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Aerosol extinction spectral profiles in the marine atmospheric surface layer

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Introduction

The marine and coastal atmosphere surface layer appreciably determines radiation processes, and also processes of the conditions forecast and opportunities of the surface transmission. Besides represents significant interest of research of physical processes in the marine and coastal atmosphere surface layer for the further perfection, development and check numerous mesoscale models.

Aerosol extinction in the marine and coastal atmosphere is dominated by scattering and absorption due to atmospheric aerosol. This influences on a dependence of the optical radiation extinction is important for remote sensing in the boundary layer, cloud properties etc. Aerosols in the surface layer are important to large number of processes. In particular, they transfer water vapor, heat and matter through the air-sea interface, interact with the temperature and humidity fields by evaporation and condensation, scatter radiation, and may act as condensation nuclei in the formations of cloud and fog.

The greatest effects on near shore scattering extinction will be a result of sea-salt from breaking waves and variations in relative humidity. These influences will be superimposed upon aerosol generated by open ocean sea-salt aerosol that varies with wind speed.

The focus of our study is the optical radiation extinction due to aerosol in a specific coastal region. Taking into account known complexity of carrying out of corresponding experimental works, we undertake attempt of modeling of aerosol extinction in the marine atmospheric surface layer c with use MEDEX code (Piazzola, Kaloshin et al., 2003, 2004)[1,2,3].

The aerosols are also very important to the propagation electro-optical radiation through the atmosphere. The performance of electro-optical systems can be substantially affected by molecular composition and aerosol particles that scatter and absorb electromagnetic radiation. While the molecular extinction is relatively constant and can be calculated using propagation codes such as MODTRAN, influence of the aerosols are much less well characterized. It depends from many factors. The coastal zone is characterized by specific processes, which are necessary to better understand for the atmospheric models used in the EO propagation. In particular, surf zone is a very strong source for sea spray aerosol. Indeed, concentrations and optical properties (chemical composition) of aerosol particles into the atmosphere are very variable both in time and in space. Estimations show that at low to moderate wind speed the aerosol concentration over the surf are 1-2 orders of magnitude higher than over the open ocean.

1. The code Medex

The code MEDEX consists of the Mediterranean coastal aerosol model (see below) coupled to a Mieprogram. The extinction coefficient, $\sigma(\mathrm{km}^{-1})$, of electromagnetic radiation by aerosol particles is given by:

$$\sigma = \int Q(r, \lambda, m) \cdot [\frac{dN(r)}{dr}]\pi r^2 dr, \tag{1}$$

where $N(r)$ is the particle size distribution, i.e., the number of particles per cubic centimeters per microns, and $Q(r, \lambda, m)$is the extinction efficiency of a particle (assumed to be spherical) with radius r and complex refractive index m at wavelength λ. The choice of the values for the refractive index m has an important impact on the calculation of the aerosol extinction. Because the prevailing winds at the Mediterranean coastal site causes the air masses to spend considerable distance over water, MEDEX assumes that marine aerosols dominate the distribution. Therefore, the refractive index for sea salt as proposed by Volz[4] is used in the model. As mentioned above, The MEDEX model calculates the particle size distribution$N(r)$ from the Mediterranean aerosol model, but it is also possible to enter a measured aerosol size distribution. The output of MEDEX consists of the aerosol size distribution and extinction at a height of 25 meters. In addition, MEDEX offers an option to calculate the vertical profile of aerosol extinction, from 0 to 25 m height. The format of the output is compatible with the input format of MODTRAN, which allows MEDEX to supply MODTRAN with aerosol extinction parameters.

1.1. Aerosol size distribution in coastal environment

The prediction of the aerosol extinction depends on the accuracy of the aerosol size distribution model. The aerosols in coastal zones consist of a complex mixture of aerosol particles, i.e., a marine component generated at the sea surface by the interaction between wind and waves, and a continental contribution emitted from natural and/or anthropogenic sources. The aerosol mixture in coastal zones depends critically on the wind direction. Changes in the wind direction are accompanied by variations in meteorological parameters such as relative humidity, atmospheric stability and boundary layer height. In turn, this results in changes in the physical processes affecting aerosols (generation, transport, deposition), thus causing a great variability of the aerosol size distribution and composition. In particular, the variation in wind direction is accompanied by a change of fetch, i.e., the distance traveled over water by an air mass before reaching the measurement location. The fetch influences the whitecap coverage and hence the sea surface-generated particle concentration, since wave breaking is different for a fully developed sea compared to growing wave field periods.

