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SHIPBORNE MEASUREMENTS OF OPTICAL ATMOSPHERIC PARAMETERS ABOVE THE BLACK SEA*

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ABSTRACT

This presentation demonstrates results of shipborne measurements of atmospheric optical parameters above the Black Sea. The measurements were made during an international experiment “Black Sea - Interkosmos”. The goal of the experiment was to validate and improve various algorithms for passive remote sensing of surface sea layer, specifically for estimation of seawater biological properties.

The measurements were carried out from a research vessel and an aircraft-laboratory. The area of investigation was in the western part of the Black Sea. A suite of submersible and remote sensing instruments was used on the research vessel. The ship measurements included hydrological, hydrooptical and biological parameters of the seawater. The aircraft measurements included multispectral measurements of upwelling light field (see joint presentation E8).

The database presented here includes spectral transmission and spectral optical thickness of atmosphere, and a ratio of direct to diffuse illumination. This database also includes an angular radiance indicatrix measured at sun almucantar at six wavelength: 420, 502, 566, 625, 732 and 844 nm. All results are presented in graphical form. The tables of these results are available in a published report

Keywords: ocean optics, atmospheric optics, atmospheric correction

1. INTRODUCTION

In September 1984 an International experiment “Black Sea – Interkosmos-84” was carried out. The goal of the experiment was to enhance and test various methods of passive optical remote sensing of the upper sea layer for the purposes of determining biological and optical properties of seawater. The program of this experiment included simultaneous measurements of hydrophysical and biological properties of seawater [1, 2], parameters of the upwelling light [3], and optical properties of the sea-atmospheric system [4]. Independent

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measurements of optical parameters of the atmosphere were also carried out [3]. Measurements were made with submersible and remote sensors from the moving vessel and during the free drifting stations. Simultaneous measurements of upwelling light radiance were carried out from the airborne optical laboratory. The area of measurements was located in the western part of the Black Sea (see the map of the stations in Ref. [1]). The coordinates and time of atmospheric-optical measurements are given in Table 1.

Here we present only experimental measurements of atmospheric optical properties measured from the ship.

2. SPECTRAL OPTICAL PROPERTIES OF ATMOSPHERE ABOVE THE SEA

Atmospheric optical properties were measured with the following sensors: multispectral photometers “FS” and “MKS-BS” developed and manufactured in German Democratic Republic. A hand-held multichannel spectrometer “FS” was used to determine atmospheric optical parameters in 31 spectral bands (379–796 nm) [5]. A multichannel spectrometer “MKS-BS” was used to measure spectral radiance of sea surface in nadir, spectral radiance of the sky in zenith, and direct and diffuse solar irradiances in spectral range of 417–879 nm [6]. Both sensors were calibrated in absolute units. Mean spectral resolutions for spectrometer “FS” at 50% level was 10-16 nm, and for spectrometer “MKS-BS” was 10–12 nm. Spectral resolution stability of both devices was checked periodically.

Atmospheric-optical measurements were made with spectrometer “FS” using direct Bouguer method. The following parameters were measured:

– spectral transmission of the whole atmosphere:

$$T(\lambda) = S(\lambda) \big/ \left[\eta \, E_{\otimes}(\lambda) \cos Z_{\otimes} \right], \quad (1)$$

here $S(\lambda)$ is an irradiance by direct sunlight on the sea level; η is a correction coefficient that takes into account seasonal variation of the Earth-Sun distance; $E_{\otimes}(\lambda)$ is the spectral solar constant taken from Ref. [7]; $Z_{\otimes}$ is the solar zenith angle;

– total Bouguer atmospheric optical thickness:

$$\tau_B(\lambda) = -\cos Z_{\otimes} \ln T(\lambda), \quad (2)$$

Table 1. Atmospheric measurements stations. 43th Cruise of R/V “Mikhail Lomonosov”

