Influence of wind conditions on aerosol extinction in the sea and coastal atmosphere surface layer

G.A. Kaloshin

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received August 18, 2006

Synchronous measurements of aerosol extinction $\alpha(\lambda)$ in marine environment show an increase of the sea salt aerosol concentration at a growing wind speed. At the same time, the opposite effect is observed in coastal conditions. There is a decrease of $\alpha(\lambda)$ at increasing wind speed in the sea and coastal surface layers. This means that the change in the scattering value can be described (when ignoring the effects of the second order at high wind speeds) by a source modulated by the changing wind speed and direction. The hypothesis is proposed, which is proved by results of calculations by the author's aerosol model allowing an explanation of this visible contradiction. It is offered to use the fetch for the explanation. It is shown, that at small fetch (coastal conditions) and increasing wind speed, there is a decrease of aerosol extinction $\alpha(\lambda)$ in the spectral wavelength range $\Delta\lambda = 0.2–12$ μm, and at big fetch (marine condition) an increase of $\alpha(\lambda)$ occurs at an increasing wind speed.

Introduction

It is well known that the coastal zone is characterized by complex processes of aerosol generation, especially at continental wind. Wind is an essential factor affecting the spectral dependence of the aerosol extinction in the near-water layer of marine and coastal atmosphere. The mechanisms of the effect of wind on aerosol extinction are essentially different under coastal and marine conditions (conditions of open water). The surf zone strongly affects the air mass up to several tens of kilometers. According to the model estimates, the concentration of "surf" aerosol decreases by an order of magnitude at the distance of 25 km downwind. The $\alpha(\lambda)$ value in the surf zone can be by up to two orders of magnitude greater than that under marine conditions.[1] Vertical gradient of $\alpha(\lambda)$ also can be stronger than under marine conditions.

To date, the composition of the mixture of particles of marine, surf, and continental origins is poorly studied, in spite of the fact that aerosol investigations in coastal zone have a long history. Chemical composition of continental particles is also poorly studied. It is difficult to take into account the contribution of the surf zone. Besides, coastal regions are inhomogeneous. The available database of aerosol microphysical and optical characteristics is limited in the range of meteorological conditions, season, and geography.

At present, it is objectively difficult to control for all aforementioned processes; sometimes it is unclear, by means of which parameters it can be done; for example, how to record the surf zone or topography of the coastal zone. So, the explanation of one or another physical process in many cases has a qualitative character.

The study of the wind effect is important in solving the radiative problems and in the problems of forecasting the energy extinction of optical radiation when estimating parameters of optical-electron devices and systems.

The main attention in this paper is concentrated on the results of simulation of the aerosol extinction peculiarities under the wind effect in specific coastal region, where the effect of surf zone is strong and where the properties of marine and continental aerosol are coupled.

1. The effect of wind under marine conditions

It was shown[1–5] that the $\alpha(\lambda)$ increase is observed at the increase of the wind velocity under open ocean conditions. The most essential increase of $\alpha(\lambda)$ occurs, when the wind velocity exceeds 7–8 m/s. Authors explain this by the fact that, starting from this velocity, the salt aerosol concentration dramatically increases, which is the result of appearance of surfs on the sea surface, that, in turn, is connected with the increase of the wind velocity. This corresponds to moderate wind of 3–4 balls on the Beaufort scale.

The revealed wind velocity dependence of the extinction coefficient increase was confirmed later by microphysical measurements of the marine aerosol accompanied by nephelometric measurements of the aerosol scattering $\sigma(\lambda)$ at wavelengths of $\lambda = 0.45$, 0.55, and 0.7 μm [Ref. 6] and by microphysical measurements[7] accompanied by lidar measurements at wavelengths of $\lambda = 0.53$ and 1.04 μm [Ref. 8]. It is meant here that $\alpha(\lambda)$ and $\sigma(\lambda)$ practically coincide in the aforementioned wavelength range. It was also

0235-6880/07/07 523-05 $02.00

shown[7] that this dependence is linear in the wind velocity range $U = 5 \div 12$ m/s (Fig. 1, curve *1*).

