INTERPRETATION OF REMOTE SENSING DATA FROM EASTERN AREAS OF THE BALTIC SEA

J.Lokk[1], V.Pelevin[2] and V.Solomakha[2]

[1] Institute of Thermophysics and Electrophysics,
Acad.of Sci. of the Estonian SSR, Paldiski Rd.1,
Tallinn 200031, USSR, VII Commission

[2] Institute of Oceanology, Acad.of Sci. of the USSR,
Krasikov Str.23, Moscow 117218, USSR, VII Commission

A method for the determination of concentrations of optically active substances (phytopigments, suspended and yellow matter) in waters with high concentrations and unequal indices of optically active substances is suggested. The method has been worked out relying on the Baltic Sea phenomenon but it can also be applied to other water bodies (seas as well as internal ones) of similar parameters.

Possible ways of applying remote sensing to the admixture concentration determination in the eastern Baltic waters are considered. It is known that the waters there are highly trophic and strongly subjected to human impact. In most papers devoted to the interpretation of spectral aerocosmic information on the sea surface, empiric relations between one or two characteristics of upward radiation spectrum and the chlorophyll "a" concentration were reached (Clark, 1981; Smith and Baker 1982; Shifrin, 1983, Shturm, 1984; Sugihara, Kishino and Okami,1985). In the present paper an attempt of a more profound use of the upward radiation spectrum has been made. Let us consider the coefficient of the sea surface spectral brightness equal to $R = \frac{L_{\delta\lambda} - L_{z\lambda}}{L_{0\lambda}}$ (Lokk and Pelevin, 1978; Pelevin, 1978), where $L_{\delta\lambda}$ is the brightness of the upward radiation above the sea surface, $L_{z\lambda}$ the sky brightness in the zenith, $L_{0\lambda}$ the brightness of the white diffuser, placed horizontally above the sea surface, f =0.02 the value of the Frenel reflection coefficient for the smooth water surface and normal light beam inclination, λ the light wavelength. To determine the spectra of ρ_λ, $L_{\delta\lambda}$, $L_{z\lambda}$ and $L_{0\lambda}$ were directly measured. The experimental values of ρ_λ were obtained in the Baltic in 1986 and 1987 using the spectroradiometer with a set of interferencial lightfilters:

λ_1 = 381 nm; λ_2 = 438nm; λ_3 = 500 nm;

λ_4 = 555 nm; λ_5 = 596 nm; λ_6 = 670 nm.

For calculations the formula of spectral brightness coefficient most directly connecting the parameter with the hydrooptical characteristic of the water, was chosen (Lokk and Pelevin, 1978):

$$\rho_\lambda = K \frac{b_{b\lambda}}{a_{\omega\lambda} + a_{y\lambda} + a_{p\lambda} + a_o + b_{b\lambda}} \quad (1)$$

where $b_{b\lambda}$ is the coefficient of light backscattering; $a_{\omega\lambda}$, $a_{p\lambda}$, $a_{y\lambda}$, a_o the coefficients of absorption in pure water, plankton pigments, dissolved organic "yellow" matter, suspended matter (excluding pigments, phytoplankton), K =0.11 (Pelevin, 1978). It is belived (Pelevina,1980) that the coefficient of absorption in the dissolved organic ("yellow") matter changes with the spectrum as $a_{y\lambda} = a_{y\lambda_0} \cdot exp\, K(\lambda_o - \lambda)$, where K =0.0148 ÷ 0.0152 m^{-1}. In calculations K =0.015 m^{-1} and λ =500 nm. It is presumed that the construction of absorption in phytoplankton pigments is proportional to the chlorophyll "a" concentration C mg·m-3:

$$a_{p\lambda} = a^*_{p\lambda} \cdot C \quad m^{-1}.$$

After the analysis of various publications (Jerlov, 1970; Ochakovskij, et al.,1974; Popov, Fedorov and Orlov,1979; Optics of Ocean, 1983) the following coefficient values were adopted: $a^*_{p381} = 0.036\ m^2 \cdot mg^{-1}$; $a^*_{p438} = 0.059\ m^2 \cdot mg^{-1}$; $a^*_{p500} = 0.042\ m^2 \cdot mg^{-1}$ for specific absorption in pigments and $a_\omega = 0.014\ m^{-1}$; $a_{\omega438} = 0.011\ m^{-1}$; $a_{\omega500} = 0.021\ m^{-1}$; $a_{\omega555} = 0.053 m^{-1}$; $a_{\omega596} = 0.15\ m^{-1}$ in pure water (on natural basis). The spectral dependence $b_{b\lambda}$ in condition of the additive contribution of backscattering by large $b_{bl\lambda}$ and small $b_{bs\lambda}$ fractions of suspended matter is selected as follows (Optics of Ocean, 1983):

$$b_{b\lambda} = b_{b\omega500} \cdot \left(\frac{500}{\lambda}\right)^{4.3} + b_{bl500} \cdot \left(\frac{500}{\lambda}\right)^{0.3} + b_{bs500} \cdot \left(\frac{500}{\lambda}\right)^{1.7}.$$

