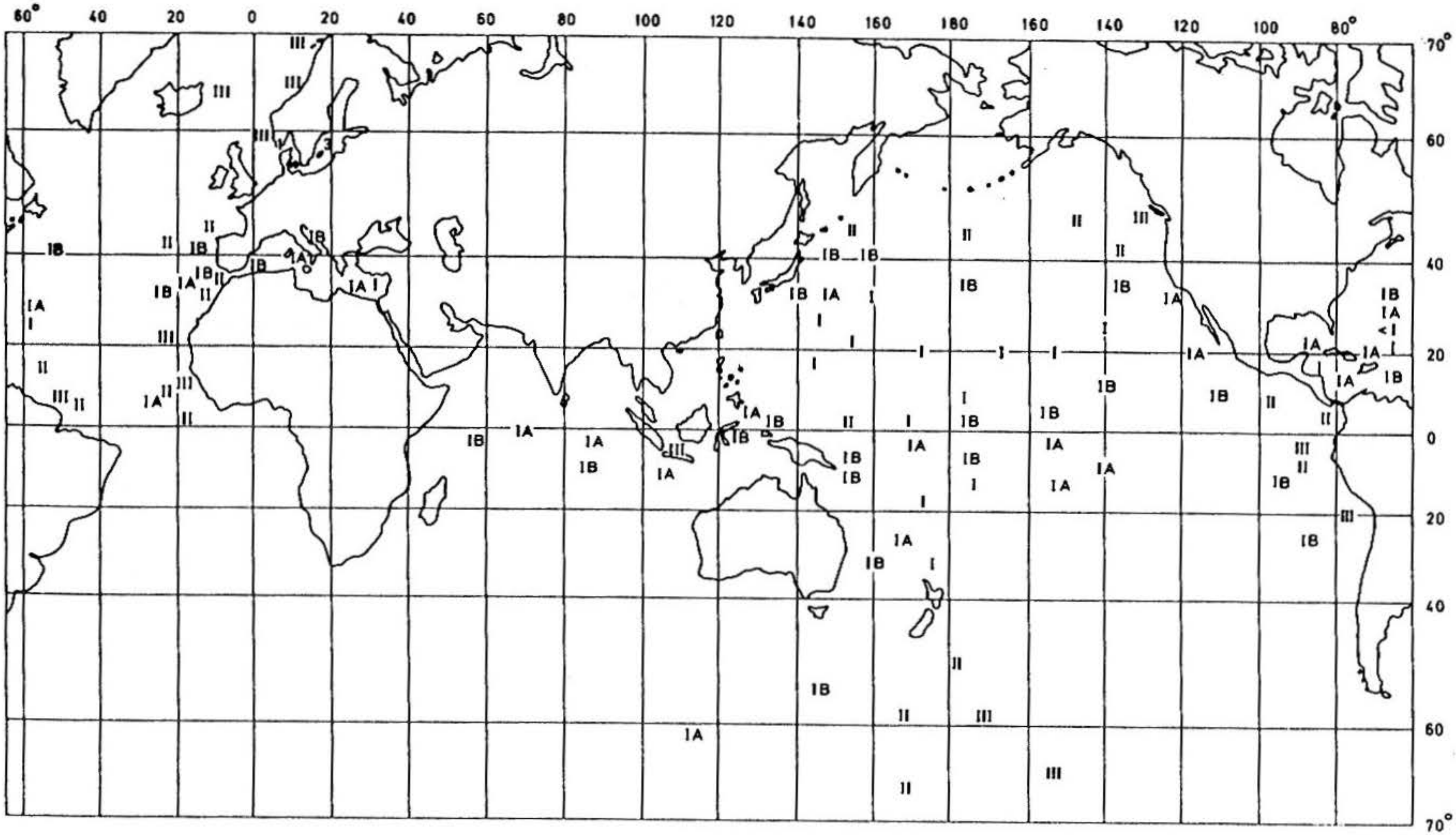

Figure 3. Regional distribution of optical water types. [Jerlov (1976)]