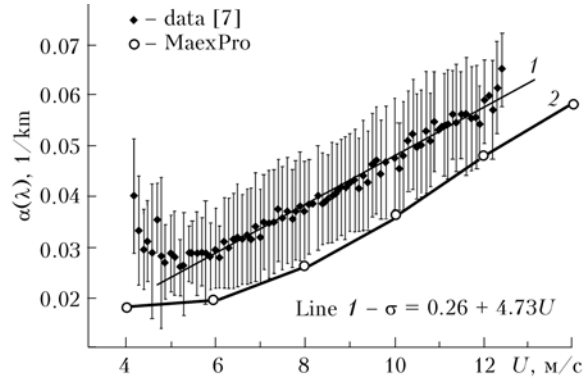

Fig. 1. The dependence of aerosol extinction coefficient $\alpha(\lambda)$ on wind velocity U under marine conditions: *1* is linear regression of experimental data[7] at the correlation coefficient $R = 0.989$; circles (curve *2*) are results of calculations by Maexpro model[9–12] for: the measurement height $H = 5$ m, the relative humidity $f = 80\%$, the wavelength $\lambda = 0.55$ μm, and the fetch $X = 120$ km.

For comparison, Figure 1 shows the calculation results obtained by the microphysical model MaexPro (**M**arine **a**erosol **e**xtinction **pro**file)[9–11] and the software package of the same name[12] at the input parameters close to or coinciding with the experimental conditions.[7] The fetch is the distance on the open water, on which generation and transfer of aerosol particles occur. This parameter characterizes the size of the area and the intensity of generation of the marine salt aerosol. The fetch can be determined using the map of the measurement region on the required scale with the grid and the known wind direction. The distance from one coast downwind to the measurement site (in km) is the fetch, or the distance on the open water from the windward side. The application range of fetch in the aerosol model Maexpro is 3–120 km.[9–11] Note that selection of the wind velocity is limited by the range of applicability of the model by this parameter, equal to 3–18 m/s.[9–11] The results of calculations approximated by curve *2* show the same as in the experiment tendency of the aerosol extinction coefficient increase with the wind velocity.

2. The effect of wind under costal conditions

In Ref. 7, together with the revealed dependence of $\alpha(\lambda)$ increase at increasing U under marine conditions, the opposite dependence was revealed for the coastal zone, namely: the decrease of the salt particle concentration at increasing wind velocity in the range $U = 5$–12 m/s. The dependence was called the Dilution effect. The experimental data[7] were obtained in the framework of the international complex program SEAS (The **S**horeline **E**nvironment **A**erosol **S**tudy) realized at the southeast coast of the Oahu Island, Hawaii. The duration of continuous measurements was more than 80 days.

The revealed regularity of decreasing $\alpha(\lambda)$ at increasing wind velocity[7] is illustrated in Fig. 2. The results of calculations by the model MaexPro are also shown here for comparison. The results of calculations (line *2*) confirm the experimentally revealed tendency of decreasing the aerosol extinction coefficient at increasing wind velocity.

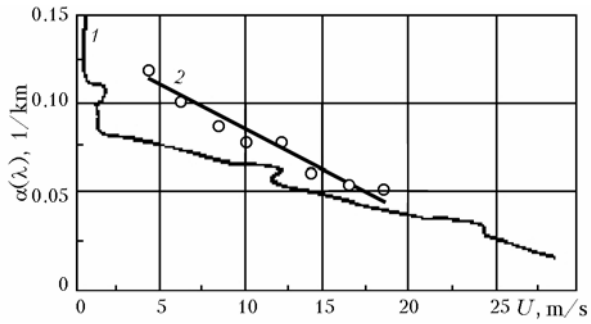

Fig. 2. The dependence of $\alpha(\lambda)$ on the wind velocity U under coastal conditions: curve *1* is experimental data[7]; circles are results of calculations by Maexpro model[9–12] for: $H = 20$ m; $f = 80\%$; $\lambda = 0{,}55$ μm; and $X = 3$ km.

The authors[7] explain this effect by the peculiarities of interaction of the wave field with the coastal line relief. The effect is that, under coastal conditions, as the wind velocity increases, an ever-increasing air volumes are transferred during unit time over the generation source region (surf zone). The aerosol concentration is mixed (dissolved, diluted) inside large air volumes, ignoring the effects of second order appearing at high wind velocities. So, the linear decrease of $\alpha(\lambda)$ is observed at increasing wind velocity near the coast. The authors[7] do not accent attention on the $\alpha(\lambda)$ behavior at $U = 4$–5 m/s, obviously, assuming these measurements not quite reliable.

