About the effect of the air mass type on aerosol optical thickness of the Northern Atlantic atmosphere

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Peculiarities of the aerosol turbidity of the atmosphere under conditions of different types of air masses (equatorial, marine tropical, marine mid-latitude, and continental) are considered based in the data obtained during two cruises of the Research Vessel *Akademik Mstislav Keldysh* in Atlantic Ocean. It is noted that the differences in spectral AOT of the atmosphere in different air masses are statistically significant. It is shown that the aerosol turbidity of the atmosphere in air masses of marine origin is appreciably determined by the influence of relative humidity of air and wind velocity.

Introduction

It is well-known that variability of the aerosol optical thickness (AOT) of the atmosphere over ocean is determined mainly by spatial inhomogeneities[1] and synoptic variations due to the change of air masses.[2,3] The effect of air masses on AOT of the marine atmosphere was considered earlier for Northern Atlantic,[4] Northern Sea, the northeast of Atlantic,[5] Baltic Sea, and Pacific Ocean.[6] However, the aforementioned investigations were carried out using quite short series of observations including changes of two to three air masses in the region of investigations.

This paper is devoted to revealing the differences in aerosol turbidity of the atmosphere over Northern Atlantic for different air masses based on the experimental data obtained during two Atlantic cruises of the Research Vessel *Akademik Mstislav Keldysh* (the 35-th cruise[7] in January–April, 1995 and the 39-th cruise[3] in August–September, 1996). Measurements of AOT were carried out within the wavelength range 0.37–1.06 μm. Determination of the type of air masses and the trajectories of their motion was carried out from the near-surface maps and the maps of baric topography. Measurements carried out in the region of dust aerosol emissions from Sahara were excluded. Finally, there were formed samples related to the following types of air mass: marine tropical (MTA), marine mid-latitude (MMA), and continental mid-latitude (CMA). Besides, for comparison, the measurements were attracted obtained in the equatorial part of Atlantic (EA). The total quantity of data was 413 hourly-averaged spectra of AOT accumulated for 62 measurement days.

Discussion of results

Consider the mean spectral dependences of the aerosol optical thickness $\tau^A(\lambda)$ in different air masses selected from the total data array (Fig. 1). It is seen that the main differences are observed in the short-wave range and are caused by different contribution of the finely dispersed aerosol.

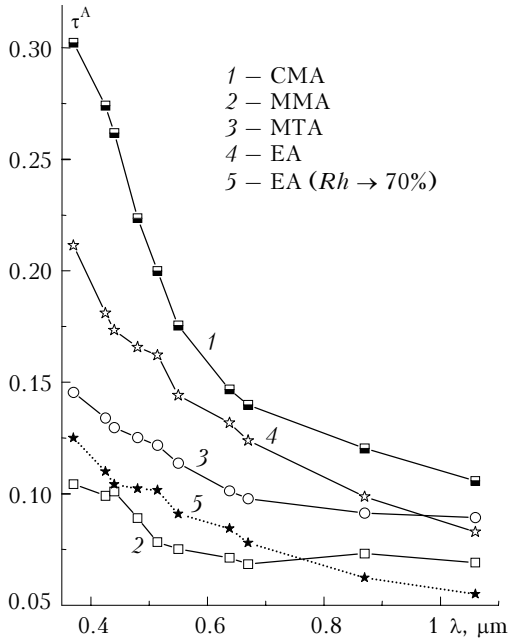

Fig. 1. Mean spectral dependencies of AOT of the atmosphere in different air masses.

The most selective spectral behavior of AOT corresponds to CMA and is caused by the effect of the fine aerosol of continental origin (Europe,

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Northern America). Three other spectra are related to marine air masses (equatorial, tropical, and mid-latitude). Spectral differences between them are determined, evidently, by the condensation mechanism, i.e., the growth of small saline particles under the effect of the relative air humidity. It is known that the scattering coefficient of aerosol particles of the marine origin is not changed at $Rh \le 75\%$ and grows as Rh increases.[8] In this case, most intensive condensation growth of fine particles is observed, that leads to the increase of selectivity of the aerosol scattering spectral behavior as the relative humidity increases. Similar dependences were also obtained for the aerosol optical thickness of the marine atmosphere.[2]

The greatest mean value of the air relative humidity ($\bar{R}h = (79 \pm 5)\%$) and, hence, the higher selectivity of the AOT spectral behavior corresponds to the equatorial air. Low humidity ($\bar{R}h = (67 \pm 8)\%$) and the spectral dependence close to neutral correspond to MMA. Spectral behavior of AOT in MTA ($\bar{R}h = (71 \pm 5)\%$) is intermediate. Note that the mean relative humidity in CMA is small ($(71 \pm 9)\%$). This confirms that the aforementioned high selectivity of the AOT spectral behavior is caused just by the fine continental aerosol emission.