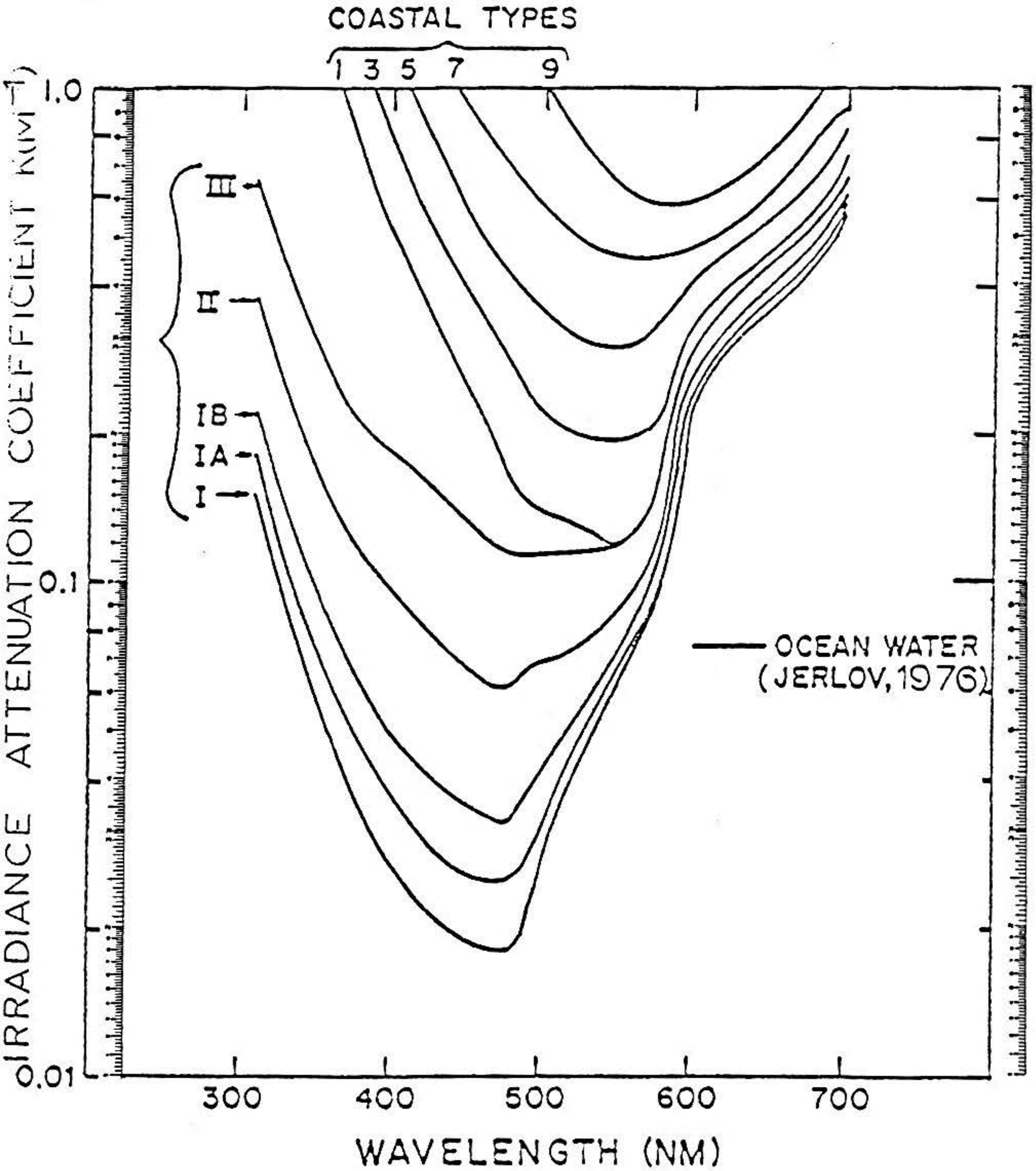

Figure 4. Spectral irradiance attenuation coefficients for downward irradiance in the surface layer for ten Jerlov water types. [ref (d) via ref (c)]

