GENERAL CHARACTERISTICS AND STATISTICAL PARAMETERS OF SPECTRAL TRANSMISSION OF THE ATMOSPHERE IN SOME REGIONS OF THE ATLANTIC

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We discuss the experimental data on the spectral transmission of the atmosphere along horizontal and vertical paths measured in some regions of the Atlantic during the 40th passage of the research vessel Akademik Vernadskii. The statistical characteristics of the variability of the visibility range and the optical thickness of aerosol in the marine atmosphere are studied in the spectral range 0.4–1.06 μm. *It is shown that the investigated regions of the Atlantic ocean can be divided into three specific districts which differ in the statistical properties of the above–mentioned parameters.*

Spectral transmission of the atmosphere along vertical and horizontal paths is the most important characteristic for the determination of both aerosol and gas composition and correct taking the atmosphere into account in the problems of spaceborne remote sounding.

One of the urgent problems is the investigation of the transmission of the marine atmosphere, whose aerosol composition has specific features.[1] In contrast to the continental, the marine aerosol was studied occasionally, in the limited number of regions, and with inadequate spectral resolution.[2] Recently the most complete data on the aerosol optical thickness (AOT) of the atmosphere have been obtained by authors of Refs. 3–5 but these data are insufficient for describing all the seasons and regions, because they have been obtained only for the limited number of regions over the Pacific and the Indian oceans and over the inland seas. At the same time, it is of interest to perform the similar measurements of the AOT in the regions that were already investigated by various authors in order to confirm or to disprove the discovered regularities in their behavior. The foregoing is true for the horizontal transmission of the atmosphere, especially due to the fact that it has been investigated only by the local nephelometric technique (see, e.g., example, Ref. 6).

In the present paper we discuss the experimental data on the spectral transmission of the atmosphere obtained in a number of regions of the Atlantic ocean and the Mediterranean during the 40th passage of the research vessel Akademik Vernadskii in 1989.

Aerosol optical thickness was measured by "long" Bouguer's method at five wavelengths (484, 552, 668, 705, and 1061 nm). Apparatus and methods of calibration, measurements, and consideration of Rayleigh scattering were discussed in detail in Ref. 7. A wavelength of 0.705 μm which lies in the region of the weak absorption band of H_2O was included to estimate the possibility of determining the total water–content of the atmosphere, but this problem remains outside the scope of this paper. The attenuation of radiation due to gases (H_2O and O_3) at other wavelengths was taken into account using the LOWTRAN–6 model.

The attenuation coefficient in the marine atmosphere was studied by the passive method[8,9] with the use of the IKOS device,[7] which was preliminary tested under coastal conditions. The test estimate of the error in determining the attenuation coefficient for coastal regions yield 0.04 km^{-1}. The measurements by the above–indicated method from onboard the vessel were carried out for the first time, and for this reason the error may increase up to 0.05–0.06 km^{-1} due to rolling and other factors. The measurements were made mainly in the spectral range visible to the eye (λ = 0.55 μm). In addition, in the 1st and partially in the 2nd regions the attenuation coefficients were measured with the use of the interference filters with the bandwidths centered at 0.43 and 0.67 μm which were later replaced by the combination of the pigmented glasses with the bandwidths centered at 0.48 and 0.66 μm, respectively.

Figure 1 shows the investigated regions and the passage of the vessel and the histograms of the AOT recurrences at a wavelength of 0.55 μm. The conditions of our experiments (regions, time, and meteorological conditions) are given in Table I.

In initial dividing the data into the typical regions the possible latitudinal features, influenced by the different types of the air masses, different continents, and possibly by the time trend during 20 and 40 days of observations (the 4th and 5th regions) were taken into consideration.

The horizontal transmission of the atmosphere was studied in the visible only at three wavelengths. The total number of days of observations was 41 while individual measurements lasted 204 days (at a wavelength of 0.55 μm).

The statistical parameters obtained by processing are given in Table II, while the histograms of the recurrences of various gradations of the meteorological visibility range (MVR) are shown in Fig. 2.

