

INFLUENCE OF THE ATMOSPHERIC AEROSOLS ON THE ION DENSITY PROFILE UP TO 30 KM ALTITUDE

Yasuhiro MORITA and Haruji ISHIKAWA

Abstract

As one of the possible interpretation of deviation of the observed small ion density profile in the stratosphere from what is expected from small ion equilibrium theory we discuss the function of aerosols, which influences the ionization equilibrium. Numerically solving the equation of ionization of equilibrium for ion density, we have been able to see the influence of aerosols on ion density profile. The result of numerical calculation shows that the influence is not important above 15 km altitude, so far as we assume the total density of aerosols experimentally given by Junge et al. (1961). This seems to stress the importance of some factors other than aerosols in the stratosphere to interpret the deviation above mentioned.

1. Introduction

Aerosols in the atmosphere influence the physical state of the atmosphere in many ways, for example they influence the atmospheric electricity, optical nature of the atmosphere, cloud physics etc. and, after all, they are thought closely to be related with the meteorological conditions of the atmosphere. The small ion density in the atmosphere is much influenced by the submicron aerosols on the ground level where the contamination attains the maximum. In this respect the effect of aerosols on the atmospheric electricity may be said to be the most predominant in the lower part of the atmosphere, i. e. in the troposphere. The physical properties of the aerosol have been studied by many investigators in the recent years. The aerosol science was first comprehensively by Davies (1966). Ruhnke (1966) investigated the correlation of light scattering to the attachment of ions to aerosols and calculated the existence of correlation between the electric and the optical properties of a turbid atmosphere. It is well established that the concentration of aerosols decrease rapidly above the exchange layer. However the presence of aerosols in the upper atmosphere is indicated by a variety of the evidences. The geophysical phenomena which can be thought to be

relevant in some way to a function of aerosols in the upper atmosphere have been discussed at many instances, in particular, the occurrence of noctilucent cloud, mother-of-pearl cloud, twilight phenomena, and meteor showers. Junge et al. (1961) and Junge (1961) discussed concentration, size distribution, vertical profiles and origin of the stratospheric aerosols and showed that they have a concentration of about one aerosol per cm^3 for the size smaller than 0.1 micron radius. In respect to the upper atmospheric electricity, a rapid decrease observed in the stratospheric small ions with increasing altitude seems mainly to be caused by the presence of large size aerosols and this is reported by several authors. Whipple (1965) described that a aerosol density of about one aerosol per cm^3 one-micron size is sufficient to account for the decrease in the ion density above 30 km altitude. Paltridge. (1965) suggested that the decrease of the ion density will be affected by stratospheric aerosols.

In this paper, we will describe the result of numerical estimation of ion densities in the balloon altitude, which has been obtained by solving an equation of ionization equilibrium involving the aerosols and discussed the influence of atmospheric aerosols on the ion density profiles as one of the possible way of accounting for the observed deviation of small ion densities profile in the balloon altitude from what is expected from small ion equilibrium theory.

2. Fundamental Equations

We begin the discussion with equations which describe formation and loss of ions and assume that small ions which are formed in the atmosphere by the reaction of ionizing agents, will partly disappear by attachment to neutral or ionized aerosols, either of opposite or of same polarity as that of small ions, where as the main process of loss of ions is assumed to be ion-electron and ion-ion recombinations. The equations describing the ionic equilibrium can be written in an analogous form to Cole and Pierce (1965) and Whipple (1965), as follows,

$$\frac{dn_+}{dt} = Q - (En_+n_- + Bn_+n_e + F_+n_+) \dots\dots\dots(1)$$

$$\frac{dn_-}{dt} = An_e - (Dn_- + En_+n_- + F_-n_-) \dots\dots\dots(2)$$

$$n_+ = n_e + n_- \dots\dots\dots(3)$$

where, n_+ , n_- , and n_e are the densities of positive ions, negative ions and electrons, respectively. Q is the rate of production of electrons and positive ions, A is the attachment coefficient of electrons to neutral molecules to form negative ions, B is the recombination coefficient between electrons and positive ions, E is the recombination

coefficient between negative and positive ions, D is the detachment coefficient of electrons from negative ions and F_+ , F_- are the aerosol factors which relate with the attachment coefficient of ions to aerosols and number density of them. Bricard (1965) showed that, if all the aerosols are monodisperse, the aerosol factor, F_+ , F_- can be expressed as follows,