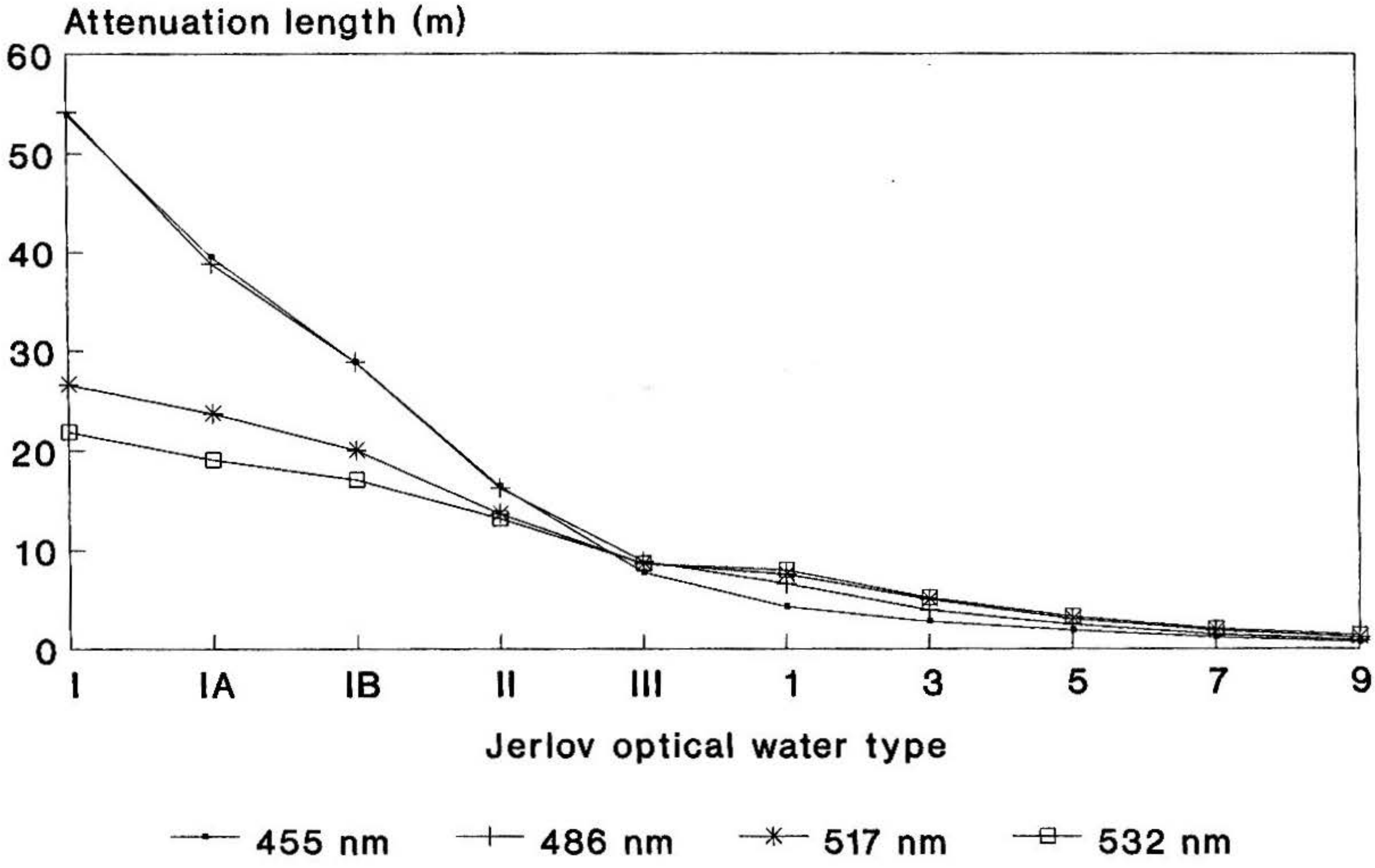

Figure 5. Attenuation length vs. water type for four wavelengths.