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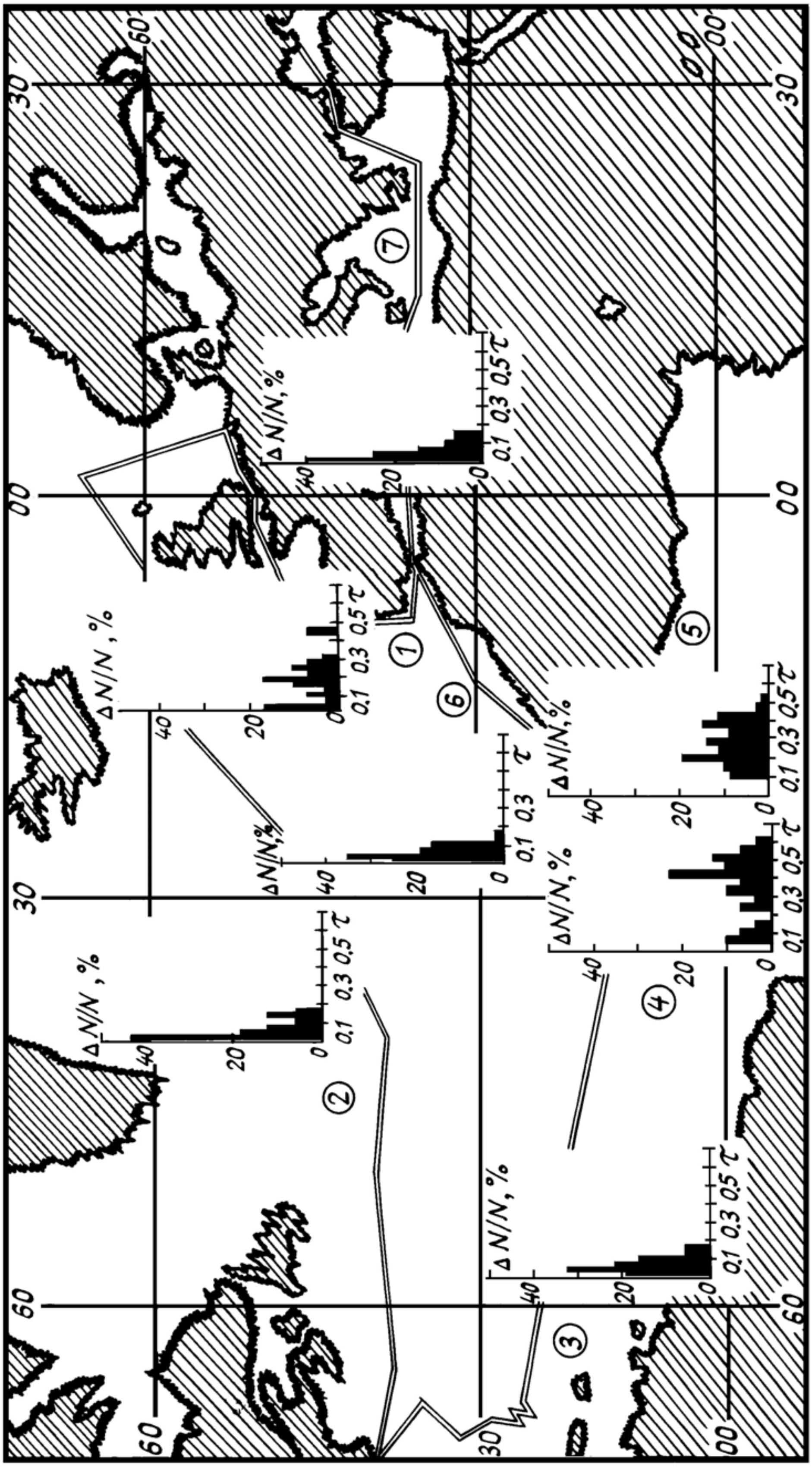

FIG. 1. Navigational chart showing the regions of our experiments and the passage of the scientific–research vessel and the histograms of the AOT recurrences.