$$F_+ = \beta_0^+ N_0 + \sum_{p=1}^{\infty} (\beta_{i,p}^+ N_p^+ + \beta_{a,p}^+ N_p^+) \dots\dots\dots(4)$$

$$F_- = \beta_0^- N_0 + \sum_{p=1}^{\infty} (\beta_{i,p}^- N_p^- + \beta_{a,p}^- N_p^-) \dots\dots\dots(5)$$

where N_0 , N_p^+ and N_p^- represent the number density expressed in cm^3 of neutral, positive and negative ionized aerosols, respectively, which carry p -elementary charges on themselves. $\beta_{i,p}^+$ is the attachment coefficient of small positive ion to an ionized aerosol carrying p -positive elementary charges on it and $\beta_{a,p}^+$ is the attachment coefficient of small positive ion to an ionized aerosol carrying p -negative elementary charges on it. $\beta_{i,p}^-$ is the attachment coefficient of negative small ion to an ionized aerosol carrying p -negative elementary charges on it and $\beta_{a,p}^-$ is the attachment coefficient of negative small ion to an ionized aerosol carrying p -positive elementary charges on it. Assuming a charge symmetry at every moment, we obtain $F_+ = F_- = F$ as follows,

$$F = \beta_0 N_0 + \sum_{p=1}^{\infty} (\beta_{i,p} + \beta_{a,p}) N_p \dots\dots\dots(6)$$

where, $\beta_0 = \beta_0^+ = \beta_0^-$

$$\beta_{i,p} = \beta_{i,p}^+ = \beta_{i,p}^-, \quad \beta_{a,p} = \beta_{a,p}^+ = \beta_{a,p}^-$$

The attachment coefficient, may be defined from the equation given by Bricard (1965), which disregards the electric image. Then we get,

$$\beta_{i,p} = \frac{p\pi R^2 v \frac{e^2}{kT} \exp \frac{-pe^2}{kT(R+D)}}{\frac{pe^2}{kT} + \frac{v^2}{4D} R^2 \left[1 - \exp \frac{-pe^2}{kT(R+D)} \right]} \dots\dots\dots(7)$$

$$\beta_{a,p} = \frac{p\pi R^2 v \frac{e^2}{kT} \exp \frac{-pe^2}{kT(R+D)}}{\frac{pe^2}{kT} - \frac{v^2}{4D} R^2 \left[1 - \exp \frac{-pe^2}{kT(R+D)} \right]} \dots\dots\dots(8)$$

$$\beta_0 = \frac{\pi R^2 v}{1 + \frac{vR^2}{4D(R+D)}} \dots\dots\dots(9)$$

where, D is the diffusion coefficient of small ion, R is radius of aerosol, v is thermal velocity of small ion, k is the Boltzmann constant and they are expressed as follows,

$$\left. \begin{aligned} D &= k_0 \frac{kT}{e} \cdot F(p, T) \\ D &= \frac{1}{3R\lambda} \left[(R + \lambda)^3 - (R^2 + \lambda^2)^{\frac{3}{2}} \right] - R \\ \lambda &= \frac{8}{3} \cdot \frac{k_0}{e\sqrt{\pi}} \left(\frac{m}{2} kT \right)^{\frac{1}{2}} \cdot F(P, T) \end{aligned} \right\} \dots\dots\dots(10)$$

$$\left. \begin{aligned} v &= \left(\frac{kT}{m} \right)^{\frac{1}{2}} \\ F(P, T) &= \left(\frac{P_0}{P} \right) \cdot \left(\frac{T}{T_0} \right) \end{aligned} \right\} \dots\dots\dots(10)$$

where, λ is mean free path, k_0 is mobility at STP and m is the mass of the small ion, respectively. Further we shall assume that there is an equilibrium between the small ion production and their attachment to aerosol, then,

$$\frac{dn_+}{dt} = \frac{dn_-}{dt} = 0, \quad \frac{dN_p}{dt} = 0 \dots\dots\dots(11)$$

From (1), (2), (3) and (11) we get the following cubic equation for an equilibrium state,

$$\begin{aligned} (BE)n_+^3 + (AE + BD + EF + BF)n_+^2 \\ + (DF + AF + F^2 - FQ)n_+ - (A + D + F)Q = 0 \dots\dots\dots(12) \end{aligned}$$

If the atmosphere is clean and aerosol free, the aerosol factor F is equal to zero, and the equation (12) becomes identical with what is derived by Cole and Pierce (1965).

