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PROPERTIES OF MARINE OPTICAL COMPONENTS IN THE ULTRAVIOLET PART OF THE SPECTRUM

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Abstract

Most of the examined optical components have absorption coefficients that are less than two times larger in the UV-B part of the spectrum than in the blue part. Only for yellow substance and the clay fraction of biotite has the ultraviolet absorption coefficient been found to be more than four times greater than the corresponding blue coefficient. In the open ocean most of the optical variation will be caused by phytoplankton and associated detritus, and the influence of this component on the vertical attenuation coefficient is of equal magnitude in the UV-B and blue parts of the spectrum.

1. Introduction

Jerlov's optical classification of ocean water types (Johnson and Kullenberg, 1946, Jerlov, 1976, 1978) is based on linear relations between the vertical attenuation coefficients K_d of downward irradiance. In his classification the relation between the coefficients $K_d(310)$ and $K_d(465)$ at 310 and 465 nm can be described by

$$K_d(310) = 0.062\ m^{-1} + 4.75\ K_d(465) \tag{1}$$

Højerslev and Aas (1991) analysed observations from North Atlantic surface waters with a salinity above 35.0 psu and found that a very good correlation between the coefficients was obtained by the linear function

$$K_d(310) = 0.078\ m^{-1} + 1.04\ K_d(465) \tag{2}$$

The large deviation between eq. (1) and the obtained relation (2) came as a surprise. However, in retrospect it may be said that it is perhaps more surprising that the relation between Jerlov's values of K_d in the ultraviolet and blue parts of the spectrum had not been commented upon earlier. Although his measurements probably are correct, their representativity for clear ocean water with a low content of yellow substance may be doubted.

Although eq. (1) has about the same offset value as eq. (2), its most striking feature is that its slope is more than 4 times as steep. The coefficient K_d is dominated by the absorption coefficient a, and very few optical components in the sea exhibit an absorption coefficient which is 4 times larger at 310 nm than at 465. It may therefore be useful to take a look at the spectral dispersion of some of the optical components that are likely to appear in the oceanic and coastal waters.

2. Optical properties of dissolved organic matter

2.1. Yellow substance

The dissolved organic matter of optical influence in the sea was termed "Gelbstoff" (yellow substance) by Kalle (1938). The spectral variation of the absorption coefficient a_y due to yellow substance can be described as

$$a_y(\lambda) = a_y(\lambda_o)\ e^{-\gamma(\lambda-\lambda_o)} \tag{3}$$

where λ is the wavelength in air, and γ a quasi-constant. In the Baltic γ has been observed to vary about 0.014 ± 0.003 nm^{-1} (Lundgren, 1976, Højerslev, 1980), which means that the ratio $a_y(310)/\ a_y(465)$ will vary in the range 9 ± 4. Figure 1 shows the spectral dispersion of yellow substance when γ=0.014 nm^{-1} and $a_y(450)$=0.212 m^{-1}. In the Gulf of Mexico γ has been observed to vary in the same range (0.011 - 0.017 nm^{-1}) (Carder et al., 1989), and elsewhere in the range 0.010 - 0.020 nm^{-1} (Bricaud et al., 1981, Højerslev, 1988).