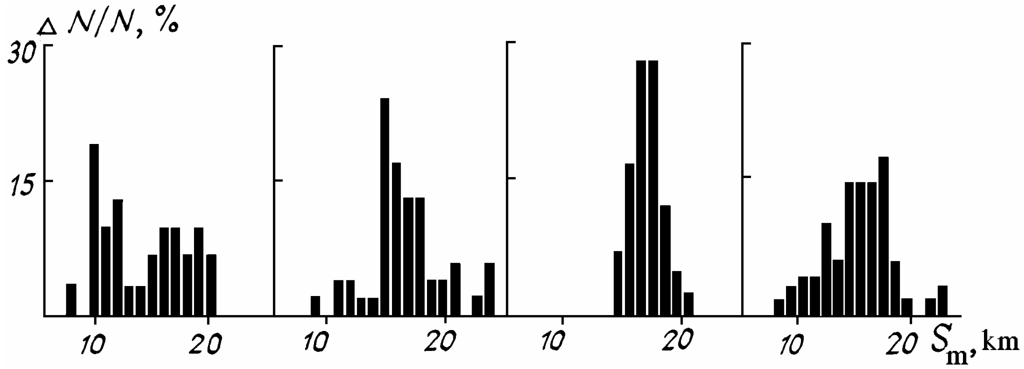

FIG. 2. Histograms of the MVR recurrences in different regions (from the 1st to the 4th regions, respectively.

TABLE I. Characteristics of the conditions of our experiments, 1989.

Serial number of the region	Region	Date	The number of days / The number of series	Meteorological conditions				
				Air temperature (°C)	Relative humudity (%)	Partial pressure of the water vapour (mbar)	Pressure (mbar)	Wind velocity (m/s)
1	The Western and Nothern coasts of the Europe	September 1–11	6/29	10.9–24.2	57–91	8.51–24.40	1012.7–1029.1	1.0–14.7
2	The Nothern and Central Atlantic	September 13–October 3	8/17	10.1–25.6	59–89	7.38–27.52	1004.4–1026.5	5.3–26.2
3	The Western part of the Central and Equatorial Atlantic	October 4–11 and 29–30	10/39	25.9–28.0	62–83	22.0–27.69	1009.9–1018.6	1.4– 12.7
4	Tropical Atlantic ("Dark sea"; the 1st polygon)	October 12–26	10/32	26.7–28.4	74–84	27.54–30.73	1009.1–1014.6	1.4–10.2
5	Tropical Atlantic ("Dark sea"; the 2nd polygon)	October 11 – December 4	13/85	22.5–28.5	76–88	23.06–31.09	1007.8–1041.9	0.6–10.9
6	The Nothern Tropic (The Nothern–Western coasts of Africa)	December 5–20	9/52	19.0–22.2	71–94	18.16–21.89	1012.7–1018.1	0.8–9.0
7	The Mediterranean	December 15–20	6/49	13.3–22.4	53–90	11.9–19.2	1015.7–1018.0	3.0–12.2
	Entire passage	September 1 – December 20	62/303	10.1–28.5	53–94	7.38–31.09	1004.4–1029.1	0.6–26.2

The analysis showed that the range of action in measuring the visibility range got narrower up to 25 km due to the low altitude (for the given method) of location of the IKOS device and due to the influence of rolling which cannot be entirely excluded. The results obtained for the visibility range varying from 8 to 25 km may be assumed likely and consistent with the data of previous investigations.

As expected, the atmosphere was clearest over the Western part of the Central Atlantic (the 3rd region). Stability of the "optical weather", i.e., small standard deviations and narrow histograms of the MVR distribution, was largely peculiar to the 3rd region.

The regions near the coasts of Europe and Africa (the 1st and the 4th regions, respectively) differ in the increased turbidity and instability of the atmosphere (broad histograms), influenced by the continents, i.e., by the industrial activity in the Europe and entrainment of dust carried out from the West Africa. The statistical parameters of the second region were intermediate in values.

TABLE II. Statistical characteristics of the variability of the light attenuation coefficients.

