O. Kopelevich

Topic 7: Oceanic Optical Properties and Models

Oceanic constituents and their optical properties

Pure water and sea water

Suspended particles

Yellow substance

Biological optical properties

Models of seawater absorption, scattering and backscattering

Spectral absorption by pure water (Pope and Fry 1997)

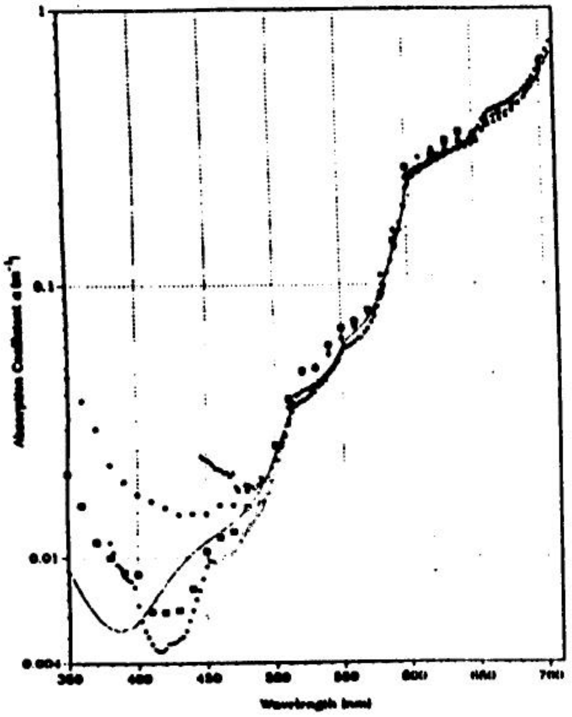


Fig. 10. Present results (●) for the absorption of pure water plotted with those from Buiteveld *et al.*[2] (smooth curve), Tam and Patel[4] (△), Smith and Baker[6] (○), and Sogandares and Fry[3] (□).

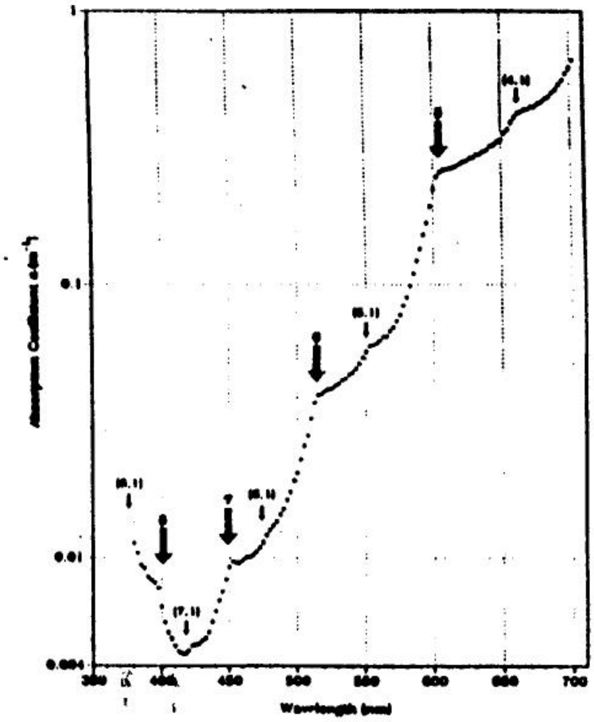
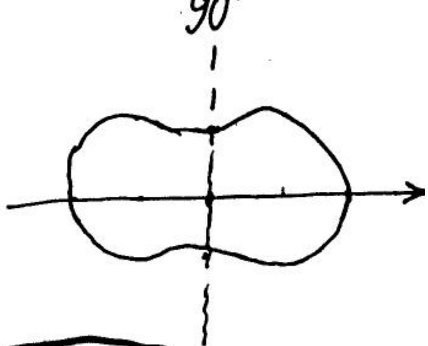


Fig. 12. Present results for the absorption of pure water. A large arrow with a boldface integer n indicates the predicted position of a shoulder that is due to the nth harmonic of the O–H stretch; the small arrows with mode assignments (*j*, 1) indicate the predicted position of a combination of the *j*th harmonic of the O–H stretch with the fundamental of the scissors mode.

$$\beta_w(\theta) = \beta_w(90^\circ)\cdot\left(1 + 0{,}84\cos^2\theta\right);$$

$$\beta_w(90^\circ) = Const.\cdot\lambda^{-4.2};$$

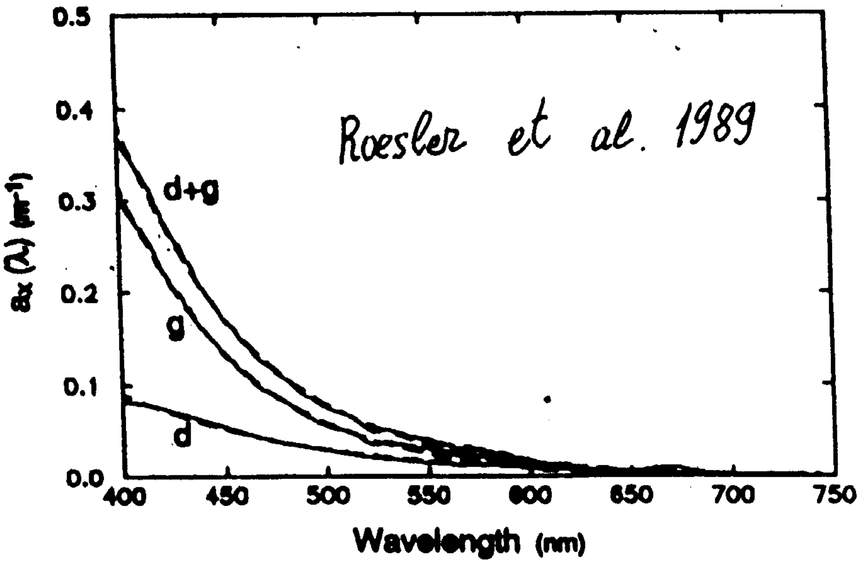
$$b_w = 16.085\cdot\beta_w(90^\circ);\quad b_{Bw} = \frac{1}{2}b_w.$$



$$\boxed{b_{sw}(550) \approx 2\cdot 10^{-3}\,m^{-1}}$$

Absorption by yellow substance

$$a_y(\lambda) = a_y(\lambda_o)\cdot\exp[-S(\lambda_o - \lambda)];$$



$S_g = 0.016 \pm 0.002$ nm^{-1} (0.014 ÷0.019 nm^{-1});