Analysis of Ref. 13 and 14 also shows the tendency of decreasing $\alpha(\lambda)$ at increasing wind velocity, at least, in the IR wavelength range under coastal conditions. However, in our opinion, insufficient statistics of measurements does not allow one to draw reliable conclusions relative to $\alpha(U)$ behavior in the visible wavelength range.

Note that, when measuring $\alpha(\lambda)$ spectra under breeze wind conditions, authors[13,14] mistakenly thought that they dealt with marine aerosol under "stable wind from seaside." In reality, neither the shape of $\alpha(\lambda)$ spectra, nor their difference at the wind direction change (sea – continent) confirm this fact.

3. Discussion of the results

The virtual contradiction in aerosol extinction under marine, open water, and coastal conditions (appearance of the Dilution effect) can be explained if to assume that the greater fetch values correspond to marine conditions,[9,10,15,16] and small fetch values correspond to coastal conditions.

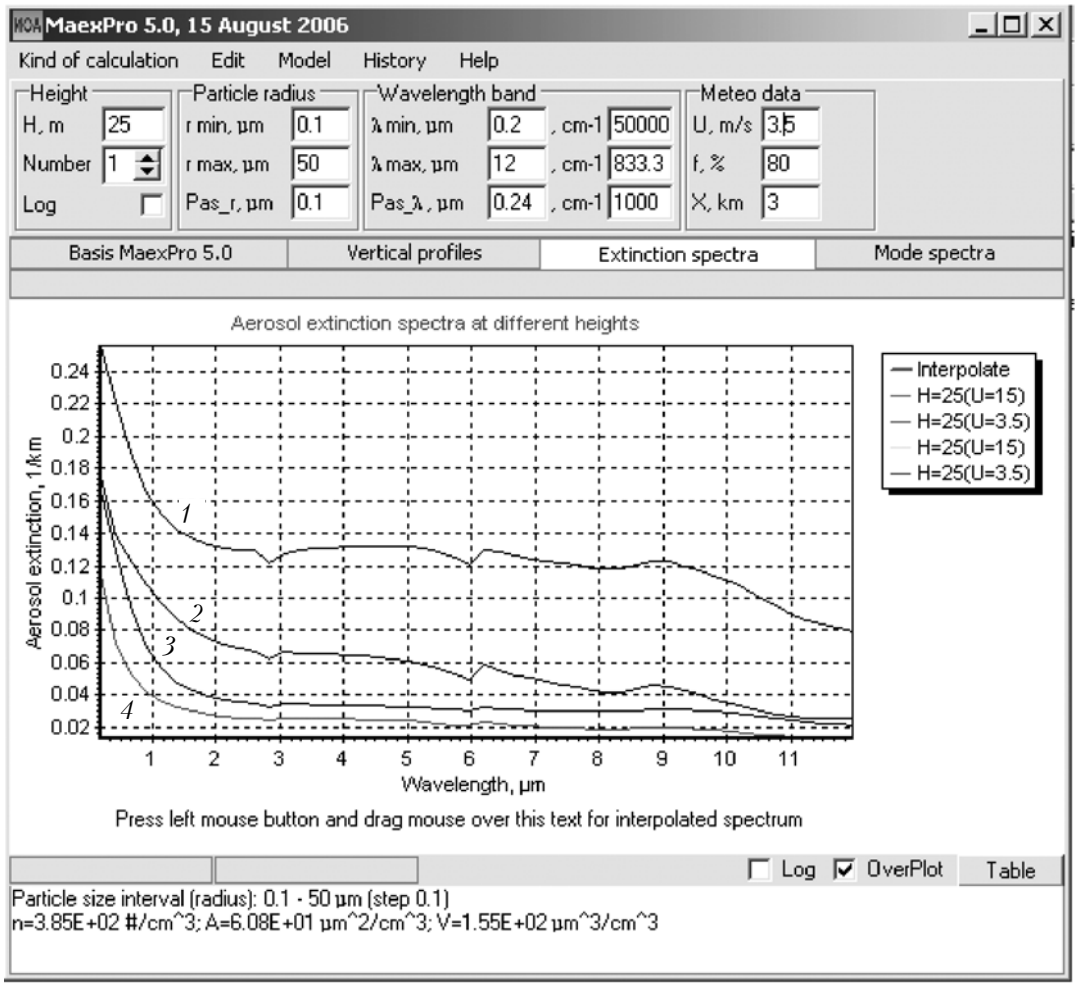

Fig. 3. Spectra $\alpha(\lambda)$ for different U and X calculated by microphysical model Maexpro[9–12]: U = 15 m/s, X = 30 km (curve *1*), U = 3.5 m/s, X = 3 km (curve *2*); U = 3.5 m/s, X = 30 km (curve *3*), and U = 15 m/s, X = 3 km (curve *4*).

Spectral behavior of $\alpha(\lambda)$ is shown in Fig. 3.

Curves *1* and *3* show that at large fetch X = 30 km (marine conditions) $\alpha(\lambda)$ increases with the increase of U from 3.5 to 15 m/s. On the contrary, at small X = 3 km under coastal zone conditions (curves *2* and *4*) $\alpha(\lambda)$ decreases at increasing U from 3.5 to 15 m/s. The Dilution effect is observed. Consider this in a more detail.

3.1. Spectral behavior of $\alpha(\lambda)$ under coastal zone conditions (X = 3 km)