Serial number of the region	Characteristic	MVR, km	$\varepsilon_{0.43}$, km^{-1}	$\varepsilon_{0.48}$, km^{-1}	$\varepsilon_{0.55}$, km^{-1}	$\varepsilon_{0.66}$, km^{-1}	$\varepsilon_{0.67}$, km^{-1}	$\overline{\gamma}$
1	min	8.0	0.4	–	0.20	–	0.24	–
	average	13.67	0.53	–	0.31	–	0.34	–
	max	19.86	0.76	–	0.49	–	0.61	–
	Standard deviation	3.52	0.08	–	0.08	–	0.1	–
	N	31	17	–	31	–	16	–
2	min	8.9	–	0.19	0.16	0.12	–	1.15
	average	16.21	–	0.27	0.25	0.24	–	
	max	23.76	–	0.54	0.44	0.53	–	
	Standard deviation	3.15	–	0.09	0.05	0.09	–	
	N	54	–	25	54	24	–	
3	min	14.33	–	0.21	0.19	0.11	–	1.01
	average	16.96	–	0.24	0.23	0.24	–	
	max	20.03	–	0.3	0.27	0.35	–	
	Standard deviation	1.25	–	0.02	0.02	0.03	–	
	N	42	–	36	38	38	–	
4	min	8.3	–	0.19	0.18	0.22	–	1.08
	average	15.25	–	0.28	0.27	0.25	–	
	max	22.23	–	0.4	0.47	0.36	–	
	Standard deviation	2.86	–	0.05	0.06	0.03	–	
	N	70	–	62	70	64	–	

* Note. For the investigation of the 1st and partly the 2nd regions we used the filters with the bandwidths centered at 0.43 μm and 0.67 μm, respectively.

Estimations of the spectral behavior of ε_k showed that the ratio $\gamma = \varepsilon_{0.48}/\varepsilon_{0.66}$ lies within the limits 1.0–1.15. In addition, over the open ocean the neutral behavior can be seen (the 3rd region) while over the regions near the continent the dependence $\gamma > 1$ starts to be manifested. It may be explained by the fact that over the open ocean the aerosol attenuation is primarily caused by the coarsely dispersed fraction (marine aerosol) which determines the neutral behavior of the AOT in the investigated spectral range. When approaching to the continent the influence of the submicron fraction of aerosol became stronger and accordingly the dependence on the wavelength arises. We note for comparison that over the coastal regions of the inland sea[10] the spectral dependence was more pronounced ($\overline{\gamma}$ = 1.28–1.67) than over the ocean.

In the investigations of the AOT of the atmosphere the data with sufficient statistics were obtained with more adequate spectral resolution. In each region the total number of days of observations varied from 6 to 15 with the repetition frequency of the measurements being in the limits 0.5–2 h^{-1}.

The general behavior of variations in the AOT during the passage is shown in Fig. 3 while the main statistical characteristics of the variability of the AOT (average values $\overline{\tau^a}$ standard deviations (SD) σ_τ, coefficients of variation V_τ,) for 7 regions at the 5 wavelengths are presented in Table III.

It can be seen from Table III that the atmosphere was more turbid near the Western coast of Europe and "Dark sea" (the 1st, 4th, and 5th regions). The maximum values of the AOT (at λ = 0.55 μm) in these regions were equal to 0.46, 0.60, and 0.51, respectively. Just the same regions exhibited the maximum variability of the AOT that was manifested in the broad diagrams of the AOT recurrences (Fig. 1) and in the fact that their standard deviation was larger by a factor of 2 (σ_τ(1, 4, and 5) > 0.1, while σ_τ(2, 3, 6, and 7) ≤ 0.05). As to the average values and variances of the AOT, the results for the 1st region were close in value to the data obtained in Refs. 3 and 5 for the coastal regions and coincided with the value $\tau^a_{0.55}$ = 0.2 accepted in the standard radiation model.

The regions with the numbers 2, 3, and 6 may be regarded as merely oceanic with the smallest values of the AOT lying in the limits 0.01–0.03 and with the average values varying from 0.05 to 0.07. It is of interest to note, that decreasing the average value of the AOT by the factor of 4–6 (compared to the coastal regions) was followed by decreasing the variance while the variation coefficients remained practically unchanged.

The difference between the 1st, 4th, and 5th regions can be easy explained by their proximity to the continent and by the preferred directions of wind, which carries out the dust (mineral) fraction of the aerosol or the anthropogeneous aerosol from the continental to the marine atmosphere.