The fact that AOT of the atmosphere in air masses formed over the marine surface is significantly determined by the relative air humidity[2,6] can be illustrated by reducing the values of τ_λ^Λ, obtained in EA, to the values corresponding to the relative humidity $Rh < 75\%$ using the dependence $\tau_\lambda^\Lambda(Rh)$ [Ref. 2]:

$$\tau_\lambda(Rh) = a_\lambda + b_\lambda Rh, \qquad (1)$$

where

$$a_\lambda = -0.521 - 4.68\exp(-3.89\lambda);$$
$$b_\lambda = 0.00747 + 0.0633\exp(-3.72\lambda).$$

As is seen in Fig. 1, the $\tau^\Lambda(\lambda)$ spectral behaviors in EA at $Rh < 75\%$ and MMA are quite close to each other. This confirms that the main differences between the aerosol turbidity of the atmosphere in marine mid-latitude and equatorial air are determined by the relative air humidity.

To compare quantitatively the spectral AOT of the atmosphere in different air masses, we, like authors of Ref. 6, selected two parameters: $\tau_{0.55}^\Lambda$ and α of the Angström formula:

$$\tau^\Lambda(\lambda) = \beta\lambda^{-\alpha}. \qquad (2)$$

The Angström parameter α characterizes the selectivity of the spectral behavior of AOT and $\beta \approx \tau^\Lambda$ (1 μm). Our estimates have shown that the differences between two samples, related to different air masses, are statistically significant with a confidence probability $p \ge 0.95$ for at least one parameter.

Note that quite good agreement of our data with the results of more complete investigations[6] available to data is observed in the mean values of $\tau_{0.55}^\Lambda$ and α. The values of $\bar{\tau}_{0.55}^\Lambda$ and $\bar{\alpha}$ in MMA are close to the data obtained in Pacific Ocean (Fig. 2), the parameters in CMA are intermediate between the data for northeast part of Atlantic and Pacific Ocean. In all cases, the passing from MMA to CMA is accompanied by the increase of $\bar{\tau}_{0.55}^\Lambda$ and $\bar{\alpha}$. The difference in the data for MTA can be explained by the contribution of marine aerosol generated under the effect of wind. The wind velocity during measurements in Pacific Ocean in MTA was higher than in MMA (7 and 4 m/s, respectively).

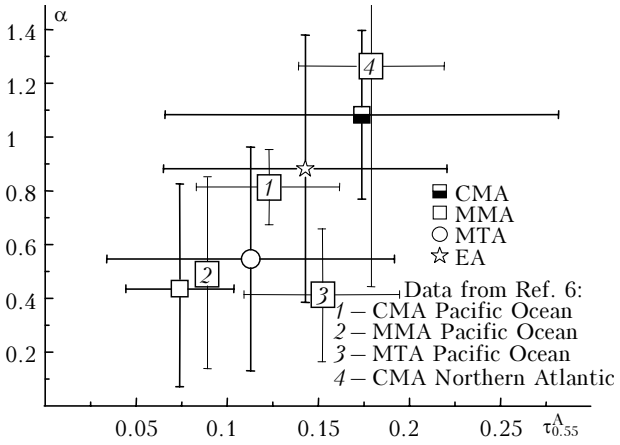

Fig. 2. Variability of $\tau_{0,55}^\Lambda$ and α.

In order to demonstrate that "wind" aerosol can make noticeable contribution into transparency of the marine atmosphere and, hence, hide the difference between air masses, consider two samples related to the open ocean in mid-latitudes. The spectral dependences of AOT in two types of marine air masses, mid-latitude and tropical, are shown in Fig. 3.

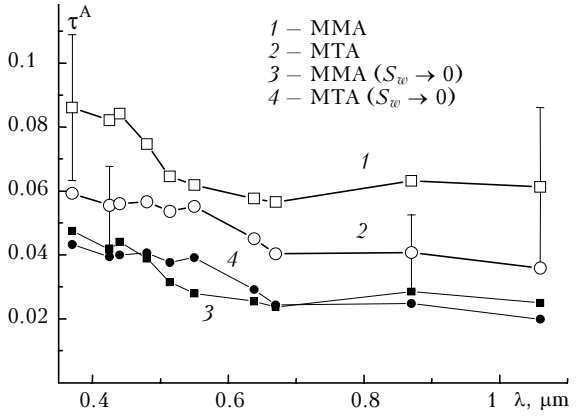

Fig. 3. Mean and reduced to $S_w = 0$ spectral dependences of AOT over open ocean in mid-latitudes under conditions of MMA and MTA.

The differences between mean values of $\tau^{\Lambda}_{0.55}$ and α for two samples are insignificant ($p = 0.95$). At the same time, AOT of the atmosphere in conditions of MMA is greater than in MTA, that disagrees with the aforementioned results (see Fig. 1). Analysis of the meteorological parameters has shown that the mean values of the relative humidity in these samples almost coincide ($\bar{R}h = (72 \pm 3)\%$ for MMA and $\bar{R}h = (72 \pm 5)\%$ for MTA), but the wind velocities differ ($\bar{S}_w = (8 \pm 2)$ m/s for MMA and $\bar{S}_w = (4 \pm 2)$ m/s for MTA).

