1991

Aerospace Monitoring of Water Quality

Anatoly A. Gitelson
University of Nebraska - Lincoln, agitelson2@unl.edu

Ferenc Szilagyi
Water Resources Research Center, Budapest, Hungary

Published in: Geoscience and Remote Sensing Symposium, 1991. IGARSS '91. Remote Sensing: Global Monitoring for Earth Management
DOI: 10.1109/IGARSS.1991.577669. Copyright 1991, IEEE. Used by permission. Pages 75-78, volume 1

AEROSPACE MONITORING OF WATER QUALITY

Anatoly Gitelson and Ferenc Szilagyi*

Ben-Gurion University, J.Blaustein Inst.for Desert Research
Sede-Boker Campus 84990, Israel
*Water Resources Research Center, H-1453 Budapest, P.O.B. 27, Hungary

ABSTRACT

The potential of using remote sensing for the detection of chlorophyll-a (CHL), dissolved organic matter (DOM), and suspended matter (SM) concentrations in coastal and inland waters was investigated using measurements of (ir)radiance spectra along with simultaneous earth-reference data. The range of CHL was 0.1 to 350µg/l, SM was 0.1 to 43 mg/l, and DOM absorption at the 380 nm was 0.1 to 10 $^{-1}$. Factor and signature analysis reveal allometric relationships between constituent concentrations C_k and functions of reflectance Z_k of the type $C_k=aZ_k^b$. Appropriate functions of R were found: $Z_{chl} = R(700)/R(675)$, $Z_{sm} = R(560)/R(520)$, and $Z_{dom}=\{R(480)+k[R(700)/R(675)]\}/R(630)$. The maximum estimation errors were: CHL - 3 µg/l, DOM - 0.065 µgC/l, and SM - 4 mg/l.
Keywords: irradiance, optical properties.

1. INTRODUCTION

The main goal of this research is to establish remote sensing methods for estimating relevant water quality components. An improved solution for this problem is obtained by developing optical models of water bodies on the basis of relationships between (ir)radiance spectra and the simultaneously obtained earth-reference data. We developed a method for interpreting remotely sensed data from inland and coastal waters. These typically highly productive waters are a troublesome problem for remote sensing, because numerous suspensions (phytoplankton, detritus, non-organic suspended matter, yellow substance, etc.) vary in character and amount within short distances and time intervals, and can modify the upwelling visible radiation measured remotely [1-6].

2. MATERIALS AND METHODS

Several hundred spectral (ir)radiance measurements were conducted along with simultaneous ground-data references in the test areas [5-12]. Water quality samples were collected for measuring the total of phytoplankton CHL phaeopigments, and biomass, SM, DOM, absorption and scattering coefficients, in vivo excitation and emission fluorescence spectra of CHL and DOM [8,12]. Radiometric measurements were taken from either a boat or an aircraft including upwelling and downwelling spectral (ir)radiance at the wavelengths 430 to 750 nm, laser-stimulated fluorescence of DOM (at the 400 to 560 nm) and CHL (at 685nm). Over the study ecosystems, CHL ranged from 3 to 350 µg/l, SM - from 2 to 43 mg/l, and DOM absorption coefficient at 380 nm from 0.1 to 10 m^{-1}. Between different study areas, water quality is quite distinctive. We believe that by using broad range of aquatic ecosystems from oligotrophic to hypertrophic we are able to develop comprehensive optical models and algorithms for remote estimation of water quality.

3. RESULTS

The reflectance (R) spectrum reveals a low R at the wavelength 430 to 480 nm, which is due to absorption by both algal pigments (e.g. chlorophyll-a) and yellow substance. The minima between 560 and 700 nm correspond to the absorption maxima of phytoplankton pigments. At 675 nm a reflectance minimum corresponding to the CHL absorption band is quite clear. These is an increase in reflectance at the wavelengths 560-590 nm, which is the result of low absorption by photosynthetic pigments coupled with an increase in scattering when particle concentration increases. A peak of R is also notable at 685 to 720 nm. In productive waters this maximum may shift and reach 720 nm when CHL increases to concentrations higher than 100 µg/l [10,14]. The result strongly supports the hypothesis: the peak can be explained a minimum in the combined absorption curves of algae and water [10].