$S_d = 0.011 \pm 0.002$ nm^{-1} (0.006 ÷0.014 nm^{-1});

$$a_y(\lambda) = \begin{cases} a_y(\lambda_o)\cdot\exp[-S_1(\lambda - \lambda_o)], & \lambda < 500\text{ nm}; \\ a_y(\lambda_o)\cdot\exp[-S_1(500 - \lambda_o)]\cdot\exp[-S_2(\lambda - 500)], & \lambda \geq 500\text{ nm}; \end{cases}$$

(Kopelevich et al. 1989)

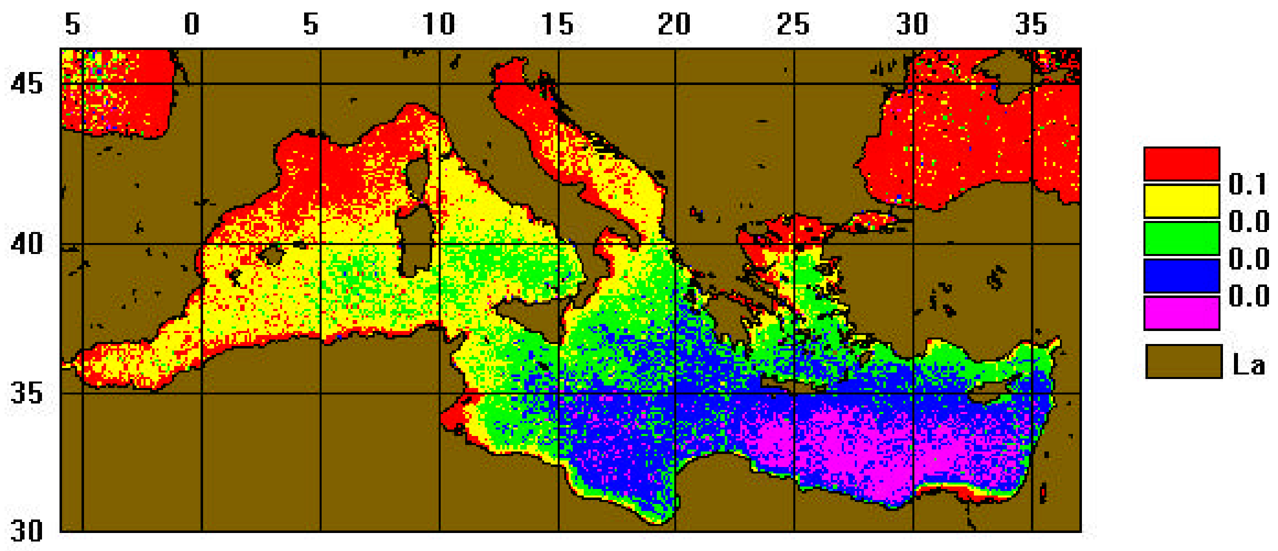
$S_1 = 0.017 \pm 0.001$ nm^{-1} (0.015 ÷0.019 nm^{-1});

$S_2 = 0.011 \pm 0.001$ nm^{-1} (0.010 ÷0.013 nm^{-1});

Fulvic acid - 0.019 nm^{-1}, Carder et al. 1989

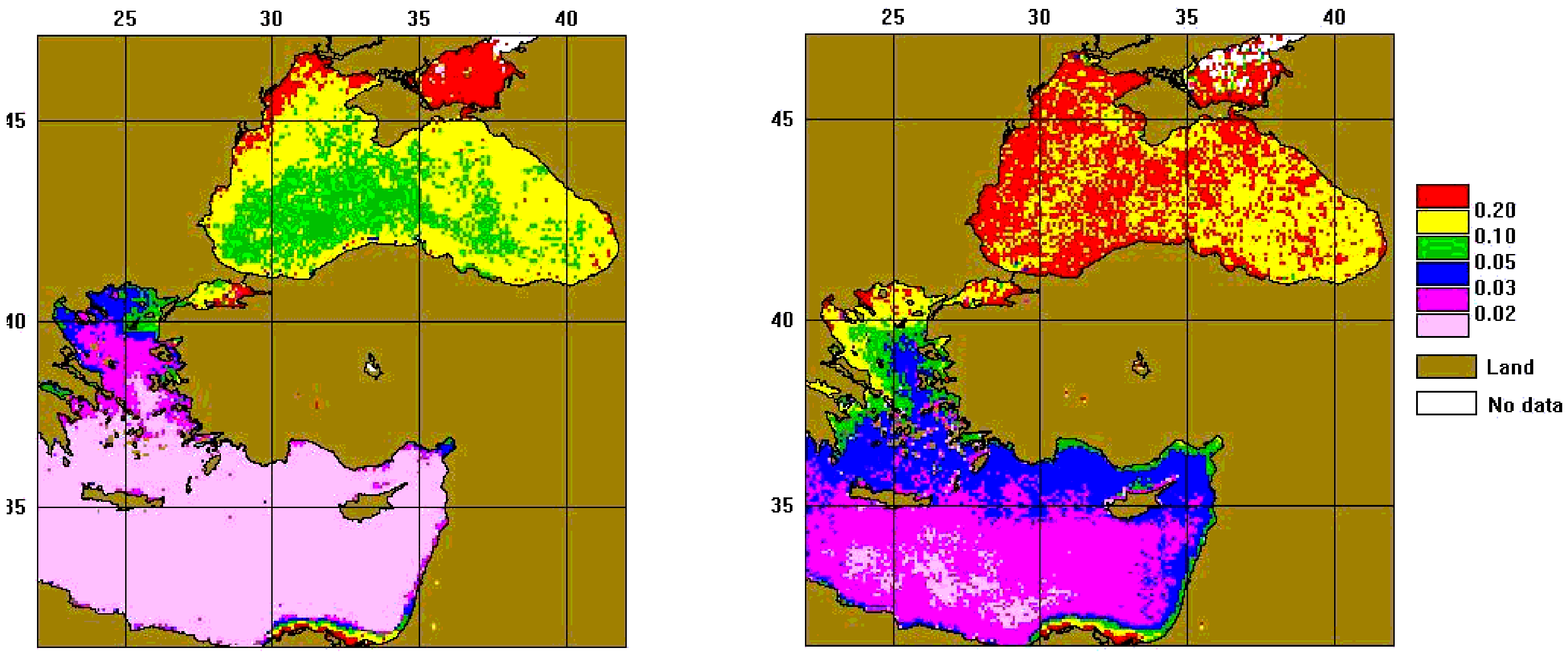
Humic acid - 0.011 nm^{-1}.

