Spectral Relative Clarity of Black and Aegean Seas
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Abstract – The data on relative clarity or visibility of blue, green, red, and white (Secchi) disks measured in 1984 at the Black and Aegean seas during the 9th trip of the research vessel “Professor Kolesnikov” are presented. The analysis of results of measurements show strong correlation between visibilities of colored and Secchi disk. The regresional relationship between visibilities of blue, green and red disks and the visibility of the Secchi (white) disk are given and discussed.

INTRODUCTION

The idea to use colored Secchi disks to estimate relative spectral clarity of seawater was proposed in 1968 by N. Jerlov [1]. Yet in spite of the abundance of works devoted to the visibility of white Secchi disk there are almost no publications about visibility of colored disks except the black one [2]. World oceanographic archives contain millions of Secchi disk measurements made during the period of more than one hundred years [3-5]. These measurements give very little information about spectral characteristics of studied waters. The regresional relationships between visibility of colored disks and Secchi disk proposed in this paper will give us means to convert historical non-spectral Secchi disk data into spectral information.

IN SITU MEASUREMENTS

The results of simultaneous measurements of the spectral relative clarity, or visibilities of blue, green, red and white (Secchi) disks, made in 1984 at the Black and Aegean seas are presented. The measurements are made at 45 stations during the 9th trip of the research vessel “Professor Kolesnikov”. At about seventy percent of the oceanographic stations the simultaneous measurements of yellow and black disks also have been made. The spectral albedos of Secchi and colored disks have been measured with a spectral photometer and presented in Fig. 1.

WHITE AND COLORED DISKS VISIBILITY

The results of statistical analysis show strong correlation between visibilities of blue, green, red (Zb, Zr, Zg) and Secchi (Zw) disks (See. Fig. 2). They are represented by the following regressions:

\[ Z_b = 0.675923821 \cdot Z_{w}^{1.066472}, \quad r^2 = 0.9234386, \quad (1) \]
\[ Z_g = 0.890360716 \cdot Z_{w}^{0.948397}, \quad r^2 = 0.8837671, \quad (2) \]
\[ Z_r = 0.646411940 \cdot Z_{w}^{0.849426}, \quad r^2 = 0.7662292. \quad (3) \]

The theories of the Secchi disk visibility [6, 7] are based on the non-spectral approach. It is possible to modify these theories to incorporate the spectral dependencies of the inherent optical properties of the sea [8-10]. In this case it is possible to formulate a theory of the color disk visibility that incorporates spectral contrasts and averaging procedure over CIE chromatic coordinates [11]. The inherent optical properties of seawater may be expressed through four concentrations of substances suspended and dissolved in seawater: concentration of chlorophyll, concentration of large biogenic particles, concentration of small terrigenic particles, and concentration of yellow substance. Consequently, the four theoretic equations for visibility of Secchi and three colored disks include eight unknown parameters: four disk visibility depths and four concentrations of dissolved and suspending matter. In order to solve them we need an additional four equations. Equations (1)-(3) of this note may serve this purpose. As an additional fourth equation we may choose a regression that connects the Secchi disk visibility depth with the concentration of chlorophyll [5, 10] or with the beam attenuation coefficient [12, 13].

CONCLUSION

It was shown that the visibility of colored disks is closely connected with the visibility of white or Secchi disk. The derived empirical relationships between relative clarieties of colored and white disks may be used for the restoration of the spectral dependencies of inherent optical properties from the Secchi disk measurements.

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Figure 1. Spectral albedos of white (or Secchi), blue, green, and red disks.

Figure 2. Visibility of blue, green and red disks in the Black and the Aegean seas as a function of white (or Secchi) disk visibility.