Published in: Geoscience and Remote Sensing Symposium, 1991. IGARSS '91. Remote Sensing: Global Monitoring for Earth Management
DOI: 10.1109/IGARSS.1991.577669. Copyright 1991, IEEE. Used by permission. Pages 75-78, volume 1

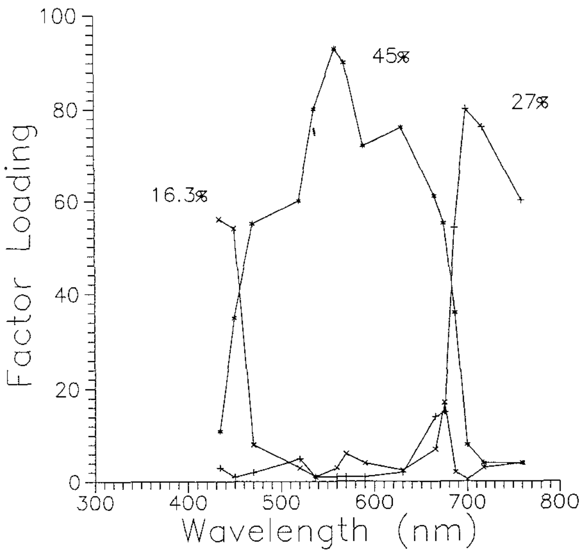

Figure 1. Extracted factor solution and their correlation with spectral channels.

We used factor analysis to identify the independent components that cause variability in the radiance spectrum, as well as the wavelengths, that are sensitive to these factors [3,4,11]. The analysis indicates that over 88% of reflectance dispersion value at the wavelengths 430 to 750 nm can be accounted for by three factors (Figure 1). The first factor accounts for 16.3% of the reflectance dispersion, the second factor - 45.3%, and third - 27%. Based on this analysis, we suggest that the spectral bands that are more suitable for the estimation of water quality are 690-710 nm for CHL, 540-590 nm for SM, and 450-480 nm for DOM [7,8].

Factor and signature analysis indicates that the reflectance ratio Zk relates to constituent concentrations Ck satisfactorily by using a relationship of the form:

$$C_k = aZ^b \qquad (1)$$

For assessment of CHL and SM concentrations with acceptable accuracy, we recommend the following:

for C_{chl}:

$$Z=R(700)/R(675),\ R(700)/R(560),\ \text{and}\ [R(700)-R(675)]/[R(700)+R(675)] \qquad (2)$$

for C_{sm}:

$$Z=[R(560)-R(520)]/[R(560)+R(520)]\ [R(560)-R(630)]/[R(560)+R(630)],\ \text{and}\ R(560)/R(520) \qquad (3)$$

Development of decoding index for derivation of dissolve organic matter concentration from reflectance spectrum is rather complicated by the fact that DOM

Table 1. Parameters and statistics of relationships $C_{chl}=aZ^b$ for different water areas.

Water bodies	Z = R(700)/R(560) a	b	r	F	C_{chlavg} µg/l
Lake Balaton, 1985	125.21	2.32	0.95	2046	48.8
Lake Balaton, 1986	94.63	2.19	0.95	488	63.3
Lake Balaton, 1988	68.03	2.59	0.86	101	10.2
Lake Mugelzee, 1986	217.02	1.84	0.95	1700	101.4
Lake Mugelzee, 1988	196.37	1.31	0.88	820	72.3
River Don, 1983	67.36	2.84	0.97	107	18.5
River Don, 1984	71.52	2.91	0.84	85	12.9
River Donec, 1983	58.56	2.25	0.98	107	24.6
River Donec, 1984	72.24	2.82	0.92	118	7.9