It is well known that the coastal zone conditions are characterized by significant concentration of submicron aerosol of continental origin, which dramatically decreases with the increase of the coastal aerosol particle size. It is illustrated in Fig. 4, in which it is seen that the spectrum *2* is steeper than the spectrum *1* [Ref. 16].

Physical explanation of this fact can be as follows. The relative concentration of submicron fraction increases at a small fetch and increasing wind velocity from 3.5 to 15 m/s with a simultaneous decrease of the aerosol coarse fraction. The increase of generation of the coarse fraction from breaking wave ridges is compensated by dilution by continental particles due to advection. It is observed in the $\alpha(\lambda)$ spectral behavior, which becomes more pronounced especially in the visible wavelength range, that is a characteristic of the continental aerosol with small concentration of particles of coarse fraction.

In this case, the effect of sea on the particle size distribution is less significant in comparison with the effect of surf zone. This occurs due to development of the process of emission and gradual removing of aerosol particles at a weak wind. The decrease is observed at all wavelengths, and, which is more important, at short wavelengths, where fine (continental) aerosol makes the main contribution into $\alpha(\lambda)$. Emission of the fine aerosol is not balanced by the equivalent generation of marine aerosol at such a short fetch. Note that here $\alpha(\lambda = 3 \div 5\ \mu m) > \alpha(\lambda = 8 \div 12\ \mu m)$.

Thus, $\alpha(\lambda)$ in the wavelength range $\Delta\lambda$ = = 0.2–12 μm decreases at a small fetch at the increasing wind velocity.