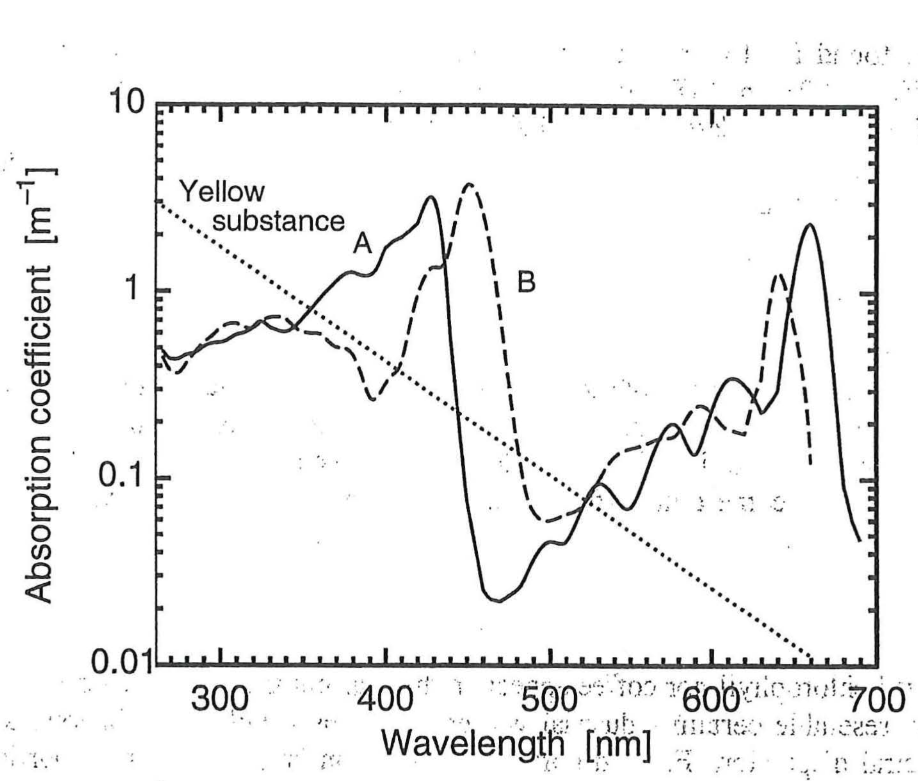

Figure 1. Absorption coefficients of chlorophylls a *(A) and* b *(B) (0.1 mg/l) (after Zscheile and Comar, 1941, Harris and Zscheile, 1943) and yellow substance (1 mg/l, γ=0.014 nm^{-1}) (after Lundgren, 1976, Nyquist, 1979, Højerslev, 1980) as functions of wavelength.*

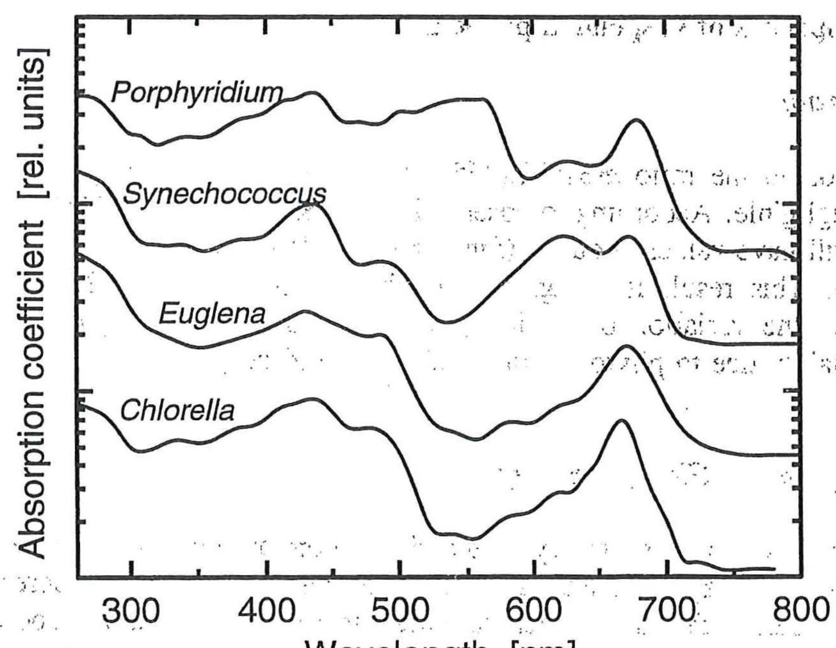

Figure 2. Absorption coefficients (arbitrary units) of different phytoplankton species as functions of wavelength (after Shibata et al., 1954).

Nyquist (1979) found for Baltic waters that a yellow substance content of 1 mg/l corresponded to $a_y(450)=0.212$ m^{-1} (Figure 1). However, similar specific absorption coefficients from the Gulf of Mexico (Carder et al., 1989), calculated for 450 nm, vary in the range 0.007-0.13 m^{-1} mg^{-1} l, with the mean value 0.022 m^{-1} mg^{-1} l, which is a factor 10 less than the value found by Nyquist.