Water bodies	Z = R(700)/R(675) a	b	r	F	C_{chlavg} µg/l
Lake Balaton, 1985	15.64	2.95	0.96	2140	48.8
Lake Balaton, 1986	27.94	2.28	0.96	512	63.3
Lake Balaton, 1988	13.33	3.21	0.88	115	10.2
Lake Mugelzee, 1986	55.70	1.75	0.98	2600	101.4
Lake Mugelzee, 1988	66.02	3.02	0.92	1100	72.3
River Don, 1983	12.12	3.10	0.96	105	18.5
River Don, 1984	10.20	3.42	0.89	98	12.9
River Donec, 1983	13.10	3.05	0.98	107	24.6
River Donec, 1984	9.32	3.41	0.96	144	7.9

Published in: Geoscience and Remote Sensing Symposium, 1991. IGARSS '91. Remote Sensing: Global Monitoring for Earth Management
DOI: 10.1109/IGARSS.1991.577669. Copyright 1991, IEEE. Used by permission. Pages 75-78, volume 1

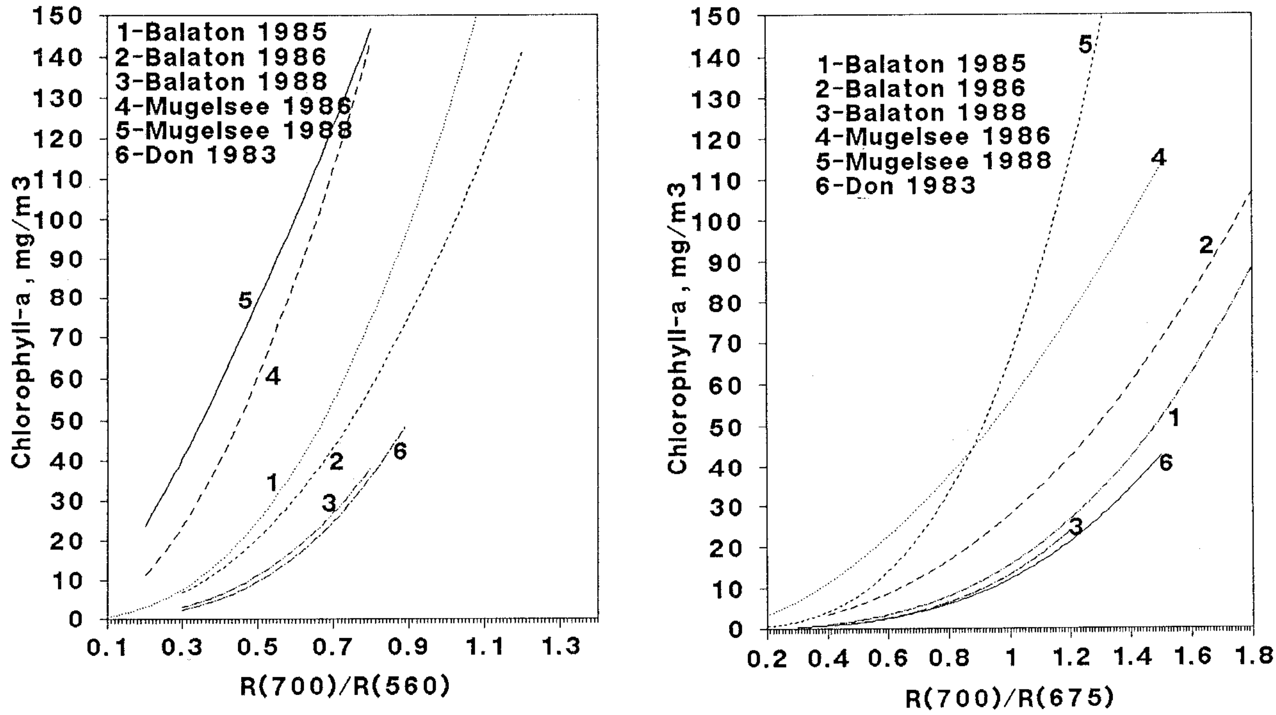

Figure 2. Relationships between CHL concentration and reflectance ratios R(700)/R(560) and R(700)/R(675).