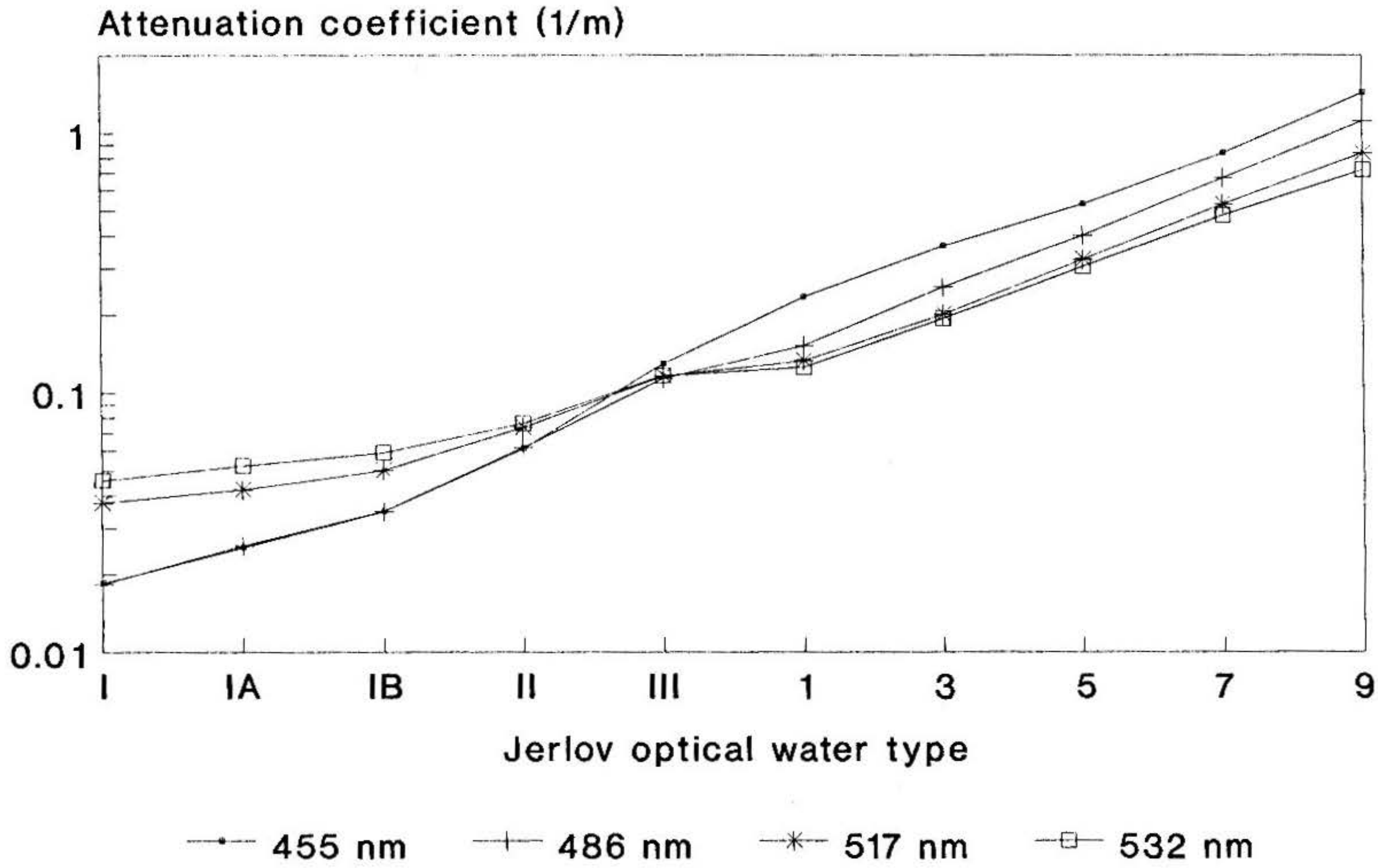

Figure 6. Attenuation coefficient vs. water type for four wavelengths.

Table 1. Irradiance transmittance for surface water of different water types.

Water type	Wavelength (nm)															
	310	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700
1. Irradiance transmittance (%/m)																
I	86	94	96.3	97.2	97.8	98.1	98.2	97.3	95.8	93.9	91.5	79	74	70	66	57
IA	83	92.5	95	96.3	96.9	97.4	97.5	96.9	95.3	93.5	91.0	78.5	73	69	65	56.5
IB	80	90.5	94	95	95.9	96.5	96.8	95.9	94.7	93	90.5	78	72.5	68.5	64	56
II	69	84	89	91	92.2	93.5	94	93.2	92.7	91.5	89	77	71.5	67	63	54
III	52	73	80	83	85	87.5	89	89	89	88.5	86	74	69	64	60	52
1	17	30	45	60	70	78	84	87	88	88.5	86	74	69	64	60	52
3	9	19	32	46	58	68	75	80	82	83	81	72	67	63	57	49
5	3	10	21	33	46	57	65	70	73	74	72	67	62	58	52	45
7		5	12	21	31	41	49	56	61	63	63	62	58	53	46	40
9		2	5	9	15	21	29	37	46	53	56	55	52	47	40	33
2. Irradiance transmittance (%/10 m)																
I	22	54	68	76	80	83	83.5	76	65	53	41	9.5	4.7	2.7	1.5	0.4
IA	16	46	60	68	73	77	78	73	62	51	39	9.1	4.5	2.5	1.4	0.3
IB	11	37	52	60	66	70	72	66	58	49	37	8.6	4.3	2.4	1.3	0.3
II	2.5	17	30	38	44	51	54	50	47	41	32	7.4	3.5	1.8	0.9	0.2
III	0.2	4	11	16	20	26	31	32	31	30	23	5.2	2.4	1.2	0.5	0.1
1				0.6	2.7	8.2	18	25	27	30	22	5.0	2.5	1.1	0.6	0.2
3					0.5	2.1	5.5	11	13.5	15	12	3.7	1.8	1.0	0.4	
5						0.4	1.4	2.7	4.5	5	3.7	1.8	0.8	0.4	0.2	
7								0.3	0.7	1.0	1.0	0.8	0.5	0.2		
9										0.2	0.3	0.3	0.2			