2.2. *Dissolved chlorophyll*

The spectral dispersion of chlorophyll *a* and *b* dissolved in ethyl ether solutions is presented in Table 1 and Figure 1 . The ratio $a(310)/a(465)$ is 25 for chlorophyll *a*, and 0.39 for chlorophyll *b*. However, in living algae the chlorophylls are concentrated in chloroplasts, and the optical properties become quite different, as shown in section 3.1 below.

2.3. *Coffee*

Neither dissolved chlorophyll nor coffee appear in the sea, but the coffee is a brown organic liquid that may resemble certain industrial wastes, and thus it will be of interest to take a look at its spectral dispersion. Filtered coffee probably consists of very small particles and dissolved matter, and its attenuation coefficient is most likely dominated by absorption, and the ratio $c_{cof}(310)/c_{cof}(465)$ from Table 1 becomes approximately 10. However, other measurements have shown significant variations in the spectral dispersion of coffee, probably depending on the manufacturing process and the properties of the coffee beans.

3. Optical properties of suspended particles

3.1. *Phytoplankton*

The contribution to the ratio $a(310)/a(465)$ in sea water from living phytoplankton cells seems to be negligible. According to observations by Shibata et al. (1954) (Figure 2, Table 2), the ratio will have values about 1. (Similar values have been observed for benthic algae (Biebl, 1952)). This result is in agreement with the slope of eq. (2), and supports the assumption that the variation of K_d in clear ocean waters with a low content of yellow substance is mainly due to phytoplankton and associated detritus.

3.2. *Particles from the Glomma estuary*

The optical conditions in the estuary of the river Glomma will probably be dominated by eroded material like clay particles and yellow substance (Næs, 1983, Sørensen and Aas, 1994). The particles with a size larger than 0.2 μm have an attenuation coeffient c_p which at 310 nm is 1.9 times the coefficient at 465 nm, while the suspended and dissolved material less than 0.2 μm has a coefficient c_f with a similar ratio of 8.3 (Figure 3, Table 3) (Aas et al., 1989). The last coefficient seems to be mainly due to yellow substance on wavelengths

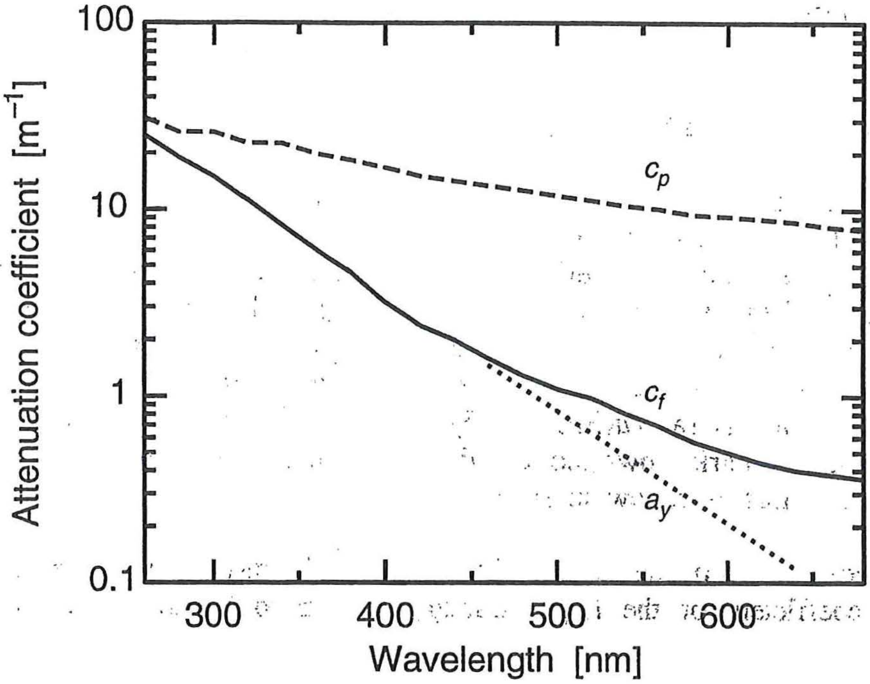

Figure 3. Attenuation coefficients c_p of the particle fraction (diameter > 0.2 μm, concentration probably about 19 mg/l), and c_f of the residue after filtration (diameter < 0.2 μm) in surface waters of the Glomma estuary, as functions of the wavelength. The absorption coefficient a_y of yellow substance is suggested by the dotted line (after Aas et al., 1989).