does not have unique spectral feature on radiance spectra. Along with its absorption effect, high portion of the upwelling (ir)radiance at the 430-480 nm can be contributed to the solar induced fluorescence of dissolved organic matter [1,8,12]. Our method of DOM concentration assessment was based on ratio of reflectance at 480 nm (most sensitive to changes in the DOM concentrations) to reflectance at the reference wavelengths 520 and 630 nm (least sensitive to changes in the concentrations of water quality components) [11]. As reflectance at 480 nm depends not only on C_{dom} but also on C_{chl}, influence CHL took into account by using item kR(700)/R(675) as first approach. For derivation dissolved organic matter from reflectance spectrum following ratios were used:

$$Z=\{R(470)+k[R(700)/R(675)]\}/R(520) \text{ and } \{R(470)+k[R(700)/R(675)]\}/R(620) \quad (4)$$

Using equation 1 with 2-4 we had obtained : for CHL correlation coefficient (r) was r > 0.96 and estimation error δC_{chl} < 2.5 μg/l; for SM - r > 0.92 and δC_{sm} < 3 μg/l; for DOM - r > 0.90 and δC_{dom} < 0.5 μgC/l [7,9]. The parameters of the equation 1 for estimation of C_{chl} along these correlation coefficients, and averaged CHL concentrations (C_{chlavg}) for different water areas are shown in Table 1

The relationship between C_{chl} and reflectance ratio varies over different water areas and in the different seasons. Comparing the shape of the curves shown on Figure 2 to an averaged chlorophyll-a concentrations it becomes clearly that the

Table 2. Correlation coefficients of C_{chl} vs, R(700)/R(675) and C_{chl} vs, R(700)/R(560) relationships and chlorophyll estimation errors (δC_{chl}) taking averaged values of CHL into consideration.

Water bodies	R(700)/R(560) r	R(700)/R(560) δC_{chl}	R(700)/R(675) r	R(700)/R(675) δC_{chl}	C_{chlavg} μg/l
Lake Balaton, 1985	0.793	18.0	0.950	8.3	48.8
Lake Balaton, 1986	0.946	10.0	0.961	7.8	63.3
Lake Balaton, 1988	0.777	2.5	0.899	1.7	10.2
River Don, 1983	0.943	2.7	0.912	3.1	18.5
River Don, 1984	0.822	3.1	0.934	2.0	12.9
River Donec, 1983	0.981	2.0	0.897	2.2	7.8
River Donec, 1984	0.936	1.4	0.902	2.1	24.6

Published in: Geoscience and Remote Sensing Symposium, 1991. IGARSS '91. Remote Sensing: Global Monitoring for Earth Management
DOI: 10.1109/IGARSS.1991.577669. Pages 75-78, volume 1

curves tend to shift toward the lower range of ratios R_i/R_j values, when C_{chl} increases. This indicates that the position of the curves $C_{chl}=a[R_i/R_j]^b$ and values of parameters a and b are determined by the average trophic state of the water body. It is possibly to improve the relationship $C_{chl}=a[R_i/R_j]^b$ by using correction factors that depend on the averaged CHL concentration. The estimated CHL concentration is:

$$C_{chl}=a(C_{chlavg})Z^{b(Cchlavg)} \qquad (5)$$

where the values of $a(C_{chlavg})$ and $b(C_{chlavg})$ are determined:

for ratio R(700)/R(560):

$$a = 1.46 \; C_{chlavg} + 44.25, \; r = 0.91$$
$$b =-0.013 \; C_{chlavg} + 2.9, \; r =-0.89 \qquad (6)$$

for ratio R(700)/R(675):

$$a = 0.473 \; C_{chlavg} + 1.68, \; r = 0.92$$
$$b =-0.013 \; C_{chlavg} + 3.50, \; r =-0.96 \qquad (7)$$

In Table 2 estimation errors and correlation coefficients are shown.