Table 2. Downward irradiance attenuation coefficient $K_d \cdot 100\ m^{-1}$

Water type	Wavelength (nm)															
	310	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700
I	15	6.2	3.8	2.8	2.2	1.9	1.8	2.7	4.3	6.3	8.9	23.5	30.5	36	42	56
IA	18	7.8	5.2	3.8	3.1	2.6	2.5	3.2	4.8	6.7	9.4	24	31	37	43	57
IB	22	10	6.6	5.1	4.2	3.6	3.3	4.2	5.4	7.2	9.9	24.5	31.5	37.5	43.5	58
II	37	17.5	12.2	9.6	8.1	6.8	6.2	7.0	7.6	8.9	11.5	26	33.5	40	46.5	61
III	65	32	22	18.5	16	13.5	11.6	11.5	11.6	12.0	14.8	29.5	37.5	44.5	52	66
1	180	120	80	51	36	25	17	14	13	12	15	30	37	45	51	65
3	240	170	110	78	54	39	29	22	20	19	21	33	40	46	56	71
5	350	230	160	110	78	56	43	36	31	30	33	40	48	54	65	80
7		300	210	160	120	89	71	58	49	46	46	48	54	63	78	92
9		390	300	240	190	160	123	99	78	63	58	60	65	76	92	110

Table 3. Attenuation length in seawater for light of four wavelengths inferred from figures 1 and 4.

	Wavelength (nm)							
	455		486		517		532	
Figure No.	1	4	1	4	1	4	1	4
Water type	Attenuation Length (m)							
I	53.4	54.4	54.9	53.5	26.4	26.8	22.4	21.3
IA	----	39.5	----	38.8	----	23.7	----	19.1
IB	----	28.8	----	28.8	----	20.0	----	17.1
II	17.6	15.3	16.7	15.8	13.4	13.9	13.2	13.1
III	7.7	7.8	8.8	8.9	8.5	8.8	8.6	8.6
1	4.3	4.3	6.5	6.7	7.5	7.6	8.0	8.0
3	2.8	2.7	4.0	3.9	5.1	4.9	5.3	5.1
5	1.9	1.9	2.5	2.5	3.1	3.1	3.3	3.3
7	1.2	1.2	1.5	1.5	1.9	1.9	2.1	2.1
9	0.7	< 1	0.9	< 1	1.2	1.2	1.4	1.4

Table 4. Attenuation coefficient and attenuation length in seawater for light of four wavelengths.

	Wavelength (nm)							
	455	486	517	532	455	486	517	532
Water type	Atten coefficient (m^{-1})				Atten length (m)			
I	0.019	0.018	0.038	0.046	53.9	54.2	26.6	21.9
IA	0.025	0.026	0.042	0.052	39.5	38.8	23.7	19.1
IB	0.035	0.035	0.050	0.058	28.8	28.8	20.0	17.1
II	0.061	0.062	0.073	0.076	16.5	16.3	13.7	13.2
III	0.129	0.113	0.116	0.116	7.8	8.9	8.7	8.6
1	0.233	0.152	0.132	0.125	4.3	6.6	7.6	8.0
3	0.364	0.253	0.200	0.192	2.8	4.0	5.0	5.2
5	0.526	0.400	0.323	0.303	1.9	2.5	3.1	3.3
7	0.833	0.667	0.526	0.476	1.2	1.5	1.9	2.1
9	1.429	1.111	0.833	0.714	0.7	0.9	1.2	1.4