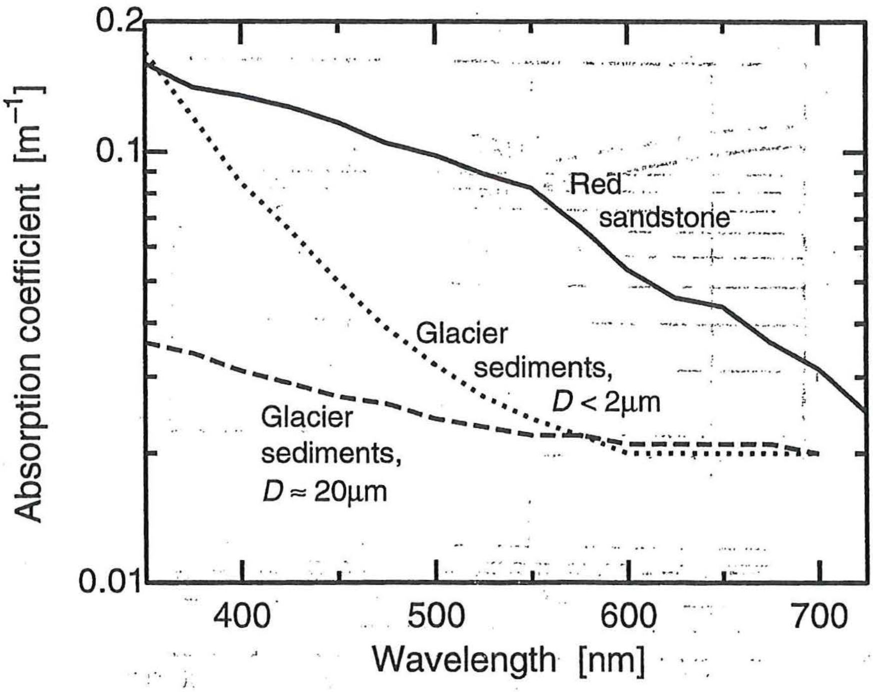

Figure 4. Absorption coefficients for the sediments of the glacierfed lake Veitastrondsvatn in Southern Norway (after Aas and Bogen, 1988), and for the sediments of red sandstone from Svalbard, as functions of the wavelength. All concentrations are 1 mg/l.

less than 450 nm, and the slope of the ~~dashed~~ dotted line in Figure 3 corresponds to a value of γ equal to 0.0142 nm^{-1}.

3.3. Particles from glacier waters

The absorption and scattering coefficients of clay and silt fractions of sediments from the glacierfed lake Veitastrondsvatn in southern Norway have been estimated by Aas (1987a, Aas and Bogen, 1988). The absorption coefficient of the particles increases only slowly towards shorter wavelengths when the diameter is about 20 μm (Figure 4, Table 4). The clay fraction with diameters less than 2 μm, however, has an absorption coefficient at 350 nm which is about 4 times larger than at 465 nm. An extrapolation of the curve towards shorter wavelengths suggests that the ratio $a(310)/a(465)$ is likely to become about 7-8. This fraction, which mainly consists of dark brown biotite, will then have a spectral dispersion in the UV-blue range similar to that of yellow substance.

The attenuation coefficients of the two size fractions from Veitastrondsvatn are presented in Figure 5. The coefficient of the larger fraction is seen to be almost independent of wavelength.

The river Bayelva flows into Kongsfjorden, Svalbard. A sample of its brown waters contained almost non-sinking small particles of red sandstone, and it was guessed that the average particle diameter was less than 2 μm. By extrapolation of the data in Figure 4 and Table 4 the ratio $a(310)/a(465)$ for these particles may be estimated to be close to 1.7.