3. Discussion of the result

Cole and Pierce (1965) studied in detail the electrification in the earth's atmosphere up to 100 km in altitude and gave a discussion about the numerical values of the coefficient in equation (12). In this paper, we will estimate contribution of the aerosol factor F to ion density profile where as Cole and Pierce (1965) neglected the effect of aerosols. It is essential for solving the equation (12) to define the ionization rate Q as a

function of altitude. In this respect we firstly preferred Q profile given by Prof. Kawano and his groups, (private communication) who made observation of ionization rate up to 19 km altitude at Taiyo-mura Balloon Site, Univ. of Tokyo, geomagnetic latitude 26°N , and secondly, above 19 km we adopted a profile given by Neher (1967) with a correction made for a cosmic ray latitude conversion to 26°N . The two profiles are found fairly well to be continuous with each other and Figure 1 show profile thus resulted.

The knowledge of density profile of aerosols is of the next importance, and it is for estimation of aerosol factor F. As we briefly mentioned in the introduction that stratospheric aerosols have been observed by several investigators by means of indirect method made from the ground such as the optical approach. Much of the results they gave are, therefore, rather qualitative and the information involved is rather limited with respect to aerosol size and density range. Therefore, a few direct measurement of aerosols hitherto made with balloons seems to be the source of quantitative informations. The profile given by Junge et al. (1961) based on their balloon measurements are likely the limited sources of usefull information, thus we have decided to use them to estimate the aerosol factor F. However, it seems to be difficult to know the ratio of neutral to ionized aerosols, so that we are obliged to assume the Fuch's relation. The total number density

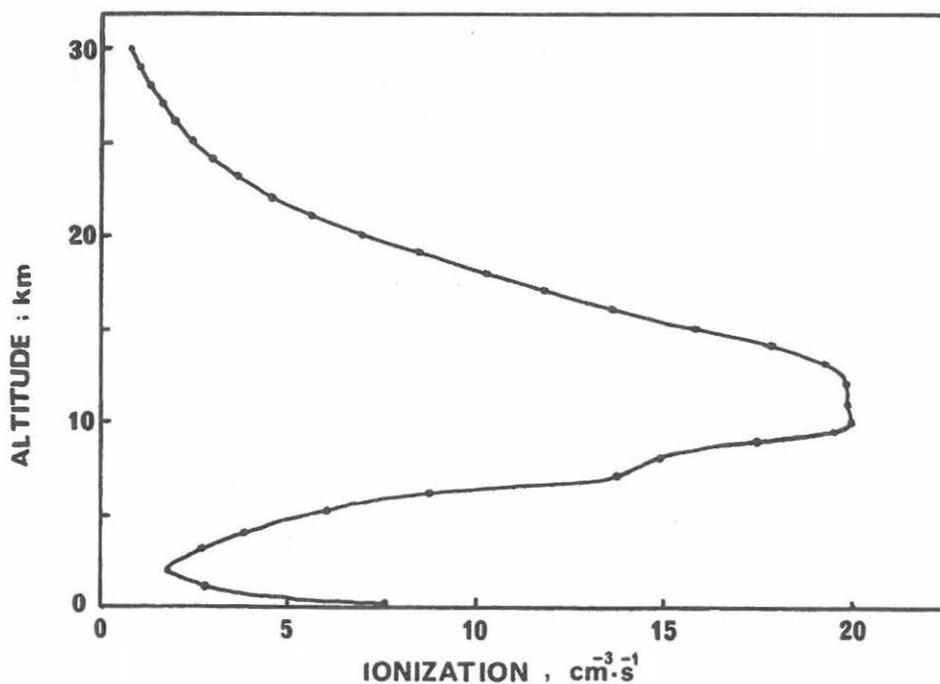


Fig. 1. Ionization rate profile taken to the present computation.