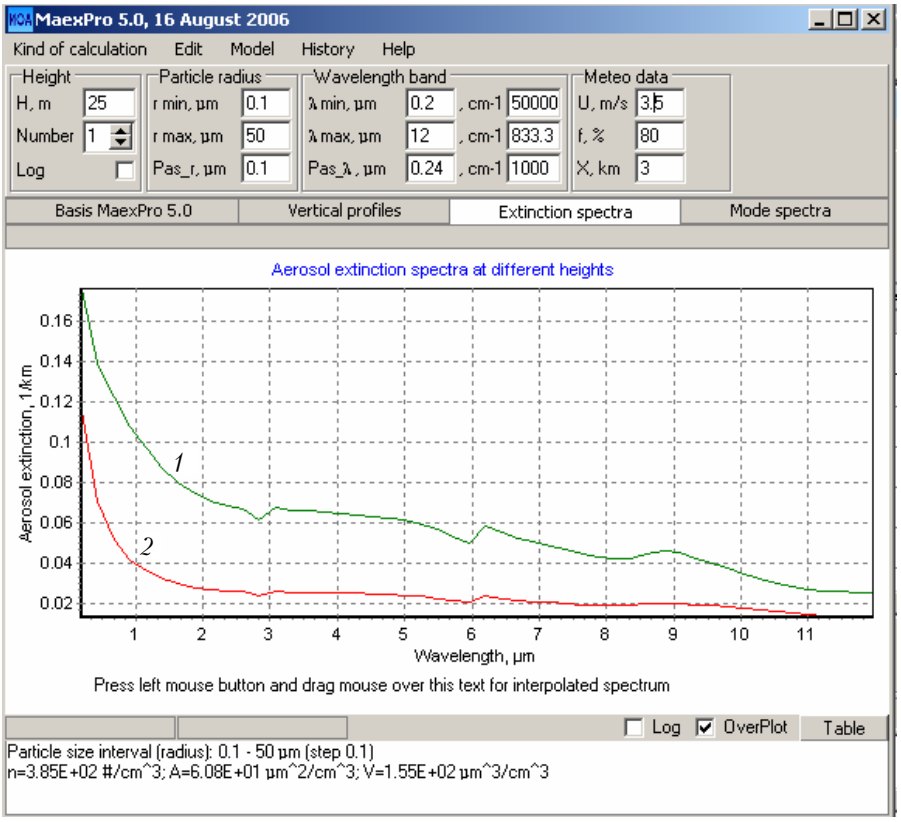

Fig. 4. Spectra of $\alpha(\lambda)$ under coastal zone conditions calculated by microphysical model Maexpro[9–12] for $U = 3.5$ and 15 m/s, curves *1* and *2*, respectively.

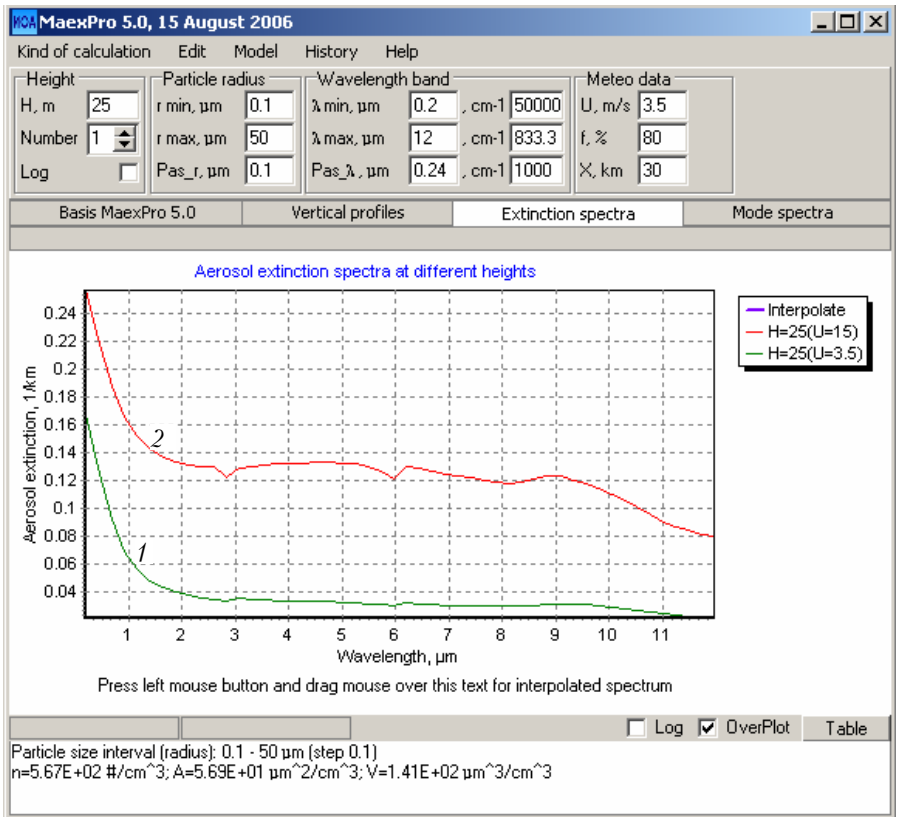

Fig. 5. Spectra of $\alpha(\lambda)$ under marine conditions at $X = 30$ km calculated by microphysical model Maexpro[9–12] for $U = 3.5$ and 15 m/s, curves *1* and *2*, respectively.