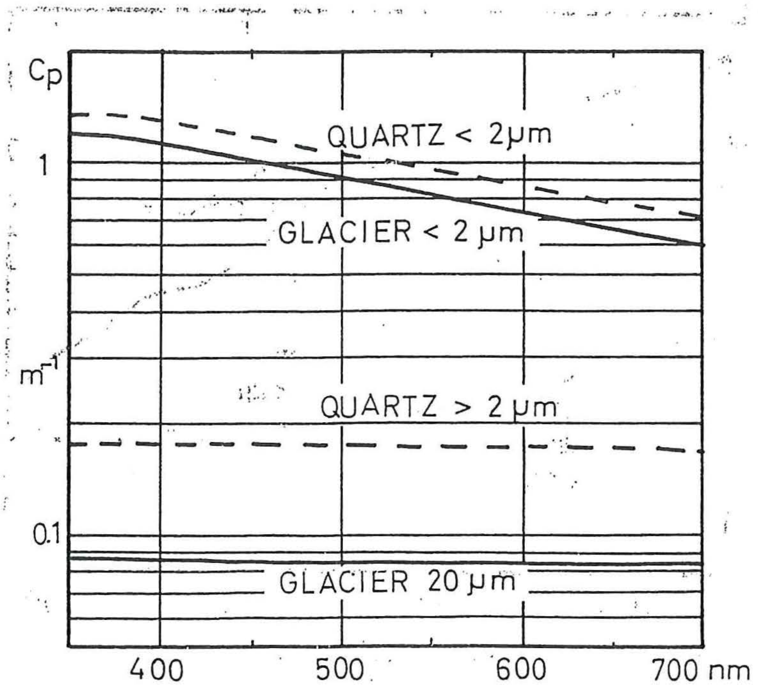

Figure 5. Attenuation coefficients of the sediments from the lake Veitastrondsvatn, and of crushed quartz, as functions of wavelength (Aas, 1987a). All concentrations are 1 mg/l.

3.4. Quartz particles

Particles from crushed natural quartz are non-absorbing in the visible part of the spectrum, and will have little influence on the vertical attenuation of downward irradiance in the sea. The attenuation coefficient of quartz becomes equal to the scattering coefficient. Size fractions of crushed quartz smaller and larger than 2 μm have been taken out by standard settling techniques. Figure 5 and Table 5 illustrate how the scattering of the larger fraction is rather independent of the wavelength, while the smaller fraction shows a pronounced scattering dispersion (Aas, 1987a).

The coefficients of pure sea water have been included in Table 5. The values for the absorption coefficient are estimates by Aas (1987b) based on Jerlov's vertical attenuation coefficients for the clearest ocean water (Jerlov, 1976), and these coefficients are slightly different from the often quoted estimates by Smith and Baker (1981). The scattering coefficients are established values by Morel (1974).

3.5. Scattering dispersion

Measurements of the volume scattering function at 45°, $\beta(45°, \lambda)$, where λ is the wavelength, have been included to complete the picture of the particles. Table 6 shows that the spectral dispersion of particle scatterance is small. The ratio $\beta(45°, \lambda)/b(\lambda)$, where $b(\lambda)$ is the scattering coefficient, has average values in different oceanic areas that vary between 0.021 and 0.035 (Jerlov, 1976). It could perhaps be expected that the ratio $\beta_p(45°)/b_p$ for the special samples of particles in Table 6 would have a much larger variation, but an interesting point is that the values only range from 0.018 to 0.045.

4. Conclusion

Of the optical components studied in this text, only the yellow substance and the clay fraction of biotite have a ratio $a(310)/a(465)$ which is greater than 4. The clay particles may dominate the optical conditions in estuaries and fjords, but we have no information which indicates that they may influence the sea at some distance from land. If Jerlov's measurements are correct, the slope in eq.(1) must then be due to yellow substance. On the other hand, the slope in eq. (2) is most probably caused by phytoplankton and associated detritus, as concluded earlier.

Acknowledgements

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References

Aas, E., 1987a. Influence of suspended particles on light conditions in water (in Norwegian). In: *Partikler i vann. Proc. symp. 22 and 23 May 1986 at Dombås, Norway,* eds. M. Nicholls and A. H. Erlandsen. Norwegian Limnologist Association, 30-46.

Aas, E., 1987b. The absorption coefficient of clear ocean water. *Rep. Dep. Geophys.*, Univ. Oslo, **67**, 17 pp.