Sta. #	N. La	E. long	Date	Time	Meteo Conditions
4234	44°49.7'	31°15.0'	08.09.84	12:00-13:13	Cloudless, haze
4235	44°48.5'	30°44.2'	08.09.84	15:00-17:00	Cloudless, haze
4240	44°30.0'	30°45.0'	09.09.84	08:45-12:41	Cloudy, 2 levels
4249	44°10.0'	31°15.0'	12.09.84	17:25-19:00	Cloudless, haze
4253	44°10.0'	29°15.0'	13.09.84	08:20-09:20	Cloudy, 1 level
4260	43°50.0'	32°15.0'	14.09.84	10:32-12:00	Cloudy, 1 level
4261	43°44.4'	32°36.1'	14.09.84	14:15-19:00	Cloudless, haze
4264	43°50.0'	34°16.1'	15.09.84	07:30-15:30	Cloudless, haze
4265	44°09.0'	34°16.0'	15.09.84	16:00-12:38	Cloudless, haze
4266	44°10.0'	33°45.0'	16.09.84	14:40-15:30	Cloudless, haze

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– total aerosol atmospheric optical thickness:

$$\tau_A(\lambda) = \tau_B(\lambda) - \tau_R(\lambda), \qquad (3)$$

here $\tau_R(\lambda)$ is a Rayleigh optical thickness for a normal atmospheric pressure taken from Penndorf [8.

Both Bouguer and aerosol optical thicknesses presented here include components due to absorption by ozone, molecular oxygen, and water vapor.

Spectral profiles of atmospheric transmission T, and total τ_B and aerosol τ_A optical thicknesses for all drift stations are shown in Figs. 1 – 3.

The numeric values of total atmospheric transmission $T(\lambda)$, total and aerosol optical thicknesses, $\tau_B(\lambda)$ and $\tau_A(\lambda)$, for all channels of spectrometer "FS" are given in Table 2 of Ref. [3]. This table also gives the following values of optical parameters measured by spectrometer "MKS-BS" on the sea level: total spectral downward solar irradiance, values of spectral sky radiance in zenith, and sea radiance in nadir.