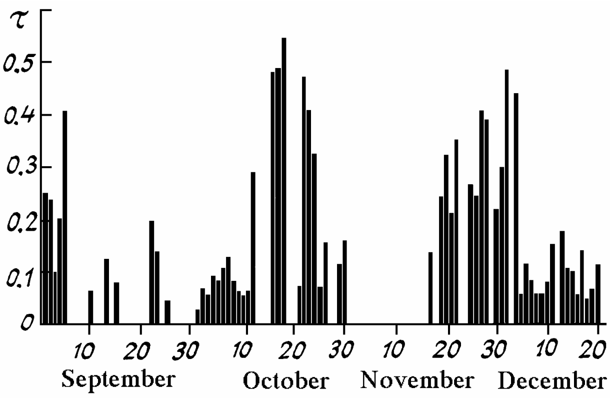

FIG. 3. Diurnal variations of the AOT at l = 0.55 μm.

TABLE III. Statistical characteristics of the AOT.

Region number	Characteristics	484 nm	552 nm	668 nm	705 nm*	1061 nm
	$\overline{\tau^a}$	0.26	0.20	–	0.13	0.06
1	σ_τ	–.21	0.13	–	0.12	–.06
	V_τ	0.82	0.62	–	0.88	0.95
	N	15	29	–	12	14
	$\overline{\tau^a}$	0.06	0.05	–	0.06	0.03
2	σ_τ	0.05	0.05	–	0.05	0.03
	V_τ	0.89	0.97	–	0.87	1.10
	N	16	16	–	15	16
	$\overline{\tau^a}$	0.08	0.07	0.05	0.13	0.04
3	σ_τ	0.04	0.04	0.04	0.04	0.04
	V_τ	0.50	0.59	0.82	0.31	0.98
	N	35	37	28	29	37
	$\overline{\tau^a}$	0.38	0.36	0.32	0.41	0.28
4	σ_τ	0.16	0.16	0.15	0.14	0.13
	V_τ	0.42	0.44	0.47	0.34	0.46
	N	31	31	31	31	32
	$\overline{\tau^a}$	0.32	0.28	0.22	0.30	0.18
	σ_τ	0.11	0.10	0.10	0.08	0.08
5	V_τ	0.36	0.38	0.43	0.27	0.43
	N	82	82	84	83	82
	$\overline{\tau^a}$	0.07	0.06	0.04	0.08	0.05
6	σ_τ	0.03	0.03	0.03	0.04	0.03
	V_τ	0.52	0.61	0.67	0.47	0.62
	N	47	48	50	49	49
	$\overline{\tau^a}$	0.07	0.06	0.05	0.06	0.04
7	σ_τ	0.04	0.04	0.04	0.05	0.04
	V_τ	0.67	0.77	0.93	0.71	1.08
	N	49	49	49	49	49
° "Ocean"	$\overline{\tau^a}$	0.08	0.07	0.05	0.09	0.04
2, 3, 6 °	σ_τ	0.04	0.04	0.03	0.05	0.03
	V_τ	0.58	0.65	0.71	0.24	0.79
	N	44	45	30	40	45
° "Dark-	$\overline{\tau^a}$	0.34	0.31	0.26	0.35	0.22
sea" 4 +	σ_τ	0.14	0.13	0.13	0.12	0.11
5°°	V_τ	0.39	0.42	0.49	0.34	0.49
	N	41	41	42	42	41
° "Coastal	$\overline{\tau^a}$	0.12	0.12	0.05	0.08	0.04
" 1 +	σ_τ	0.14	0.11	0.04	0.07	0.04
7 °	V_τ	1.11	0.90	0.78	0.85	0.94
	N	18	23	12	17	18

*Note. The absorption by the water vapor was not eliminated at the wavelenght 0.705 μm.

Characteristics of the AOT for the region of the Mediterranean (the 7th region) appeared to be similar to that for the oceanic (the 2nd, 3rd and 6th regions) and were underestimated in comparison with the data of Ref. 4. The above–indicated difference may be accounted for by the difference in the "optical weather" for different passages and by short period of our observations (6 days).

It follows from the analysis of the histograms of the AOT recurrences (Fig. 1) that the histograms are narrower and unimodular in oceanic regions. The histograms for the regions, influenced by the continents (the 1st, 4th, and 5th regions) are broad and multimodular. The same conclusions ca be made for the AOT at the other wavelengths, in addition, the considered regularities were more distinctly pronounced in the short–wave region of the spectrum, in which the variations in the average values and in the variances were larger.