Aas, E. and Bogen, J., 1988. Colors of glacier water. *Water Resources Res.*, **24**, 561-565.

Aas, E., Andresen, T., Løyning, T., and Sørgård, E., 1989. The eutrophy situation in the outer Oslofjord. Sub-project 3.7b: Optical observations - quality of the surface water as seen from observations in the surface layer (in Norwegian). Governmental Program for Monitoring of Pollution, NIVA rep. 388/90, ISBN 82-577-1644-8, 50 pp.

Biebl, R., 1952. Ultraviolettabsorption der Meeresalgen. *Ber. Dtsch. Bot. Ges.*, **65**, 36-40.

Bricaud, A., Morel, A. and Prieur, L., 1981. Absorption by dissolved organic matter of the sea (yellow substance) in the UV and visible domains. *Limnol. Oceanogr.*, **26**, 43-53.

Carder, K. L., Steward, R. G., Harvey, G. R. and Ortner, P. B., 1989. Marine humic and fulvic acids: Their effects on remote sensing of ocean chlorophyll. *Limnol. Oceanogr.* **34**, 68-81.

Harris, D. G. and Zscheile, F. P., 1943. Effects of solvent upon absorption spectra of chlorophylls *a* and *b*; their ultraviolet absorption spectra in ether solution. *Bot. Gaz.*, **104**, 515-527.

Højerslev, N. K., 1980. On the origin of yellow substance in the marine environment. In: Studies in physical oceanography. Papers dedicated to professor Nils G. Jerlov in commemoration of his seventieth birthday, ed. G. Kullenberg. *Rep. Dep. Phys. Oceanogr.*, Univ. Copenhagen, **42**, 39-56.

Højerslev, N. K., 1988. Natural occurrences and optical effects of gelbstoff. *Rep. Dep. Phys. Oceanogr.*, Univ. Copenhagen, **50**, 30 pp.

Højerslev, N. K. and Aas, E., 1991. A relationship for the penetration of ultraviolet B radiation into the Norwegian Sea. *J. Geophys. Res.*, **96**, 17003-17005.

Jerlov, N. G., 1976. *Marine optics*. Elsevier, New York, 231 pp.

Jerlov, N. G., 1978. The optical classification of sea water in the euphotic zone. *Rep. Dep. Phys. Oceanogr.*, Univ. Copenhagen, **36**, 46 pp.

Johnson (Jerlov) N. G. and Kullenberg, B., 1946. On radiant energy measurements in the sea. Svenska Hydrogr.-Biol. Komm. Skrifter, 3. Series: Hydrogr., I(1), 27 pp.

Kalle, K., 1938. Zum Problem der Meereswasserfarbe. *Ann. Hydrogr. Mar. Meteor.*, **66**, 1-13.

Lundgren, B., 1976. Spectral transmittance measurements in the Baltic. *Rep. Dep. Phys. Oceanogr.*, Univ. Copenhagen, **30**, 38 pp.

Morel, A., 1974. Optical properties of pure water and pure sea water. In: *Optical aspects of oceanography*, eds. N. G. Jerlov and E. Steemann Nielsen. Academic Press, London, 1-24.

Nyquist, G., 1979. Investigation of some optical properties of seawater with special reference to lignin sulfonates and humic substances. Dr. thesis, Dep. Anal. Mar. Chem., Univ. Gothenburg, 223 pp.

Næs, K., 1983. Basic investigations in the Hvaler area and Singlefjorden. Dissolved metals, suspended materials and sediments (in Norwegian). NIVA rep. 70/83, 100 pp.

Shibata K., Benson, A. A. and Calvin, M., 1954. The absorption spectra of suspensions of living micro-organisms. *Biochim. biophys. acta*, **15,** 461-470.

Smith, R. C. and Baker, K. S., 1981. Optical properties of the clearest natural waters (200-800 nm). *Appl. Opt.*, **20**, 177-184.

Sørensen, K. and Aas, E., 1994. Remote sensing of coastal water quality. In: Ocean Optics XII. Proc, ed. J. Jaffe. SPIE, **2258**, 332-341.