In order to check, how much the noted differences depend on the wind velocity, the measured values τ^{Λ}_{λ} were transformed into the values corresponding to $S_w = 0$. To do this, the dependence $\beta(S_w)$ presented in Ref. 2 was approximated by the polynomial

$$\beta(S_w) = \sum_{i=0}^{4} A_i S_w^i, \qquad (3)$$

where

$$A_0 = 0.01023;\ A_1 = 0.01299;\ A_2 = 0.00389;$$
$$A_3 = 3.70112 \cdot 10^{-4};\ A_4 = 8.55949 \cdot 10^{-6}.$$

Note that under the effect of the wind factor, generation of those large particles of marine aerosol is most intensive, which are characterized by the spectral dependence $\tau^{\Lambda}(\lambda)$ close to neutral. Therefore, the procedure of reducing τ^{Λ}_{λ} to its magnitude at $S_w = 0$ lies in excluding the constant "wind addition" of β calculated for the value S_w during the period of measurements. As it is seen in Fig. 3, the spectral dependences $\tau^{\Lambda}(\lambda)$ reduced to $S_w = 0$ practically coincide with each other, i.e., in this case the difference between $\bar{\tau}^{\Lambda}(\lambda)$ in tropical and mid-latitude air masses is connected just with the effect of wind velocity.

Taking into account the role of the relative humidity in formation of the atmospheric transparency in marine air masses (EA, MMA, and MTA), a possibility of estimating τ^{Λ}_{λ} from S_w and Rh was additionally considered. To do this, the values of AOT corresponding to the hourly mean values of S_w and Rh were calculated by Eqs. (1) and (3) and compared with the measured values. It is seen in the results presented in Fig. 4 that the coincidence of the calculated and measured values of AOT corresponds to the bottom of the "cloud" of points. The greatest contribution of other factors affecting the formation of the aerosol turbidity of the marine atmosphere is observed at small values of Rh and S_w (small values of the calculated AOT). As Rh and S_w increase, the difference between the calculated and measured values decreases.

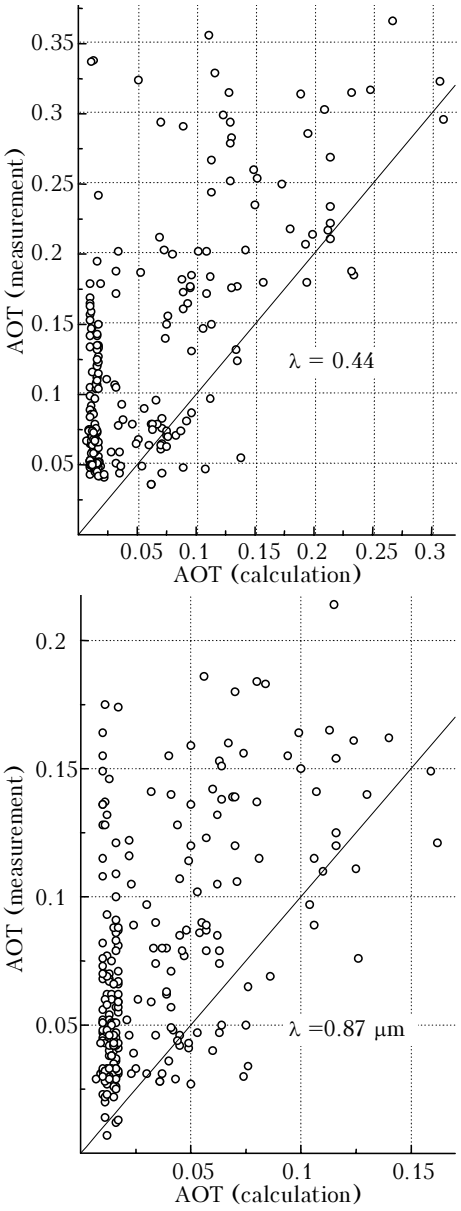

Fig. 4. Comparison of calculated and measured values of AOT of the atmosphere.

Conclusions

The main differences in AOT of the atmosphere in different air masses are observed in the short wave range, which is reflected in the spectral behavior selectivity:

CMA ($\tau^{\Lambda}_{0.55} = 0.175 \pm 0.108$; $\alpha = 1.09 \pm 0.31$),

EA ($\tau^{\Lambda}_{0.55} = 0.144 \pm 0.078$; $\alpha = 0.89 \pm 0.50$),

MTA ($\tau^{\Lambda}_{0.55} = 0.114 \pm 0.079$; $\alpha = 0.55 \pm 0.42$),

MMA ($\tau^{\Lambda}_{0.55} = 0.075 \pm 0.030$; $\alpha = 0.49 \pm 0.36$).

The difference between samples for different air masses is significant with a confidence probability no less than 0.95 for at least one of the parameters: $\tau^{\Lambda}_{0.55}$ or α.

The difference in the spectral AOT of the atmosphere in marine air masses is significantly determined by the effect of the relative air humidity characteristic for each type of air mass. At the same time, this difference can be hidden due to marine aerosol generated under the effect of wind factor.

Acknowledgements

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