N of aerosols, and can be expressed as follow,

$$N = N_0 + 2 \sum_{p=1}^{\infty} N_p \dots\dots\dots(13)$$

According to Fuch's relation,

$$N_p = N_0 \exp\left(\frac{-p^2 e^2}{2RkT}\right) \dots\dots\dots(14)$$

Thus, we can rewrite the expression for F given by equation (6) as follows,

where, $F = N_0 \left(\beta_0 + \sum_{p=1}^{\infty} B_p \right) \dots\dots\dots(15)$

$$B_p = (\beta_{i,p} + \beta_{a,p}) \cdot N_p / N_0 \dots\dots\dots(16)$$

From (13), (15) and (16), we get,

$$F = N \cdot \left(\beta_0 + \sum_{p=1}^{\infty} B_p \right) / \left(1 + 2 \sum_{p=1}^{\infty} N_p / N_0 \right) \dots\dots\dots(18)$$

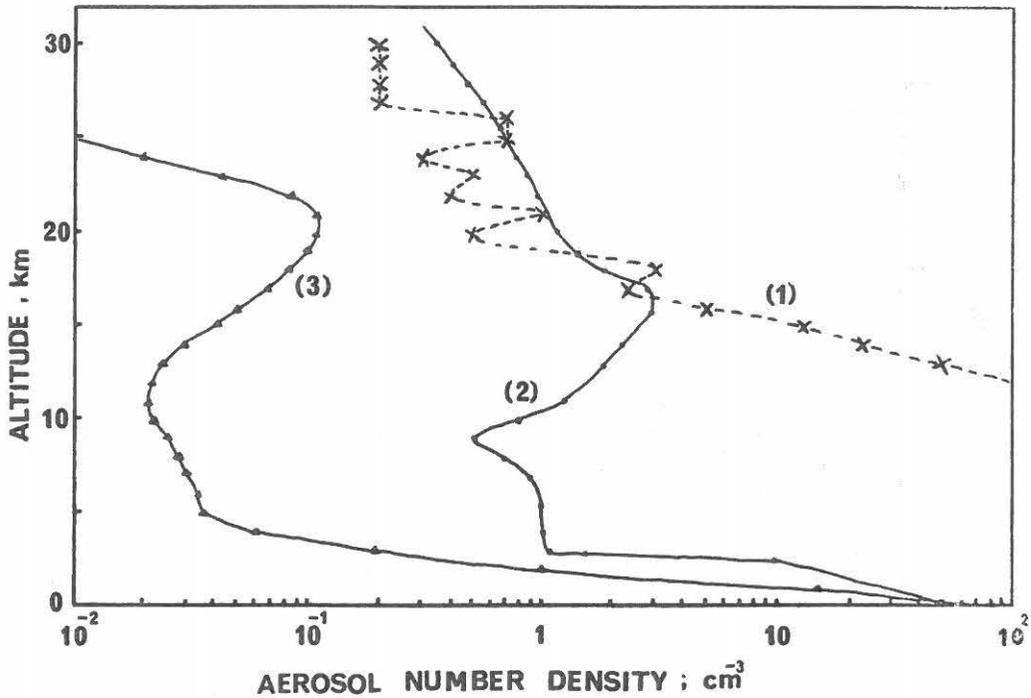


Fig. 2. The experimental profiles of aerosol number density,
 (1), (3) : The profile given by Junge et al.
 (2) : The profile given by Rosen.

Figure 2 shows the aerosol number density profile given by Junge et al. (1961) and a profile given by Rosen (1964) for aerosols larger than 0.3 micron in radius. Thus one can calculate the aerosol factor F by the use of these informations in computing the equation (14) and (16). The result of calculation of equation (14) shows a evidence that one-micron sized aerosols carrying 15 elementary charges on it for example, occupy only 0.1 percent of neutral aerosols of the same size.