APPENDIX 1: RELATIVE CLARITIES OF WHITE (SECCHI), BLUE, GREEN, AND RED DISKS

Table A1. Spectral relative clarity of the Black (B) and the Aegean (A) seas during the 9th voyage of the R/V “Professor Kolesnikov” in 1984.

| St.#  | Date    | Time   | $Z_w$ | $Z_b$ | $Z_g$ | $Z_r$ | $N$ | Sea |
|-------|---------|--------|-------|-------|-------|-------|-----|-----|
| 1166  | 25.08   | 15:30  | 20    | 16    | 16    | 7     | 5   | B   |
| 1167  | 25.08   | 18:40  | 17    | 14    | 13    | 8     | 5   | B   |
| 1172  | 26.08   | -      | 16    | 13    | 11    | 7     | 5   | B   |
| 1173  | 26.08   | -      | 18    | 15.5  | 15    | 9     | 5   | B   |
| 1179  | 27.08   | -      | 19    | 16    | 14    | 7     | 4.5 | B   |
| 1180  | 27.08   | -      | 16    | 12    | 12    | 7     | 4.5 | B   |
| 1181  | 27.08   | 17:35  | 14    | 15    | 13    | 8     | 5   | B   |
| 1187  | 29.08   | 19:45  | 17    | 14    | 13    | 7     | 5   | B   |
| 1187  | 30.08   | 10:30  | 20    | 16    | 13.5  | 8     | 5   | B   |
| 1188  | 31.08   | 09:40  | 18    | 15    | 14    | 7     | 6   | B   |
| 1189  | 03.09   | 11:00  | 16    | 12    | 11    | 8     | 3   | A   |
| 1189  | 03.09   | 14:35  | 17    | 14    | 14    | 8     | 3.5 | A   |
| 1190  | 07.09   | -      | 33    | 30    | 23.5  | 14    | 3   | A   |
| 1191  | 07.09   | -      | 22    | 18    | 17    | 9     | 3   | A   |
| 1192  | 07.09   | -      | 27    | 24    | 20    | 11    | 3   | A   |
| 1193  | 07.09   | -      | 27    | 23    | 20    | 11    | 3   | A   |
| 1201  | 08.09   | -      | 33    | 28    | 26    | 14    | 3   | A   |
| 1202  | 08.09   | -      | 30    | 26    | 21    | 11    | 3   | A   |
| 1204  | 10.09   | 09:15  | 20    | 16    | 16    | 8     | 5   | B   |
| 1205  | 10.09   | 13:00  | 23    | 18    | 17    | 10    | 4.5 | B   |
| 1206  | 10.09   | 16:12  | 24    | 20    | 18    | 10    | 4   | B   |
| 1211  | 11.09   | 10:10  | 21    | 18    | 18    | 8     | 5   | B   |
| 1212  | 11.09   | 14:25  | 22    | 18    | 18    | 9     | 4.5 | B   |
| 1213  | 11.09   | 17:15  | 20    | 16    | 15    | 7     | 5.5 | B   |
| 1218  | 12.09   | 11:55  | 19    | 16    | 14    | 8     | 6   | B   |
| 1219  | 12.09   | 14:50  | 18    | 13    | 12    | 7     | 5   | B   |
| 1224  | 13.09   | 10:37  | 22    | 18    | 16    | 9     | 4.5 | B   |
| 1225  | 13.09   | 14:13  | 19    | 16    | 16    | 8     | 4.5 | B   |
| 1226  | 13.09   | 16:10  | 17    | 12    | 11    | 6     | 5   | B   |
| 1230  | 14.09   | 10:10  | 20    | 16    | 16    | 8     | 5   | B   |
| 1231  | 14.09   | 14:10  | 21    | 18    | 15    | 9     | 5   | B   |
| 1232  | 14.09   | 18:39  | 22    | 17    | 17    | 8     | 5   | B   |
| 1236  | 15.09   | 09:45  | 14    | 12    | 12    | 5     | 6   | B   |
| 1237  | 15.09   | 13:15  | 18    | 16    | 15    | 7     | 5   | B   |
| 1238  | 15.09   | 17:20  | 18    | 14    | 14    | 8     | 5   | B   |
| 1242  | 16.09   | 09:40  | 16    | 14    | 14    | 7     | 7   | B   |
| 1243  | 16.09   | 13:26  | 15    | 11    | 10    | 6     | 6   | B   |
| 1244  | 16.09   | 17:45  | 13    | 11    | 10    | 5     | 6   | B   |
| 1250  | 17.09   | 14:10  | 16    | 14    | 12    | 8     | 6   | B   |
| 1251  | 17.09   | 18:10  | 14    | 11    | 11    | 6     | 6.5 | B   |
| 1256  | 18.09   | 11:05  | 17    | 14    | 13    | 8     | 6   | B   |
| 1261  | 19.09   | 10:42  | 16    | 12    | 12    | 7     | 5   | B   |
| 1262  | 19.09   | 13:05  | 20    | 17    | 17    | 7     | 5   | B   |
| 1263  | 19.09   | 17:05  | 19    | 16    | 15    | 7     | 5   | B   |
| 1267  | 21.09   | 14:15  | 12    | 9     | 9     | 6     | 6   | B   |