Yellow substance may have a local origin from the degradation of phytoplankton cells and other organic particles or may be advected from a distant source. You see the mean distribution of values of the gelbstoff absorption coefficient at 440 nm in the Mediterranean derived from SeaWiFS data over November 1997 – March 1998. Disposal of the most important sources of yellow substance is well seen: they are the run-off of rivers Rhone, Po, Nile and others; the inflow of the Black Sea water through Dardanelles, and the local upwellings off the Spain and North Africa coasts. The waters with enhanced concentrations of yellow substance can extend for many miles from the sources.



These are the mean distributions of the $a_g(440)$ values (m^{-1}) in the Eastern Mediterranean and in the Black Sea (left – September – October 1997; right – November 1997 – March 1998).

In the Black sea the main source of yellow substance is the rivers in its north-western part: Danube, Dnestr, Bug, and Dnepr.



The contributions to seawater absorption from different seawater components can be estimated by three measurements with a seawater sample. The absorption by dissolved matter is determined from measurement of absorption by a filtrate through 0.2-μm Nuclepore filter. The absorption spectra of particulate sample concentrated onto glass fiber filter with nominal pore 0.7--μm is measured to determine the total particulate absorption. Then the phytoplankton pigments are removed by the extraction procedure, and absorption by detritus is measured. The difference between the total particulate and detrital spectra (before and after extraction) is considered to be phytoplankton absorption.

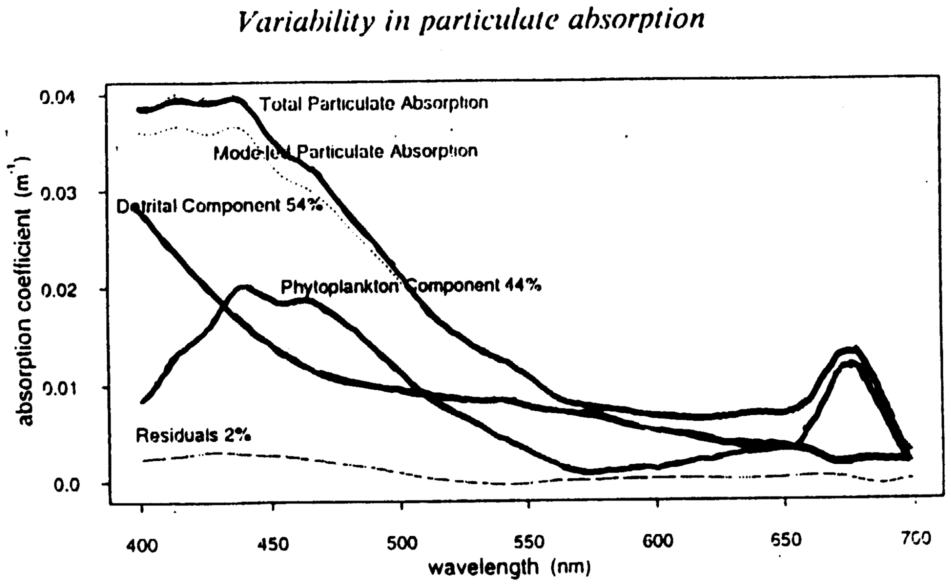


Fig. 13. Two-component decomposition of particulate absorption database (Morrow et al. 1989)

Поглощение взвешенными частицами

$$a_{вв}(\lambda) = a_{detr.}(\lambda) + a_{ph}(\lambda);$$

$$a_{detr}(\lambda) = a_{detr.}(390) \cdot \exp\left[-0.011 \cdot (\lambda - 390)\right]$$

Bricaud et al. 1995

Поглощение фитопланктоном

$$a_{ph}(\lambda) = a^*_{ph} \cdot C_{\text{хл}};$$

$$a^*_{ph}(\lambda) = A(\lambda) \cdot C_{\text{хл}}^{-B(\lambda)};$$

$$a^*_{ph}(440) = 0{,}04 \cdot C_{\text{хл}}^{-0{,}332};$$

$$a_{ph}(\lambda) = 0{,}04 \left[\frac{a_{ph}(\lambda)}{a_{ph}(440)}\right] \times C_{\text{хл}}^{0.668}$$