3.2. Spectral behavior of α(λ) under marine conditions (X = 30 km)

Three principal mechanisms of marine aerosol generation work successfully under marine conditions at the increasing wind velocity. There are film and jet mechanisms at U = 0–5 m/s, and the foam mechanism is iniciated, when wind velocity reaches about 7–8 m/s, at which droplets are torn directly from wave ridges, in contradiction to two former mechanisms of particle generation from films of breaking bubbles and jet droplets. Relative concentration of the aerosol coarse fraction essentially increases at wind velocity more than 7–8 m/s, and α(λ) dramatically increases with increasing fetch. It is illustrated in Fig. 5, where the increase of α(λ) in the wavelength range Δλ = 0.2–12 μm with increasing wind velocity is shown.

It can be supposed that the increase of the coarse fraction generation from breaking wave ridges is not compensated by dilution by continental particles due to advection. Besides, the increase of α(λ) at increasing wind velocity starting from 7 m/s is explained by increasing generation of salt aerosol, which is the result of appearance of surfs on the sea surface, which, in turn, are connected with the increasing wind velocity.

In this case $\alpha(\lambda = 3 \div 5\ \mu m) \approx \alpha(\lambda = 8 \div 12\ \mu m)$.

Conclusions

Thus, the virtual contradictory in aerosol extinction under marine and coastal conditions depending on the change of wind velocity can be related to the value of fetch: α(λ) in the wavelength range Δλ = 0.2–12 μm decreases with increasing wind velocity at a small fetch (coastal conditions), and increases with increasing wind velocity at a great fetch (marine conditions).

References

1. A.H. Woodcock, J. Meteorol. **10**, No. 5, 362–371 (1953).
2. Y. Toba, Tellus **17**, No. 1, 131–145 (1965).
3. Y. Toba, Tellus **17**, No. 3, 365–392 (1965).
4. W.C. Wells, G. Gal, and M.W. Munn, Appl. Opt. **16**, No. 3, 654–659 (1977).
5. E.C. Monahan, C.W. Fairall, K.L. Davidson, and P.J. Boyle, Quart. J. Roy. Meteorol. Soc. **109**, No. 460, 379–392 (1983).
6. G. De Leeuw, F.P. Neele, M. Hill, M.H. Smith, and E. Vignati, J. Geophys. Res. D **105**, No. 24, 29,397–29,409 (2000).
7. A.D. Clarke and V.N. Kapustin, J. of Atmos. and Ocean. Technol. **20**, No. 10, 1351–1361 (2003).
8. J.N. Porter, B.R. Lienert, S.K. Sharma, E. Lau, and K. Horton, J. of Atmos. and Ocean. Technol. **20**, No. 10, 1375–1387 (2003).
9. J. Piazzola and G. Kaloshin, J. of Aerosol Sci. **36**, No. 3, 341–359 (2005).
10. G. Kaloshin and J. Piazzola, in: *Proc. of the 23rd Int. Laser Radar Conf.*, Nara, Japan (2006), pp. 423–426.
11. J. Piazzola, G. Kaloshin, G. De Leeuw, and A.M.J. Van Eijk, Proc. SPIE **5572**, 94–100 (2004).
12. G.A. Kaloshin, S.A. Shishkin, and S.A. Serov, in: *Proc. of XIII Int. Symp. "Atmospheric and Ocean Optics. Atmospheric Physics,"* Tomsk (2006), p. 136.
13. Yu.A. Pkhalagov, V.N. Uzhegov, and N.N. Shchelkanov, Izv. Akad. Nauk USSR. Ser. Fiz. Atmos. i Okeana **24**, No. 3, 324–327 (1987).
14. M.V. Kabanov, M.V. Panchenko, Yu.A. Pkhalagov, V.V. Veretennikov, V.N. Uzhegov, and V.Ya. Fadeev, *Optical Properties of Coastal Atmospheric Hazes* (Nauka, Novosibirsk, 1988), 201 pp.
15. G.A. Kaloshin, in: *Proc. of XII Joint Int. Symp. "Atmospheric and Ocean Optics. Atmospheric Physics,"* Tomsk (2005), pp. 138–139.
16. G.A. Kaloshin, in: Proc. of XIII Int. Symp. *"Atmospheric and Ocean Optics. Atmospheric Physics,"* Tomsk (2006), p. 125.