The coefficient of light backscattering in pure water is $b_{b\omega500}$ = =0.001 m-1 (Popov, Feodorov and Orlov,1979). It was suggested that within the interval of 500 nm $\leq \lambda \leq$ 600 nm the special absorption in pigments $a^*_{p\lambda}$ changes according to the law exp$[0.015\ (\lambda_o - \lambda)]$ .The light absorption in suspended matter a_o (excluding the absorption in pigments) for calculations is considered non-selective. This way, the light absorption in pigments and dissolved yellow matter a_λ changes on the spectrum

$$a_\lambda = a_{y\lambda} + a_{p\lambda} = a_{500} \cdot exp\,[0.015 \cdot (500 - \lambda)].$$

At wavelengths 500 nm $\leq \lambda \leq$ 600 nm equation (1) is expressed as follows:

$$\rho_\lambda = K \frac{b_{b\lambda}}{a_{\omega\lambda} + a_{500} \cdot exp\,[0.015\,(500 - \lambda)] + a_o + b_{b\lambda}} \quad (2)$$

For λ < 500 nm, where the spectral way of the curves $a_{y\lambda}$ and $a_{p\lambda}$ differs considerably, equation (1) has the form

$$\rho_\lambda = K \frac{b_{b\lambda}}{a_{\omega\lambda} + (1 - \xi) \cdot a_{500} \cdot exp[0.015(500 - \lambda)] + \xi \cdot a_{500} \cdot N_\lambda + b_{b\lambda}}, \quad (3)$$

where $\xi = \frac{a_{p500}}{a_{500}}$; $N_\lambda = \frac{a^*_{p\lambda}}{a^*_{p500}}$

The reverse task - the determination of the unknown parameters b_{bl500} , b_{bs500} , a_{y500} , a_{p500} , a_0 for measuring ρ_{λ_i} , was solved by a computer, relying on the principle of minimizing the discrepancies of the measured values of ρ_{λ_i} and of the calculated values of ρ'_{λ_i} obtained from (2) - (3). The procedure of calculation is as follows. Firstly the calculation values of b_{bl500} , b_{bs500} , a_{500} , a_0 for $\sum_{i=3}^{5} | \rho_{\lambda_i} - \rho'_{\lambda_i} | = 0$ are found according to linear equations system (2). Simultaneously according to system (3) by way of the modification of a_{500} and ξ , the values of a_{p500} and a_{y500} for which the maximum values of the difference modulus $\sum_{i=1}^{2} | \rho_{\lambda_i} - \rho'_{\lambda_i} |$ are the smallest, are determined. The following conditions are satisfied:

$$b_{bl500} , b_{bs500} , a_{500} , a_0 \geq 0 \;; \quad 0 \leq \xi \leq 1 .$$

The results of calculations and measurements for stations showed in Fig. 1, are summarized in Table .

As one can see, the calculated values of the chlorophyll concentration are in good agreement with the concentrations measured in samples. The precision achieved meets totally the economic needs as well as the requirements for the studies of the large-scale variability of water mass and substance distribution in coastal areas. An analogous precision was reached for other optically active substances (suspended and yellow matter) in the water. The algorithm like that may be applied to investigations from low-flying carriers, where the influence of the atmosphere is inessential.