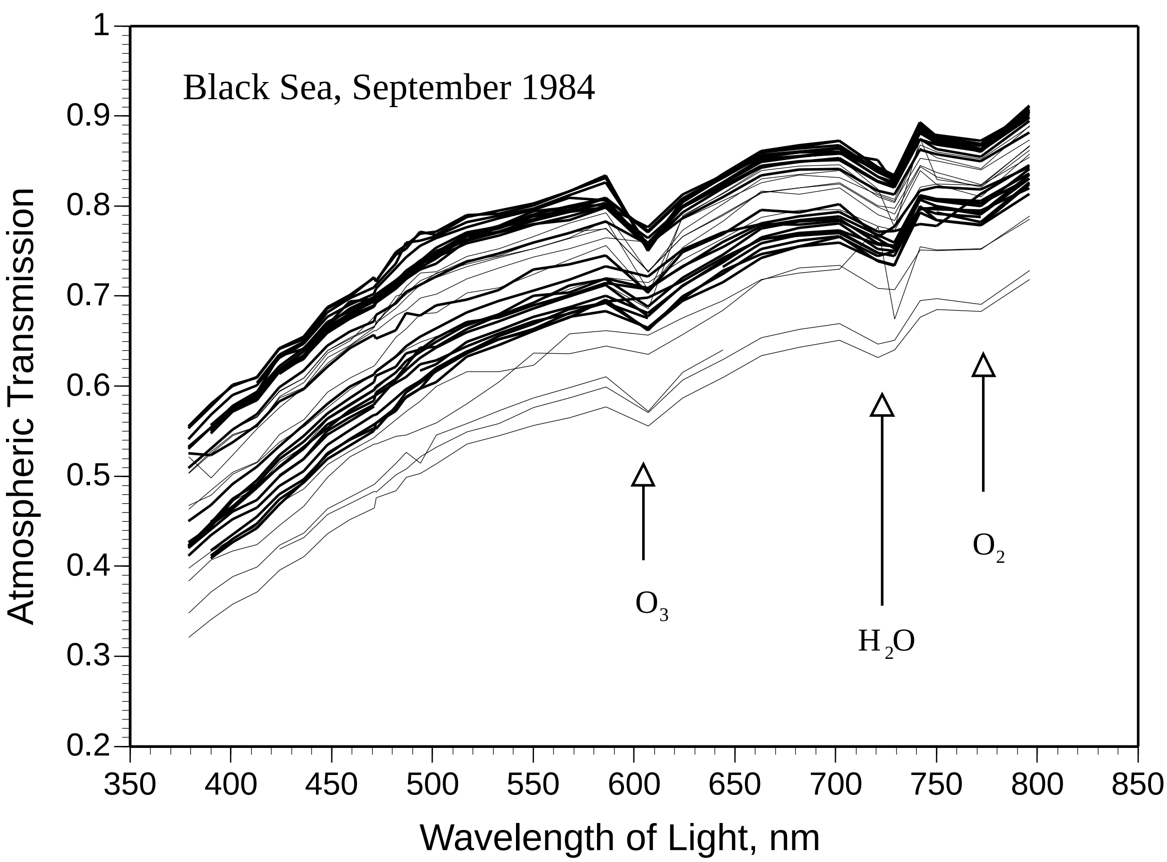

Fig. 1. Atmospheric transmission as defined by Eq. (1).

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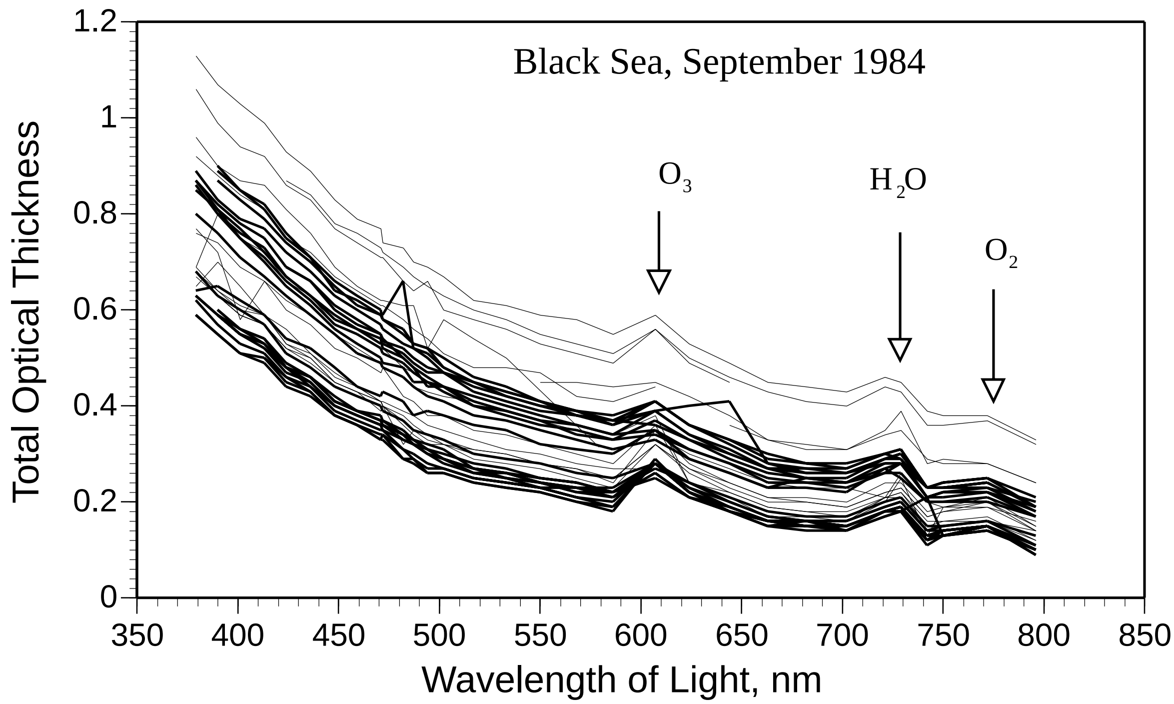

Fig. 2. Total atmospheric Bouguer optical thickness.