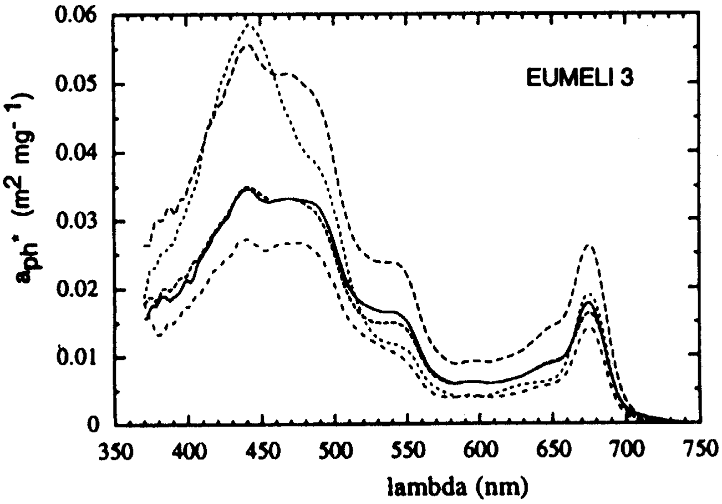
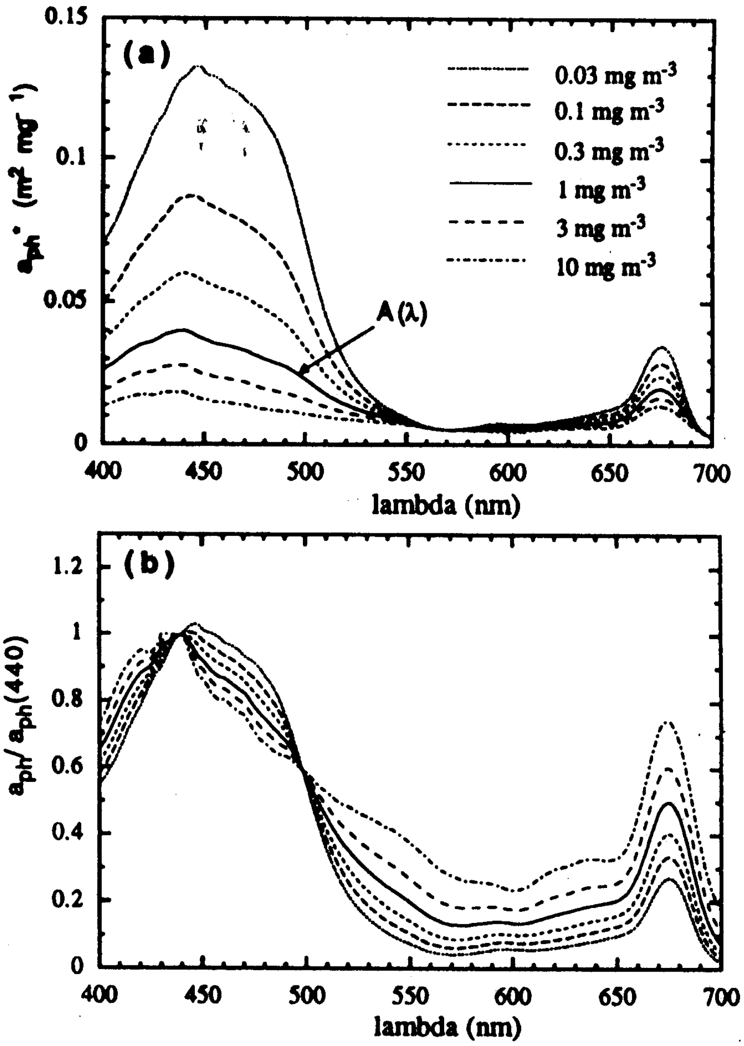


Figure 2. Examples of chlorophyll-specific absorption spectra $a^*_{ph}(\lambda)$ (in square meters per milligram), as determined at the mesotrophic site during the Eumeli 3 cruise. Note that the absorption shoulder due to phycoerythrin, as visible around 550 nm, in principle, cannot be observed on a^*_{ph} spectra obtained with *Kishino et al.*'s [1985] method.



Variability of characteristics of seawater scattering

$b(550) = 0.04 \div 3\ m^{-1}$

Parameters of the seawater phase scattering function

Parameter	Atlantic ocean and its seas (Mankovsky 1975)	Indian Ocean (Kopelevich 1983)	Petzold 1972
b_b / b	0.016-0.111	0.011-0.091	0.015-0.045
<cosθ>	0.74-0.96	0.75-0.96	0.87-0.94

Comparison between the seawater (upper) and particle (lower) scattering

Parameter	Petzold 1972		
	clear ocean	coastal ocean	turbid harbor
b, m^{-1}	0.0364 0.0338	0.196 0.193	1.75 1.75
b_b, m^{-1}	0.00164 0.00036	0.0293 0.0164	0.0363 0.0350
b_b / b	0.045 0.010	0.015 0.008	0.021 0.020
<cosθ>	0.868 0.935	0.941 0.953	0.917 0.914

Suspended particles in seawater

In open ocean:

mass concentration $0.05 \div 0.5\ g \cdot m^{-3}$;

number concentration $10^{12} \div 10^{13}\ m^{-3}$ within $0.01 \div 1 \mu m$;

$10^{8} \div 10^{11}\ m^{-3}$ $> 1 \mu m$.

Organic (biogenous) particles:

Phytoplankton, detritus 1-200 μm in particle size;

Bacteria 0.2-1.0 μm;

Viruses 0.02-0.25 μm.

Mineral (terrigenous) particles:

Finely ground quartz sand, clay minerals and others;
in open ocean less 1-2 μm in particle size.

Number size particle distribution:

$n(D) = A\, r^{-\nu}$; $\nu = 3 \div 5$.

Elements of Mie theory

The factors determining scattering by a particle:

size, material, shape, internal structure.

Spherical homogeneous particles:

$m = (n_p / n_w) - i\,(n'_p / n'_w)$ the relative complex index of refraction;

$\alpha = 2\pi r / \lambda_w = 2\pi r\, n_w / \lambda_{vac}$ the size parameter.