In order to enable the utilization of existing satellite images for the assessment of water quality, and, to determine if more optimal wave bands might be selected in the future for these purposes, we integrated the data of near surface (ir)radiance measurements with the wavelength domains over which the sensors of the extant satellites work. Normalization of reflectance spectra allowed us to obtain a close relationship of C_{chl} with the function of reflectance over wide wavelength bands. The relationships between radiance value, integrated over the bands of the MSS LANDSAT sensors, and C_{chl} in the band ratios MSS6/MSS4, MSS4/MSS4+5+6 and MSS6/MSS4+5+6 proved to be suitable for the remote sensing of C_{chl}, when observed maximum CHL values fall in the range of 20 μg/l < C_{chl} < 150 μg/l. When C_{chl} < 20 μg/l it is advisable to consider ratios MSS5/MSS4 and MSS4+5+6 in order to achieve better results [6]. We derived suitable wave bands for the utilization of future space systems NIRIS and MODIS in the assessment of water quality. By using the 480, 500, 520, 560, 630, 650, 675, 700, and 710 nm wavelengths, estimation errors should be less than 2 μg/l for CHL, 0.7 μgC/l for DOM, and 2.5 mg/l for SM.

4. REFERENCES

1. Dirks, R.W.J., "On the Color of the Sea (with reference to remote sensing)," Ph.D. Thesis, State University of Utrecht, The Netherlands, 1990, pp.78-81.

2. A.G. Dekker, T.J.Malthus and E. Seyhan, "An Inland Water Quality Bandset for the CAESAR System Based on Spectral Signature Analysis," in Proceedings of Int. Symposium "Remote Sensing and Water Resources", Enschede, The Netherlands, August 1990, pp. 597-606.

3. R. Doerffer, "Factor Analysis in Ocean Color Interpretation," in J.F.R. Gower (Ed): Oceanography from Space, Plenum Press, New York, pp. 339-345, 1981.

4. J. Fischer, R. Doerffer, and H. Grassl, "Factor analysis of multispectral radiances over coastal and open ocean water based on radiative transfer calculations," Appl. Opt., vol. 25, pp. 448-456, 1986.

5. A.A. Gitelson, G.P. Keydan, and V.N Shishkin, "Assessment of Inland Water Quality According to the Multizonal Airspace Imagery," Earth Research from Space, No.6, pp. 28-36, 1985.

6. A.A. Gitelson, A.M. Nikanorov, G.Sabo and F. Szilagyi," Etude le la qualite des esex de surface par teledetection," IAHS Publ., vol. 157, pp. 111-121, 1986.

7. A.A. Gitelson and A.M. Nikanorov, "Remote monitoring of Ecological Condition of Aquatic Ecosystems," Fate and Effects of Pollutants an Aquatic Organisms and Ecosystems, EPA 600/9-88/001, pp.166-182, 1988.

8. A.A. Gitelson and G.P.Keydan, "Remote Sensing of Inland Water Quality by Measurements in the Visible Spectrum," Acta Hydrophys., vol. 34, pp. 5-27, 1990.

9. A.A. Gitelson, and F.Szilagyi, "Radiomodels of Mesotrophic and Eutrophic Water Bodies," in Proceedings of Int. Symposium "Remote Sensing and Water Resources", Enschede, The Netherlands, August 1990, pp. 606-616.

10. A.A. Gitelson, K.Ya. Kondrat'ev, "The nature of the maximum at 700 nm on radiance spectrum and its application for remote monitoring of water quality," Transaction of the USSR Academy of Sciences, Earth Science Sections, vol. 306, pp. 60-63, 1989.

11. K.Ya.Kondrat'ev, G.P., Garbuzov, and A.A. Gitelson, "New approach to the problem of aquatic ecosystems state monitoring according to reflectance spectrum," Transaction of the USSR Academy of Sciences, Earth Science Sections, vol. 295, pp. 39-43, 1987.

12. K.Ya. Kondrat'ev, A.A. Gitelson, and A. Dubovitskij, "Remote sensing of dissolved organic matter in aquatic ecosystem," Transaction of the USSR Academy of Sciences, Earth Science Sections, vol. 295, pp.33-36, 1987.

13. K. Mittenzwey, and A.A.Gitelson, " In situ Monitoring of Water Quality on Basis of Spectral Reflectance," Int. Revue ges. Hydrobiol., vol.73, pp. 61-72, 1988.

14. W.L. Vos, M. Donze, and H. Buiteveld, "On the reflectance spectrum of algae in water: The nature of the peak at 700 nm and its shift with varying concentration," Delf, The Netherlands, 86-22, 1986.