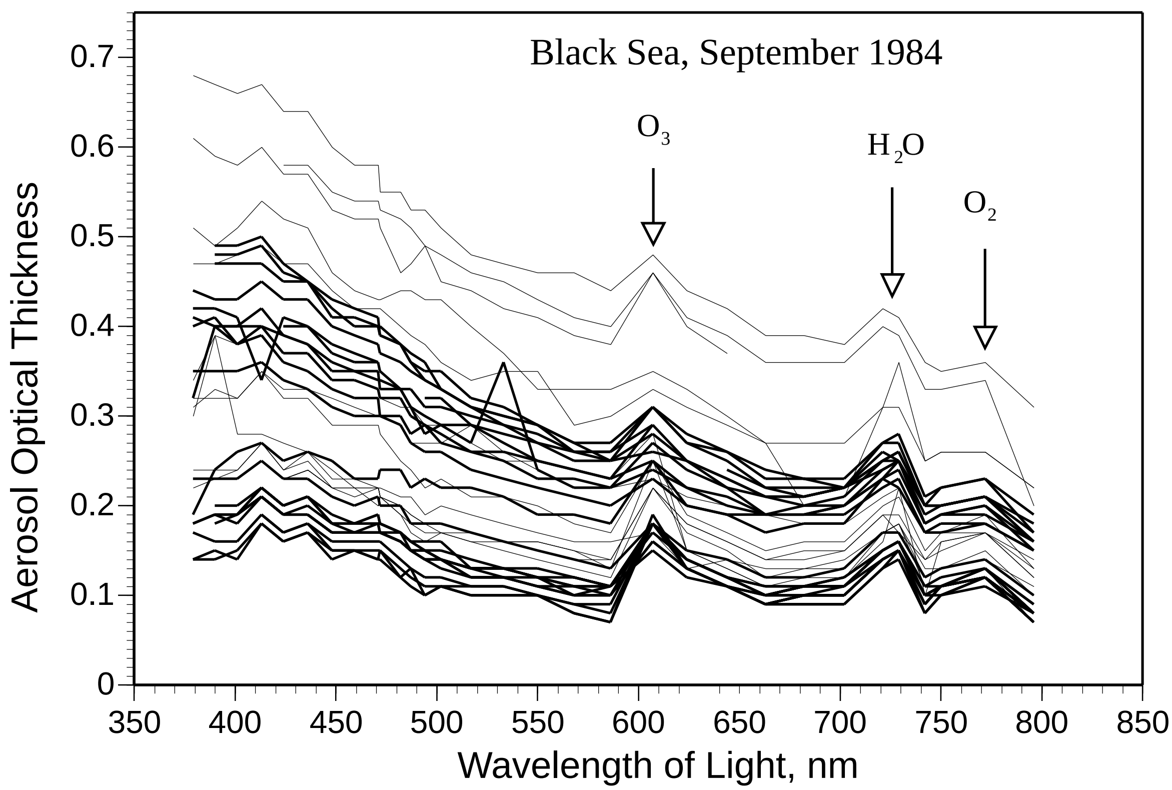

Fig. 3. Total aerosol optical thickness.

3. RATIO OF DIRECT SOLAR RADIATION TO THE DIFFUSE ONE

For many remote sensing applications ratio of direct solar to diffuse irradiances (RDDI) plays significant role [9] because it determines such important parameters as remote sensing and diffuse reflectance of the sea [10–12].We define the following two RDDI parameters:

– ratio of direct solar radiation on a surface normal to solar rays $E_S^{\perp}$ to the diffuse radiation (irradiance) on the sea level E_D [12]:

$$q(\lambda) = E_S^{\perp}(\lambda)/E_D\,, \tag{4}$$

– ratio of direct solar radiation on a horizontal surface E_S to the diffuse radiation on the sea level E_D:

$$q^*(\lambda) = E_S(\lambda)/E_D\,, \tag{5}$$

Because solar irradiances are connected with the relationship, $E_S^{\perp}(\lambda) = E_S(\lambda)/\cos Z_{\otimes}$, the RDDI parameters are related with each other as follows:

$$q(\lambda) = q^*(\lambda)/\cos Z_{\otimes}\,. \tag{6}$$

Derivation of parameter q is given in Refs. [9, 13, 14] and Monte Carlo modeling in Ref. [15]. The values of parameter q^* measured with spectrometer “MKS-BS” are shown in Figure 4.