Zscheile, F. P. and Comar, C. L., 1941. Influence of preparative procedure on the purity of chlorophyll components as shown by absorption spectra. *Bot. Gaz.*, **102**, 463-481.

Table 1. Attenuation coefficients of chlorophylls *a* and *b* in ethyl ether solution (1 mg/l) (after Zscheile and Comar, 1941, Harris and Zscheile, 1943), and of coffee (10 mg/l)

λ nm	c_a m^{-1}	c_b m^{-1}	c_{cof} m^{-1}	λ nm	c_a m^{-1}	c_b m^{-1}	c_{cof} m^{-1}
265	4.83	4.49	13.9				
270	4.37	3.80	14.3				
280	4.60	4.14	12.9				
290	5.06	5.29	10.4				
300	5.36	6.33	9.50	500	.460	.598	.575
310	5.87	6.74	9.38	510	.460	.644	.521
320	6.44	6.39	9.58	520	.690	.713	.458
330	6.49	7.25	9.79	530	.943	.978	.417
340	6.10	7.13	10.2	540	.805	1.31	.383
350	7.13	6.10	10.2	550	.702	1.45	.358
360	9.09	5.93	10.0	560	1.09	1.54	.333
370	11.3	5.06	9.58	570	1.77	1.66	.318
380	12.6	4.60	8.92	580	1.90	1.78	.288
390	12.2	2.76	7.92	590	1.36	2.42	.267
400	17.0	3.22	7.29	600	2.30	2.30	.242
410	19.4	4.21	6.54	610	3.43	1.86	.225
420	23.0	9.43	5.54	620	3.22	1.75	.208
430	31.1	13.5	3.75	630	2.30	3.45	.200
440	6.21	17.3	2.33	640	2.99	12.7	.192
450	.782	36.8	1.38	650	12.7	6.44	.183
460	.253	26.5	1.03	660	23.2	1.15	.171
470	.219	8.05	.833	670	8.63		.163
480	.253	1.61	.708	680	.920		.154
490	.368	.667	.646	690	.460		.146

Table 2. Absorption coefficients of phytoplankton in relative units (after Shibata et al., 1954)

λ	*Euglena* a_p	*Chlorella* a_p	*Porphyridium* a_p	*Synechococcus* a_p
nm	r.u.	r.u.	r.u.	r.u.
260	55	8.6	38	150
280	46	7.5	34	130
300	28	50	24	74
320	21	50	21	60
340	19	54	23	60
360	17	54	23	56
380	19	64	28	64
400	21	71	31	68
420	25	85	36	90
440	25	89	39	98
460	22	65	27	56
480	20	63	27	48
500	15	47	31	45
520	7.5	20	32	28
540	6.0	17	36	23
560	5.5	17	36	29
580	6.8	21	21	39
600	6.8	23	14	53
620	8.3	29	17	66
640	9.5	35	16	60
660	15	61	18	57
670	17	68	23	66
680	16	45	28	62
700	8.5	20	14	28
720	5.5	12	7.0	19
740	4.8	11	5.6	18
760	4.5	11	5.6	18
780	4.5	11	5.6	18
800	4.5	11	4.9	18

Table 3. Attenuation coefficients of material larger (c_p) and less (c_f) than 0.2 μm in the surface layer of the Glomma estuary (after Aas et al., 1989)

λ	c_p	c_f	λ	c_p	c_f	λ	c_p	c_f	λ	c_p	c_f
nm	m^{-1}	m^{-1}	nm	m^{-1}	m^{-1}	nm	m^{-1}	m^{-1}	nm	m^{-1}	m^{-1}
260	31	25									
280	26	19									
300	26	15	400	16.8	3.2	500	11.9	1.1	600	9.2	0.50
320	22.7	11.3	420	15.1	2.4	520	11.2	0.98	620	8.9	0.44
340	22.7	8.3	440	14.2	2.0	540	10.5	0.81	640	8.6	0.40
360	19.9	6.1	460	13.4	1.6	560	10.1	0.69	660	8.1	0.38
380	18.4	4.6	480	12.7	1.3	580	9.4	0.57	680	7.8	0.36