Thus, all of the obtained data based on their sufficient statistics and their similarity make it possible to combine a number of regions into the characteristic zones and to analyze them individually. The 1st, 3rd, and 6th regions make up the 1st zone which included the open ocean of the Central and Northern Atlantic. The second zone, which included the Tropical Atlantic near the Western coast of Africa ("Dark sea"), consisted of the 4th and 5th regions, the data were obtained practically in the same region, but in different months. Finally, the 3rd zone included the data obtained for the coastal region (the 1st region) and for the inland sea (the 7th region). It follows from Table I that the number of the diurnal measurements of the AOT in different regions varied from 2 to 8, therefore, when combining the data into zones the appropriate statistical preprocessing of data was involved. First, the average values of the AOT for morning and afternoon measurements were obtained for each measurement day, and then the data set for three zones were formed.

It follows from the analysis for the three above–mentioned zones (the lower part of Table III) that statistical data differ in the average values, standard deviations, and variation coefficients. In addition, the average values and the variances of the AOT for the coastal district are intermediate between the zones of the "ocean" and "Dark sea" while the values of the variation coefficient turned out to be maximal. The average values and the standard deviations of the AOT exhibited the same spectral behavior while the variation coefficients varied irregularly.

When comparing the obtained data with the results of investigation published in Ref. 4, it should be noted that there are some discrepancies of these results although they are in general in good agreement. The atmosphere was found to be more transparent and variable for all the selected zones. The discrepancy in the average values was 10–30% while the values of the variation coefficients were twice as large as the corresponding values obtained in Ref. 4.

The histograms of the AOT recurrences for the zones under investigation are shown in Fig. 4. The single maximum of the most probable value $\tau^a_{0.55} \simeq 0.05$ stands out against the background of this dependence for the ocean zone. There are two maxima located near 0.38 and 0.26 which are typical of the two types of the "optical weather" in the data for "Dark sea"). The first maximum most likely corresponds to the atmosphere polluted by dust, while the second describes the background conditions in the zone at the intermediate time period. The probabilities of realizations of the two types of the "optical weather" are commensurate quantities. The first maximum practically coincides with that of Ref. 4 ($\tau^{max}_{0.55} \simeq 0.4$). The lack of the second maximum in the data published in Ref. 4, in our opinion, can be explained by the poor statistics of their investigations.

The shape of the histograms of the AOT recurrences is more complicated in the regions influenced by the continent (Fig. 4c). It is difficult to find the most probable values of the optical thickness of the atmosphere for the coastal regions because the optical weather of the atmosphere is influenced in the complicated manner by numerous variable factors. This is described by the multimodal shape of the histograms.

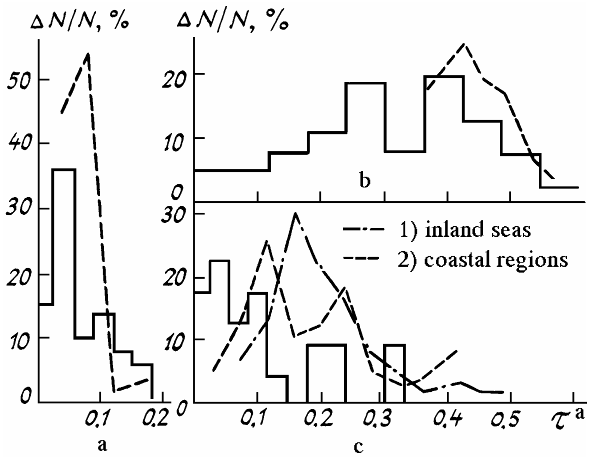

FIG. 4. Histograms of the AOT recurrences in different regions of the Atlantic: a) Northern and Central Atlantic, b) "Dark sea," and c) regions near the European Shore. Dot–dash and dashed lines show the results obtained by the authors of Ref. 4 under similar conditions (the open ocean, "Dark sea, " and the coastal regions).

Note that the marked discrepancies with the data of Ref. 4 have no fundamental significance, although the studies were not coincident in time and space (except for "Dark sea").

The study of the statistical parameters and histograms at other wavelengths showed the similarity of the analyzed regularities for the investigated regions of the ocean. In addition, the longer the wavelength (except for $\lambda = 0.705$ μm, at which the absorption by water vapor exists) the smaller was the average value and the standard deviation of the optical thicknesses. (In our next paper we will analyze the spectral features of the AOT in more detail).