$k(r, \lambda) = Q(r, \lambda)\cdot\pi r^2$ the scattering cross section, m^2,

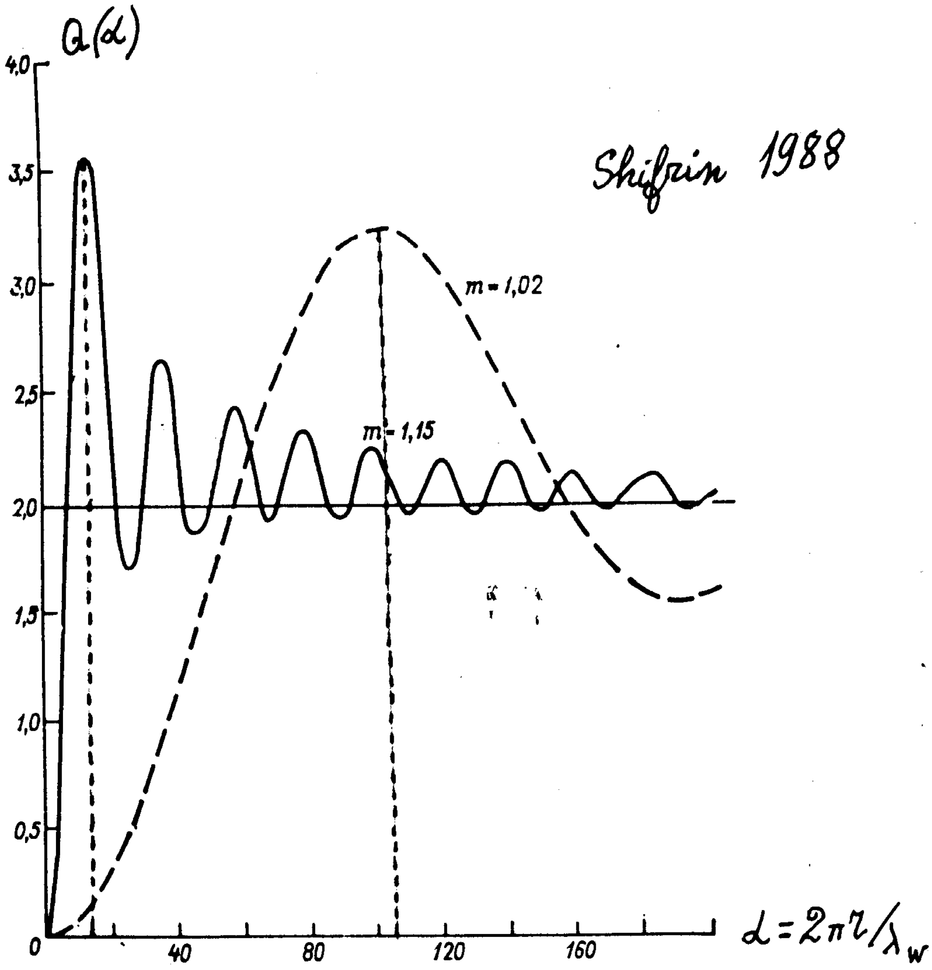
where $Q(r, \lambda)$ is the scattering efficiency.

$b(r, \lambda) = N\cdot k(r, \lambda)$, N is particle concentration, m^{-3},

$$b(\lambda) = \int_{r1}^{r2} n(r)\cdot k(r, \lambda)dr = N \int_{r1}^{r2} f(r)\cdot k(r, \lambda)dr; \quad N = \int_{r1}^{r2} n(r)dr;$$

$f(r) = n(r) / N$ the size distribution.

The scattering efficiencies of organic and mineral particles in water



For organic particles $D_{max} = \alpha_{max}\, \lambda_{vac} / \pi\, n_w = 13.3\ \mu$;

for mineral particles $D_{max} = 1.8\ \mu$.

Two-parametric model of seawater scattering

(Kopelevich 1983)

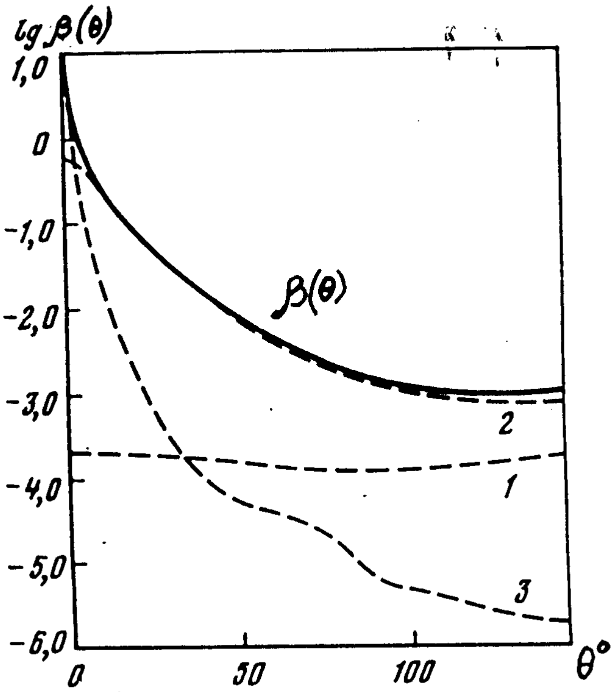
$\beta(\theta) = \beta_s(\theta)\cdot v_s + \beta_l(\theta)\cdot v_l + \beta_{sw}(\theta)\cdot;$

Small particles: m = 1.15;

$$n(r) = \begin{cases} A_o\,(r/0.01)^{-2..5}, & 0.01 \le r \le 0.05\ \mu m \\ A_1\,(r/0.05)^{-3..5}, & 0.05 \le r \le 0.1\ \mu m \\ A_2\,(r/0.1)^{-4..5}, & 0.1 \le r \le 1.3\ \mu m; \end{cases}$$

Large particles: m = 1.03;