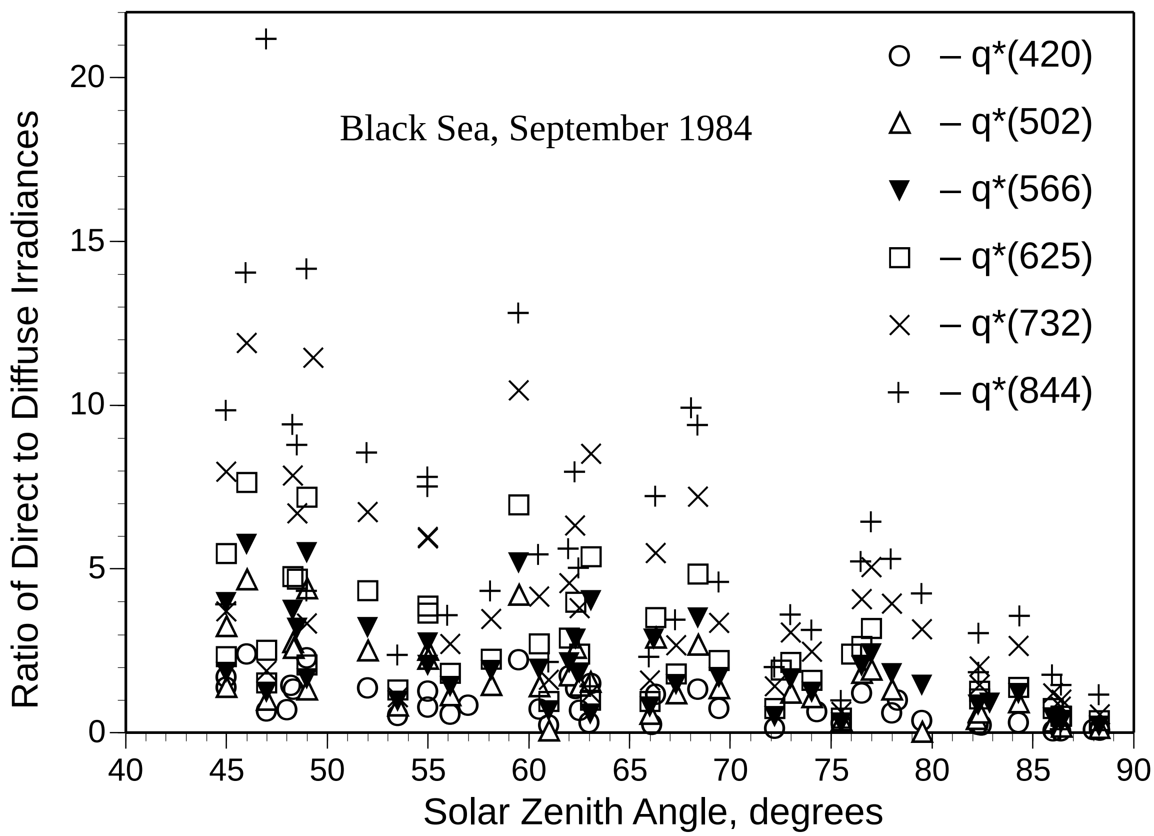

Fig. 4. Ratio of irradiance by direct sunlight to a diffuse irradiance by the sky as a function of solar zenith angle.

4. ALMUCANTAR RADIANCE INDICATRIX OF THE SKY

Normalized solar almucantar radiance indicatrix of the sky (aureole) $\mu(\psi)$ is defined by the following relationship:

$$\mu(\psi) = L_{sky}(\psi)/\tau_H \ , \qquad \tau_H = 2\pi\int_0^{\pi} L_{sky}(\psi)\sin\psi\, d\psi \ , \tag{7}$$

here $L_{sky}(\psi)$ is a sky radiance in solar almucantar, ψ is an angular distance from solar disk, $\mu(\psi)$ may be used to restore averaged over atmosphere phase function of light scattering [9] and aerosol particles size distribution [16]. Figure 5 shows almucantar radiance indicatrices for two wavelengths. Numerical values of radiance indicatrices for five channels (420, 502, 566, 625., 732, and 844 nm) measured at fifteen stations are given in Table 5. of Ref. [3].