1.2. The model for the Mediterranean coastal aerosol size distribution

The coastal aerosol model is based on a Mediterranean dataset that was acquired on the island Porquerolles near Toulon (France) between 2000 and 2001. The experimental data from Porquerolles were statistically analyzed to develop an empirical coastal aerosol model as a modification of the Navy Aerosol Model (NAM)published by Gathman.[5] A comparison between the Black Sea coast data and the Mediterranean model was proposed by Piazzola and Kaloshin[3] since the two coastal sites are often exposed to air mass transport with a large continental trajectory, and hence, with characteristics of mixed origin from the aerosol point of view. Indeed, the Black Sea is a quite closed sea with a strong influence of continental air masses coming from East or Southwest directions. This is quite similar to most of the wind conditions encountered in the Mediterranean site.

As in NAM[5], the particle size distribution$N(r)$of the coastal aerosol model, is calculated as the sum of modified lognormal functions (Eq. (**??**)), but the amplitudes of the various modes are parameterized as functions of fetch. Furthermore, as suggested by De Leeuw[6] and in accordance with the more recent Advanced Navy Aerosol Model (ANAM),[7] a fourth mode has been introduced to model the largest sea spray particles, i.e.,$N(r)$ is calculated as the sum of four modified lognormal functions:

$$dN(r)/dr = \sum_{i=1}^{4} \frac{A_i}{f} \exp\{(-C_i(\ln(r/fr_{oi}))^2\}, \quad (2)$$

where $i$gives the number of the lognormal component of $N(r)$, r_{0i} are the mode radii, i.e., r_{01}=0.03, r_{02}= 0.24, r_{03} = 2, r_{04} = 10 μm, $f$represents the dimensionless humidity growth factor .

and *Ai* and *Ci* denote the concentration (in cm-3 μm-1) and the width of the i^{th} mode, respectively.

Empirical relations for the amplitudes and widths as function of fetch and wind speed have been given by Piazzola et al.[8] These relations were obtained from regression analysis of the aerosol concentration and wind speed or fetch. As discussed in detail elsewhere,[1,2,3] the variation of the particle concentrations with the wind speed results from the relative contribution of both marine and land-originated aerosol. For larger fetch, the marine-originated particles prevail, resulting in a larger (positive) slope of the concentration/wind speed plots (increasing production with increasing wind speed). At shorter fetch, a relatively large fraction of the aerosol originates from overland. This is evident in the intercept of the concentration/wind speed plots, which exhibit a larger intercept with decreasing wind speed. This is due to the less efficient dispersion of the land-originated particles at lower wind speeds. In contrast with the Navy Aerosol Model (NAM) where the continental influence was limited to the first mode describing the smallest particles, the Mediterranean coastal model introduces the fetch in all modes. In this manner, coastal effects on the (larger) marine aerosols can also be taken into account. Such effects include the fetch-dependence of the wave field resulting in enhanced or reduced wave-breaking, and hence, marine aerosol production.

The fetch dependence of mode amplitudes A_2, A_3 and A_4 for the Mediterranean aerosol model was determined on the basis of the Porquerolles dataset using linear regression on the concentration *vs*. wind speed for particles of 0.24 μm, 2 μm and 10 μm radius. Having obtained the parameterization of mode amplitudes A_2, A_3 and A_4, the four widths, C_i, were obtained from a multi-variable fit to the experimental size distributions as function of wind speed and fetch. Optimization of the widths was obtained by assuming a limited range of variations of the mode radii, since they correspond to a physical characteristic of the aerosol size distributions. Subsequently, plots of the regression parameters (slopes and intercepts of the concentration/wind speed plots) versus fetch were fitted to an exponential function. This procedure resulted in mode amplitudes as functions of wind speed and fetch.