$n(r) = A_l\,(r/1.3)^{-3}$, $\quad r \ge 1.3\ \mu m;$



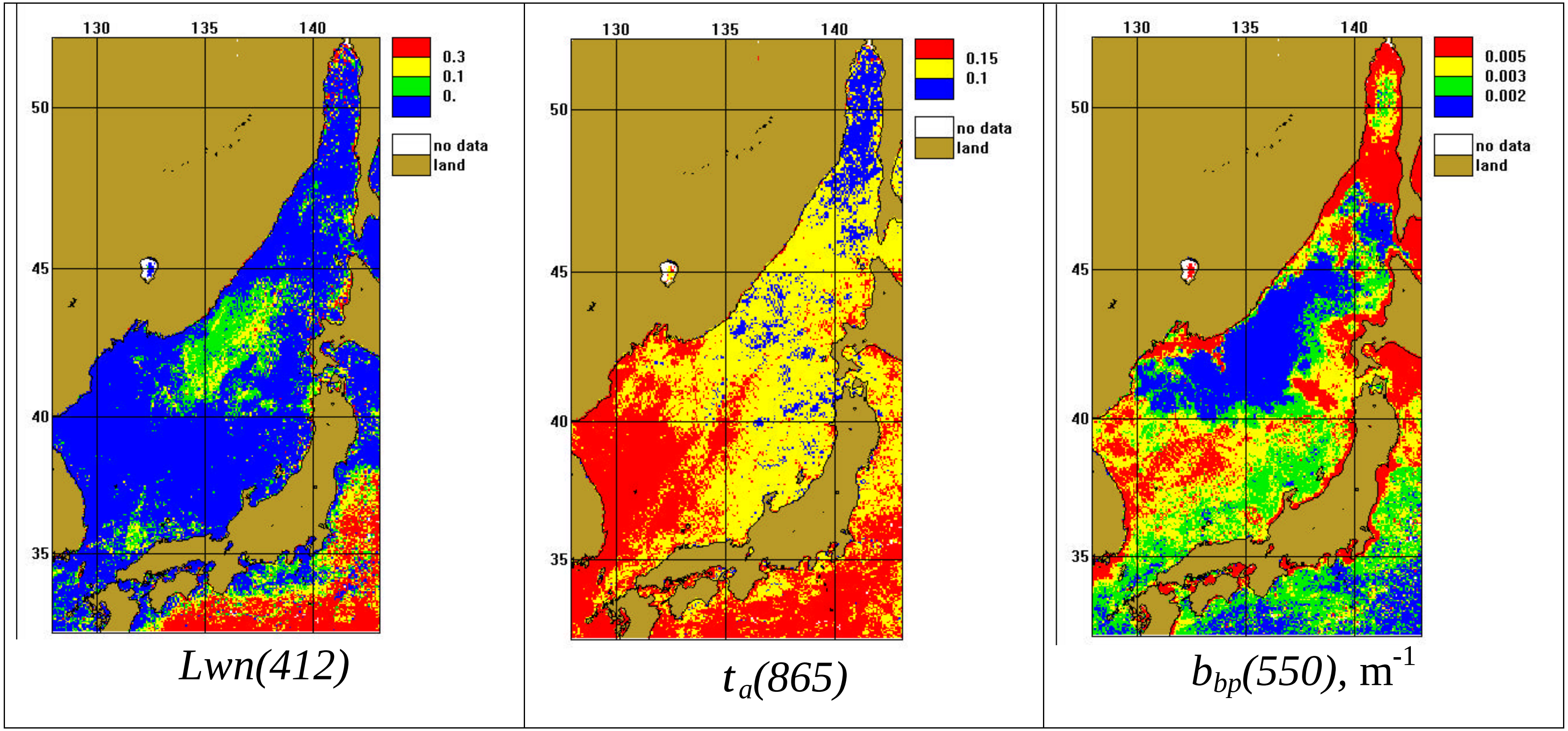
The seawater volume scattering function $\beta(\theta)$, $m^{-1}\cdot sr^{-1}$ and contributions arising from the small particles (2), large particles (3), and pure seawater (1); $v_s = \cdot v_l = 0.1\ cm^3\cdot/\ m^3$.

Influence on seawater scattering of dust particles from an aeolian input

Characteristics of seawater scattering in the area of dust-blown particles flux (St.771) and outside it (St.769).

Indian ocean, south of Hindustan (Kopelevich 1984)

Characteristic	St.771	St.769
$\beta(1^o)$, $m^{-1} \cdot sr^{-1}$	6.3	9.2
$\beta(45^o)$, $m^{-1} \cdot sr^{-1}$	0.0088	0.0017
v_l , $cm^3 \cdot / m^3$	0.128	0.200
v_s , $cm^3 \cdot / m^3$	0.087	0.014
b_b , m^{-1}	0.0056	0.0018
b_b / b	0.035	0.022



The mean monthly distributions of *Lwn(412)*, $t_a(865)$, and $b_{bp}(550)$ in the Japan Sea derived from SeaWiFS data in April 1999. It is apparent the enhanced values of *bbp* just east from the Korean peninsula are correlated with the enhanced values of the aerosol optical thickness due to the Asian dust aerosol from the Chinese desert areas.

Spectral models of seawater scattering (Kopelevich 1983)

$$b(\lambda) = b_s(550) \cdot v_s \cdot (550/\lambda)^{1.7} + b_l(550) \cdot v_l \cdot (550/\lambda)^{0.3} + b_{sw}(\lambda);$$

$$\beta(\theta, \lambda) = \beta_s(\theta, \lambda) \cdot v_s \cdot (550/\lambda)^{1.7} + \beta_l(\theta,\lambda) \cdot v_l \cdot (550/\lambda)^{0.3} + \beta_{sw}(\theta, \lambda) \cdot;$$