Note: $N$ in Table A1 stands for the water color according to the Forel-Uhle scale.
APPENDIX 2: SPECTRAL ALBEDOS OF WHITE (SECCHI), BLUE, GREEN, AND RED DISKS

Table A2. Spectral albedos of white and colored disks.

| λ, nm | Aw  | Ab  | Ag  | Ar  |
|-------|-----|-----|-----|-----|
| 400   | 0.640 | 0.123 | 0.032 | 0.05 |
| 410   | 0.650 | 0.143 | 0.032 | 0.054 |
| 420   | 0.670 | 0.165 | 0.032 | 0.039 |
| 430   | 0.675 | 0.182 | 0.032 | 0.039 |
| 440   | 0.700 | 0.165 | 0.030 | 0.039 |
| 450   | 0.720 | 0.182 | 0.026 | 0.027 |
| 460   | 0.730 | 0.181 | 0.028 | 0.024 |
| 470   | 0.750 | 0.177 | 0.030 | 0.025 |
| 480   | 0.770 | 0.164 | 0.031 | 0.025 |
| 490   | 0.780 | 0.172 | 0.035 | 0.026 |
| 500   | 0.790 | 0.139 | 0.043 | 0.023 |
| 510   | 0.800 | 0.118 | 0.076 | 0.022 |
| 520   | 0.805 | 0.104 | 0.120 | 0.024 |
| 530   | 0.810 | 0.097 | 0.135 | 0.023 |
| 540   | 0.820 | 0.094 | 0.142 | 0.023 |
| 550   | 0.825 | 0.085 | 0.149 | 0.023 |
| 560   | 0.830 | 0.068 | 0.128 | 0.025 |
| 570   | 0.840 | 0.057 | 0.112 | 0.029 |
| 580   | 0.845 | 0.051 | 0.097 | 0.042 |
| 590   | 0.848 | 0.046 | 0.088 | 0.060 |
| 600   | 0.850 | 0.042 | 0.080 | 0.080 |
| 610   | 0.850 | 0.040 | 0.076 | 0.105 |
| 620   | 0.850 | 0.040 | 0.074 | 0.121 |
| 630   | 0.850 | 0.035 | 0.065 | 0.184 |
| 640   | 0.850 | 0.032 | 0.060 | 0.275 |
| 650   | 0.850 | 0.030 | 0.057 | 0.362 |
| 660   | 0.850 | 0.027 | 0.047 | 0.411 |
| 670   | 0.850 | 0.025 | 0.047 | 0.46 |
| 680   | 0.850 | 0.025 | 0.046 | 0.488 |
| 690   | 0.850 | 0.024 | 0.046 | 0.500 |
| 700   | 0.850 | 0.022 | 0.041 | 0.510 |

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