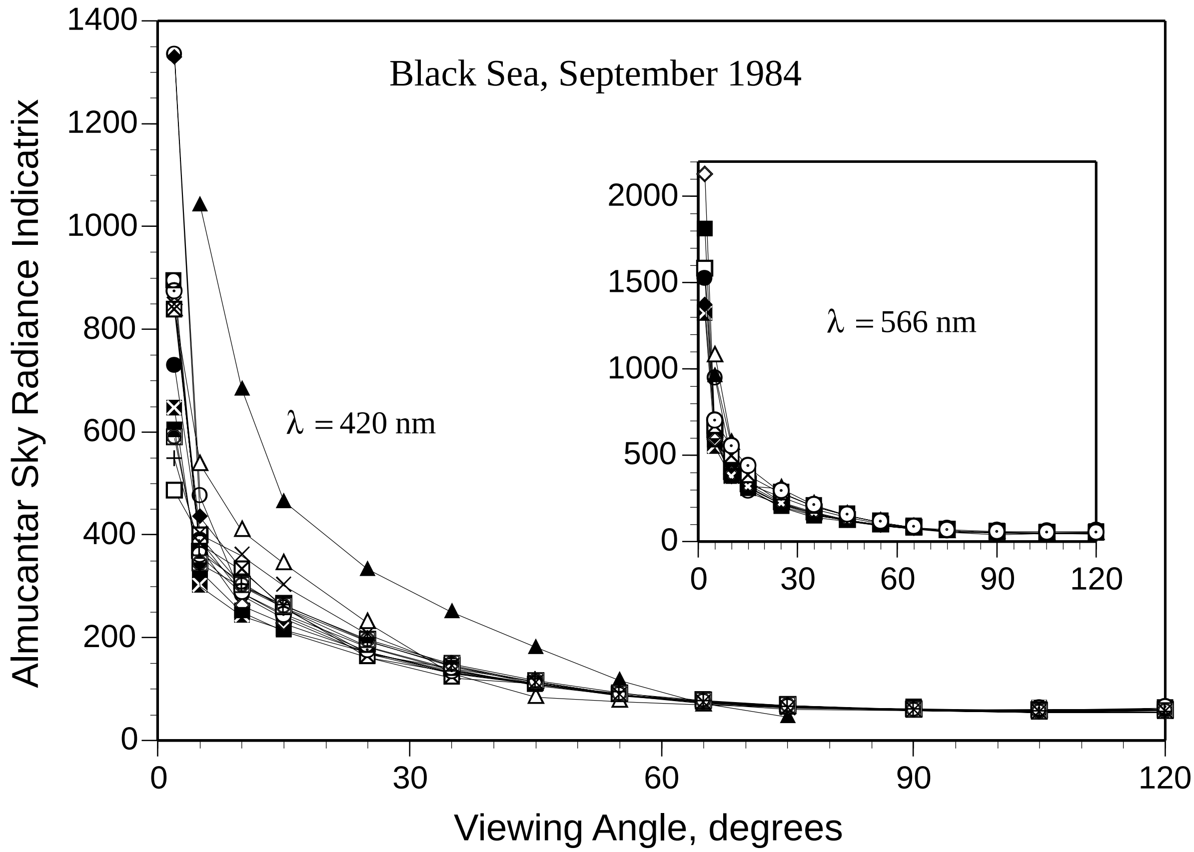

Fig. 5. Normalized almucantar sky brightness indicatrices for two wavelengths.

5. CONCLUSION

This paper describes results of the shipborne measurements of atmospheric optical parameters measured during the international marine experiment “Black Sea – Interkosmos-84”. The other two parts of this experiment include shipborne measurements of biological and optical parameters published earlier [1, 2] and measurements of atmospheric parameters from an airborne laboratory [17]. The whole set of data presented here and in Refs. [1, 17] constitutes unique set of experimental results suitable for enhancing algorithms of atmospheric corrections and restoring biological and optical properties from remote measurements.

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