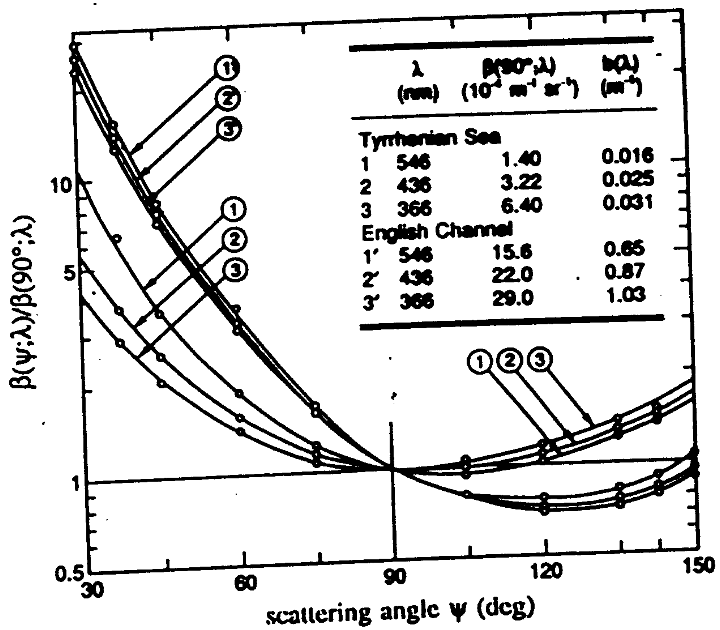


Fig. 3.16 Wavelength dependence of total volume scattering functions measured in very clear (Tyrrhenian Sea) and in turbid (English Channel) waters. [redrawn from Morel (1973)]

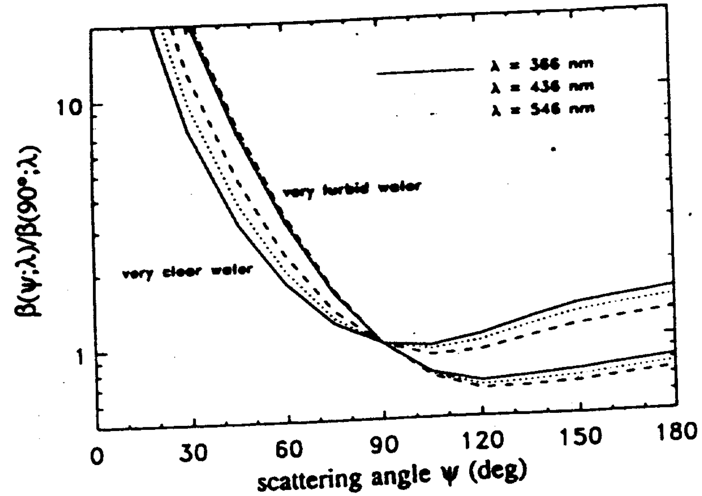
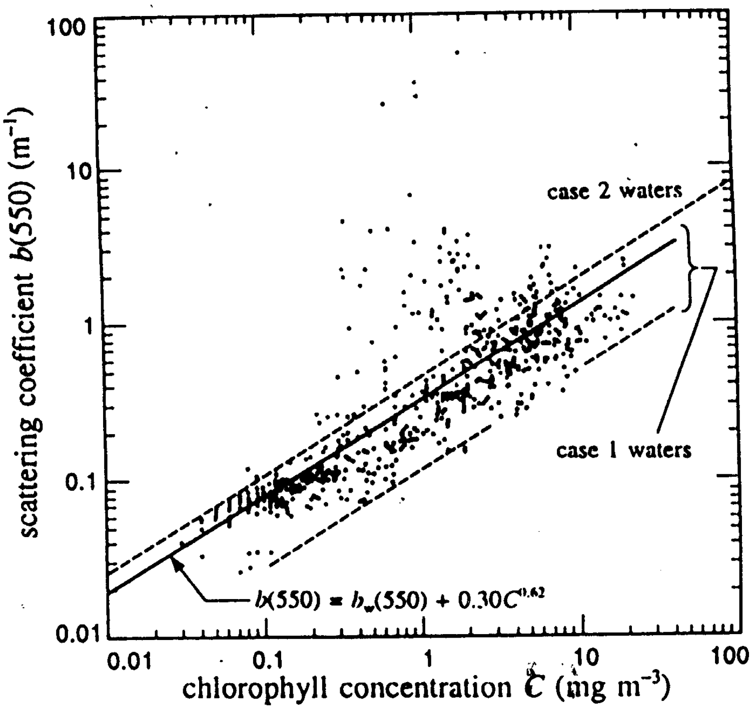


Fig. 3.19. Wavelength dependence of the Kopelevich model, Eq. (3.38), for very clear and very turbid waters. Compare to Fig. 3.16.

from Mobley (1994).

One-parametric model of seawater scattering



$b(550) = b_{sw}(550) + 0.30 \cdot (Chl)^{0.62}$;

$b(\lambda) = b(550) \cdot (550/\lambda)$ Gordon and Morel (1983);

$b(\lambda) = b_{sw}(\lambda) + b_p(550) \cdot (550/\lambda)^{n1}$;

$b_b(\lambda) = 0.5\ b_{bw}(\lambda) + b_{bp}(550) \cdot (550/\lambda)^{n2}$;

for open ocean: $n_1 = 1.0$, $n_2 = 1.45$;

for coastal waters: $n_1 = n_2 = 0$

(Kopelevich, unpublished).

Two-parametric models of spectral absorption

$a(\lambda) = a_y(\lambda) + a_{ph}(\lambda) + a_w(\lambda)$;

$$a_y(\lambda) = \begin{cases} a_y(\lambda_o)\cdot\exp[-S_1(\lambda - \lambda_o)], & \lambda < 500 \text{ nm}; \\ a_y(\lambda_o)\cdot\exp[-S_1(500 - \lambda_o)]\cdot\exp[-S_2(\lambda - 500)], & \lambda \geq 500 \text{ nm}; \end{cases}$$

(Kopelevich et al. 1989).