The geometric height of the effective homogeneous layer of the aerosol $H_0 = \tau/\varepsilon$ permits one to retrieve the aerosol altitude distribution. In our study this value turned out to be $H_0 = 0.4 \pm 0.2$ km at $\lambda = 0.55$ mm in the ocean region (3) and $H_0 = 1.3 \pm 0.7$ km at "Dark sea" (4). Increase of H_0 agrees qualitatively with increase of the relative content of the mineral fraction of aerosol at altitudes of from 1 to 4 km, noted in Ref. 1 and influenced by the entrainment of the dust carried out from the Sahara. At the same time, the obtained values of H_0 are proved to be underestimated, for example, in comparison with the data of Ref. 11 in which H_0 varied from 1 to 3 km. It may be caused by the stronger effect of the coarsely dispersed fraction of aerosol (in our case) contained in the above–water layer which results in decrease of H_0.

CONCLUSIONS

1. Our investigations confirmed the IKOS measuring device may be applicable for estimating the horizontal transmission of the atmosphere from onboard the vessel. The general behavior of the obtained qualitative data on the atmospheric turbidities is in agreement with the recent data published by other authors. At the same time, to obtain the results in more detail and more reliable, it is necessary to modify the device, to improve the algorithm of reconstruction of the attenuation coefficients ε, and to extend the spectral range.

2. The atmosphere over the Atlantic can be divided into three characteristic zones in relation to the statistical parameters of the AOT, i.e., the open ocean, the coastal regions, and "Dark sea" (tropical zone of the ocean nearby the Western coast of Africa):

a) not only the maximum transmission but also the smallest absolute variability of the AOT is typical of the open ocean;

b) "Dark sea" is characterized by the maximum turbidity, small relative variability of the AOT, and by the two modes of the most probable values of the AOT associated with the two types of the optical and meteorological state of the atmosphere;

c) The AOT for the coastal regions occupies the intermediate position in relation to average values and standard deviations, but is characterized by the largest relative variability.

In conclusion the authors thank the group of meteorologists of the 40th passage (headed by V.I. Milovanov) for the data of meteorological observations used in the analysis of the results.

REFERENCES

1. K.Ya. Kondrat'ev, N.I. Moskalenko, and D.V. Pozdnyakov, *Atmospheric Aerosol* (Gidrometeoizdat, Leningrad, 1983), 224 pp.
2. A.V. Smirnov and K.S. Shifrin, in: *Physics of the Atmospheric Boundary Layer and its Applied Aspects*, Leningrad (1984), Vol. 85, pp. 121–127.
3. K.S. Shifrin, V.M. Volgin, B.N. Volkov, et al., Issled. Zemli iz Kosmosa, No. 4, 21–30 (1985).
4. V.M. Volgin, O.A. Ershov, A.V. Smirnov, and K.S. Shifrin, Izv. Akad. Nauk SSSR, Ser. FAO **24**, No. 10, 1058–1065 (1988).
5. O.A. Ershov and A.V. Smirnov, Issled. Zemli iz Kosmosa, No. 5, 3–8 (1986).
6. A.G. Laktionov, K.Ya. Kondrat'ev, V.N. Adiashkin, et al., in: *TROPEKS–74, The Atmosphere* (1976), Vol. 1, pp. 630–637.
7. S.M. Sakerin, A.M. Ignatov, and E.B. Shibanov, in: *Ocean–Space: Atlantika–89 Experiment*, VINITI, No. 4496–V90, (Izdatinlit, Moscow, 1990), pp. 11–35.
8. D.M. Kabanov and S.M. Sakerin, Izv. Akad. Nauk SSSR Ser. FAO **19**, No. 2, 147–155 (1983).
9. V.V. Veretennikov, S.V. Loginov, and S.M. Sakerin, Atm. Opt. **2**, No. 9, 832–834 (1989).
10. M.V. Kabanov, M.V. Panchenko, Yu.A. Pkhalagov, et al., *Optical Properties of the Coastal Haze* (Nauka, Novosibirsk, 1988), 201 pp.
11. V.N. Kapustin, E.M. Kozlov, G.N. Mart'yanova, et al., in: *TROPEKS–74, The Atmosphere* (1976), Vol. 1, pp. 638–643.