Table 4. Optical coefficients of suspended sediments (1 mg/l) from the lake Veitastrondsvatn (Aas and Bogen, 1988) and the river Bayelva

	Veitastrondsvatn						Bayelva		
	D<2 μm			D≈20 μm					
λ	a_p	b_p	c_p	a_p	b_p	c_p	a_p	b_p	c_p
nm	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}
350	.17	1.02	1.19	.036	.050	.086	.16	.56	.72
375	.12	1.04	1.16	.034	.051	.085	.14	.56	.69
400	.085	1.02	1.10	.031	.053	.084	.14	.54	.67
425	.066	.99	1.05	.029	.056	.085	.13	.52	.65
450	.050	.95	1.00	.027	.056	.084	.12	.51	.63
475	.039	.92	.97	.026	.057	.084	.11	.49	.60
500	.032	.88	.90	.024	.060	.084	.098	.48	.58
525	.027	.83	.85	.023	.061	.084	.089	.46	.55
550	.024	.79	.81	.022	.062	.084	.083	.45	.53
575	.022	.75	.77	.022	.062	.084	.067	.45	.51
600	.020	.72	.73	.021	.063	.084	.053	.43	.48
625	.020	.68	.70	.021	.063	.084	.046	.42	.46
650	.020	.65	.66	.021	.063	.084	.044	.40	.44
675	.020	.61	.63	.021	.063	.084	.036	.39	.42
700	.020	.58	.60	.020	.064	.084	.031	.38	.41

Table 5. Optical coefficients of pure sea water (Morell, 1974, Aas, 1987b) and quartz particles (1 mg/l) (after Aas, 1987a)

	Sea water			Quartz	
				D<2 μm	D>2 μm
λ	a_w	b_w	c_w	c_p	c_p
nm	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}
350	.052	.0135	.064	.459	.172
375	.031	.0100	.041	.433	.171
400	.022	.0076	.030	.420	.172
425	.018	.0058	.024	.394	.173
450	.015	.0045	.020	.382	.171
475	.015	.0036	.019	.360	.172
500	.024	.0029	.027	.335	.172
525	.039	.0023	.041	.322	.171
550	.059	.0019	.061	.299	.169
575	.085	.0016	.087	.285	.169
600	.22	.0014	.22	.263	.169
625	.29	.0012	.29	.256	.168
650	.34	.0010	.34	.241	.168
675	.40	.0009	.40	.227	.168
700	.53	.0007	.53	.206	.165

Table 6. Volume scattering function $\beta(45°,\lambda)$ of particles and pure sea water, and the ratio $\beta_p(45°,\lambda)/b_p(\lambda)$

	Coffee	Lake Veitastrondsvatn		Bayelva River	Quartz	
		D<2μm	D≈20μm		D<2μm	D>2μm
	1 mg/l	1 mg/l	1 mg/l	1 mg/l	1 mg/l	1 mg/l
λ	β_p	β_p	β_p	β_p	β_p	β_p
nm	10^{-4} m^{-1}	10^{-4} m^{-1}	10^{-4} m^{-1}	10^{-4} m^{-1}	10^{-4} m^{-1}	10^{-4} m^{-1}
366	6.25	304	13.7	193	80	39
406	6.58	297	14.5	201	75	39
436	6.92	286	15.0	209	77	42
546	6.58	247	14.6	195	74	35
578	5.88	231	14.9	203	65	38
630	6.00	246	16.8	186	69	37

	Glomma Estuary	Pure sea water
λ	β_p	β_w
nm	10^{-4} m^{-1}	10^{-4} m^{-1}
366	2560	9.82
406	2800	6.27
436	3080	4.61
546	2800	1.77
578	2760	1.41
630	2330	1.07

	Lake Veitastrondsvatn		Bayelva River	Quartz	
	D<2μm	D≈20μm		D<2μm	D>2μm
λ	β_p/b_p	β_p/b_p	β_p/b_p	β_p/b_p	β_p/b_p
nm					
366	.030	.027	.035	.018	.023
406	.029	.027	.037	.018	.023
436	.030	.027	.040	.020	.024
546	.029	.024	.042	.024	.021
578	.031	.024	.045	.023	.022
630	.037	.027	.044	.027	.022