$a_{ph}(\lambda)=a^{*}_{ph}(\lambda)\cdot Chl = A(\lambda)\, Chl^{1-B(\lambda)}$ Bricaud et al. (1995);

$\grave{a}_g(\lambda) = \tilde{N}_1(\lambda)\, \grave{a}_g(488) + \tilde{N}_2(\lambda)$ Barnard et al. (1998);

$\grave{a}_p(\lambda) = \tilde{N}_1(\lambda)\, \grave{a}_p(488) + \tilde{N}_2(\lambda)$;

(1914 spectra in open ocean and coastal waters;

$\grave{a}_g(488)$ from 0.003 to 0.159 m^{-1} ; $r^2 = 0.947 \div 0.995$;

$\grave{a}_p(488)$ from 0 to 1.48 m^{-1}; $r^2 = 0.965 \div 0.996$).

One-parametric model of seawater absorption:

$\grave{a}(\lambda)=\tilde{N}_1(\lambda)\, \grave{a}(488)+\tilde{N}_2(\lambda)+\grave{a}_w(\lambda)$, Barnard et al. (1998);

$$a(\lambda) = [a_w(\lambda) + 0.06\cdot a^{*\prime}_{ph}(\lambda)\cdot Chl^{0.65}] \text{ x}$$

$$\text{x}\cdot[1 + 0.2\exp(-0.014(\lambda - 440))],$$ (Morel 1991).

Estimate of seawater absorption and scattering through K_d and D

$a(490) = 0.8\ K_d(490) – 002$, Kopelevich (unpubl.)
(accuracy is about 20%).

$K_d(\lambda_2) = M(\lambda_2) / M(\lambda_1) \cdot [\ K_d(\lambda_1) - K_w(\lambda_1)] + K_w(\lambda_2)$,

$\lambda_{1,2} = 420 \div 580$ nm Austin and Petzold (1984)

$\ln b(550) = 2.23 – 1.13 \ln D$, (accuracy is about 30%)

Kopelevich and Semshura (1988)

$b_b(550)=b_{bp}(550)/b_p(550) \cdot [b(550)-b_w(550)]+0.5\ b_w(550)$;

$b_{bp}(550)/b_p(550) = 0.01$ for open ocean,
0.02 for coastal waters.
Kopelevich (unpublished)

Haltrin's one-parametric "all-round" model
(Haltrin 1999)

Case 1

The model describes spectral absorption and scattering as well as the phase scattering functions with 5 parameters:

Chl, C_f, C_h, $C_s = \rho_s v_s$, $C_l = \rho_l v_l$,

but C_f, C_h, C_s, C_l are also represented through Chl.

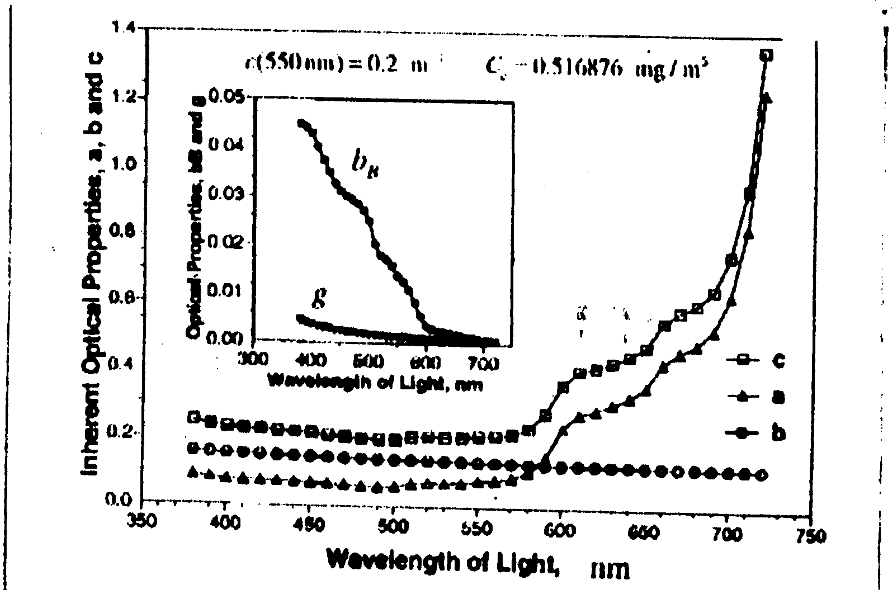


Fig. 4. Example of restored spectral inherent optical properties.

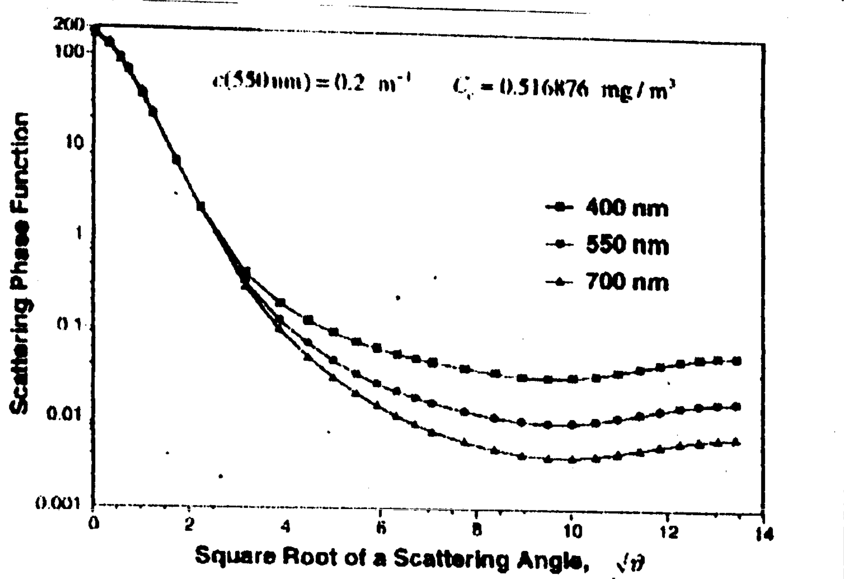


Fig. 5. Example of restored seawater scattering phase functions.