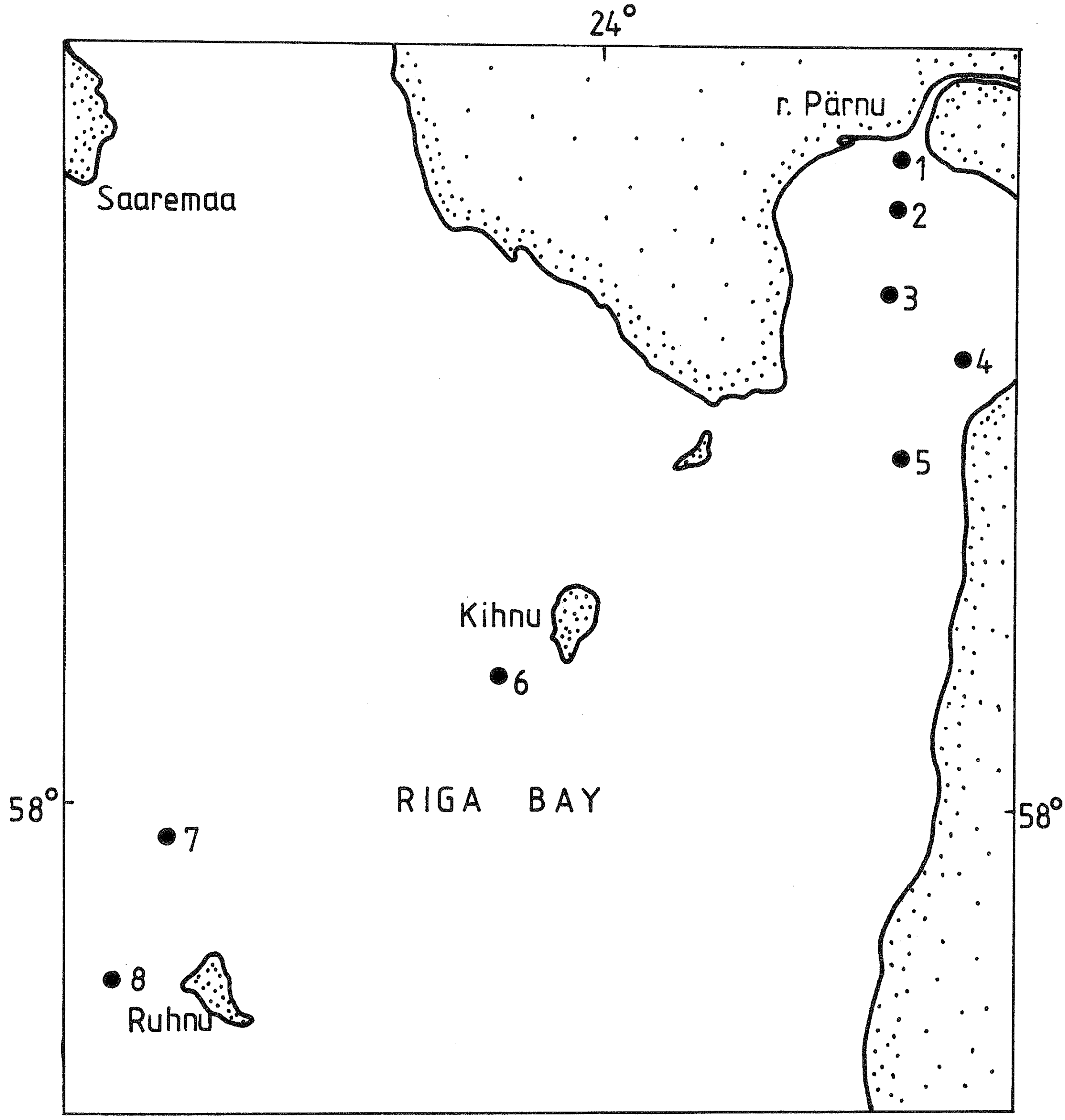

Fig.1. The area of sampling and remote measurements

The measured and calculated values of optical parameters and chlorophyll concentration

Table

Station		λ (nm)					m^{-1}					C (mg·m^{-3})	
		383	438	500	555	596	a_{500}	a_{0}	a_{ys500}	b_{bl500}	b_{bs500}	calc.	meas.
I	measured	0.007	0.016	0.026	0.040	0.045	1.10	0.11	0.80	0.38	0.01	7.3	9.0
	calculated	0.008	0.015	0.026	0.040	0.045							
2	measured	0.013	0.022	0.036	0.054	0.062	1.56	0.06	1.00	0.76	0.04	13.2	9.2
	calculated	0.013	0.022	0.036	0.054	0.062							
3	measured	0.015	0.020	0.038	0.056	0.061	0.91	0.01	0.66	0.49	0.01	6.1	7.3
	calculated	0.013	0.022	0.038	0.056	0.061							
4	measured	0.008	0.012	0.020	0.033	0.037	0.89	0.02	0.44	0.19	0.02	10.8	8.5
	calculated	0.008	0.012	0.020	0.033	0.037							
5	measured	0.006	0.007	0.014	0.023	0.025	0.75	0.06	0.42	0.12	0.00	7.9	8.7
	calculated	0.005	0.008	0.014	0.023	0.025							
6	measured	0.003	0.005	0.007	0.010	0.008	0.35	0.01	0.20	0.00	0.03	3.5	2.8
	calculated	0.003	0.005	0.007	0.010	0.008							
7	measured	0.004	0.003	0.007	0.012	0.012	0.52	0.02	0.23	0.04	0.00	6.9	2.7
	calculated	0.003	0.004	0.007	0.012	0.012							
8	measured	0.003	0.003	0.005	0.007	0.006	0.30	0.08	0.12	0.02	0.00	4.2	3.2
	calculated	0.003	0.003	0.005	0.007	0.006							

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