On the basis of more recent measurements on the island of Porquerolles,[7] the Mediterranean model was slightly modified to better take into account the aerosol size spectra measured for very short fetches, which represent complex conditions to model. This has been published in Piazzola and Kaloshin.[6]

2. Results and discussion

2.1. Influence of a humidity on aerosol extinction

Results of modeling show that the relative humidity (RH) has the most influence on $\sigma(\lambda)$. The variation of RH from 66% to 90% increases $\sigma(\lambda)$ twice. With the decrease of the humidity, the decrease of the value $\sigma(\lambda)$ is observed with a simultaneous alignment of the spectral behavior. In the range to 2 μm a significant spread of curves is observed while in the range 2 – 12 μm curves come together. With increasing the wind velocity the total particles concentration raises, with increase in a share of the large particles concentration. The increase of $\sigma(\lambda)$ is observed. In IR band $\sigma(\lambda)$ depends monotonically versus the wind velocity.

Therefore, we can draw the conclusion that the coarse particles, sea spray produced, are almost not varied in the range RH = 75 - 90%.

2.2. Influence of a wind on aerosol extinction

The variation of wind speed also strongly affects the value of $\sigma(\lambda)$. With increasing the wind speed $\sigma(\lambda)$ decreases in the IR band twice and in the visible range by $\approx$ 5%. In this case, the differences increase with decreasing RH.

The results connected with the Fetch effect at the variation of the wind speed are still unexpected. When the wind speed is equals 15 ms^{-1}, $\sigma(\lambda)$ increases with the rise of fetch. For RH = 90% $\sigma(\lambda)$ increases more than twice and for RH = 66% - more than four times. Curves become more sloping, especially it is observed in the visible spectral band due to the increase of the coarse particles concentration and at the wind speed, equals 3.3 ms^{-1}, $\sigma(\lambda)$ decreases. In addition, if the wind speed equal 6 - 8 ms^{-1} $\sigma(\lambda)$ ceases to depend from value fetch in the range 1 – 30 km.

In contrast to the effect of increased sea-salt production over open ocean due to wind speed rising above 6 - 8 ms^{-1}, we well see an opposite effect for production generated from near shore breaking waves. When wave breaking is occurring the effect of increasing wind is to pass more air over the source region per unit time such that concentrations of wave generated aerosol are lower with increasing wind speed. In the literature this effect has received the name dilution effect [9,10].

We can propose the following hypothesis, which explain this regularity. It is probable that the two processes are in competition; namely, at weak wind with rising fetch the relative concentration of submicron particles increases at simultaneous decrease of the coarse particles. The spectral behavior of the extinction coefficient is given by steeply sloping curve, typical for the continental aerosol, and then it decreases slightly with increasing fetch.

At wind speeds $<$ 6 - 8 ms^{-1}character of waves flow of air are smooth. Air overtakes a wave. At the big wind speeds air lags behind it. Thus there are closed air circulations which limit carrying out of the coarse particles in higher layers of surface layer.

This underlines the known fact that the concentration of submicron particles of the continental zone is much higher than in the coastal and sea zones. Therefore, the spectral behavior of $\sigma(\lambda)$ is of more pronounced character. Under coastal conditions, this dependence is more elastic curve.

Besides, it should noted that the extinction coefficient in the visible and IR band varies simultaneous with the coarse particles whose optical manifestation through the scattering is expanding to the visible and IR band almost equally.

The experimental data also indicate that with decrease σ(0.55) the spectral behavior becomes more sloping. This indicates of increase of the relative contribution of the coarse particles to the extinction.

The results show the importance of the marine contribution for aerosol extinction in coastal areas. In turn, this induces a strong influence of the sea surface characteristics on the aerosol extinction.

Conclusion

This paper presents modeling data of the aerosol extinction coefficient obtained with help MEDEX code. This allows observation of the extinction at different wind speeds and two fetches. The results confirm the influence of the coastal characteristics on the extinction. In particular, they show the strong influence of the marine component of the coastal particle size distribution, which makes a substantial contribution to the total extinction in the coastal environment.

This means that the variation in scattering contributions from coastal breaking waves should be predictable for similar conditions and could be described by a constant source term modulated by a variable wind speed.

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