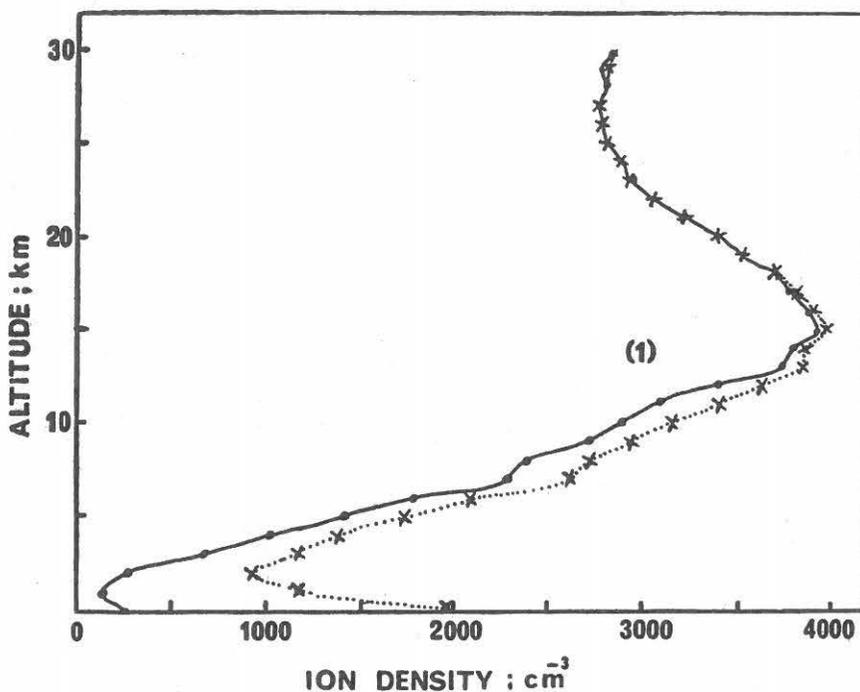


Fig. 3. The ion density profile, corresponding to the profile (1) in Fig. 2. The dotted line indicates a profile of aerosol free atmosphere.

Knowing the aerosol factor F , we have solved numerically the cubic equation (12) using an electronic computer system, and found that the equation has one real root positive and two real root negative, therefore we have always one solution of the equation which has a physical meaning. The results of computation is given in Figure 3, 4 and 5 which respectively correspond to the aerosol profile (1), (2) and (3) given in Figure 2 and the aerosol contaminated atmosphere (full line) is compared with the clean atmosphere (dotted line). General trend of the three profiles given in Figure 3, 4 and 5 is that the influence of aerosol existence to the ion density profile is the strongest in the lower level of the atmosphere up to 5 km, and the influence of the aerosols gradually disappear with increasing altitudes, so that the effect is usually negligibly small above

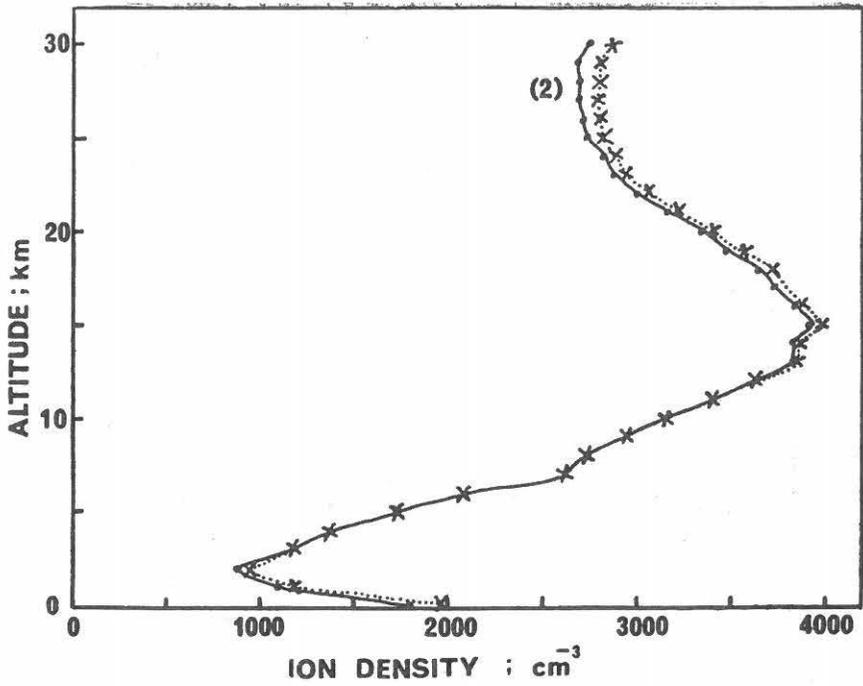


Fig. 4. The ion density profile corresponding to the profile (2) in Fig. 2.

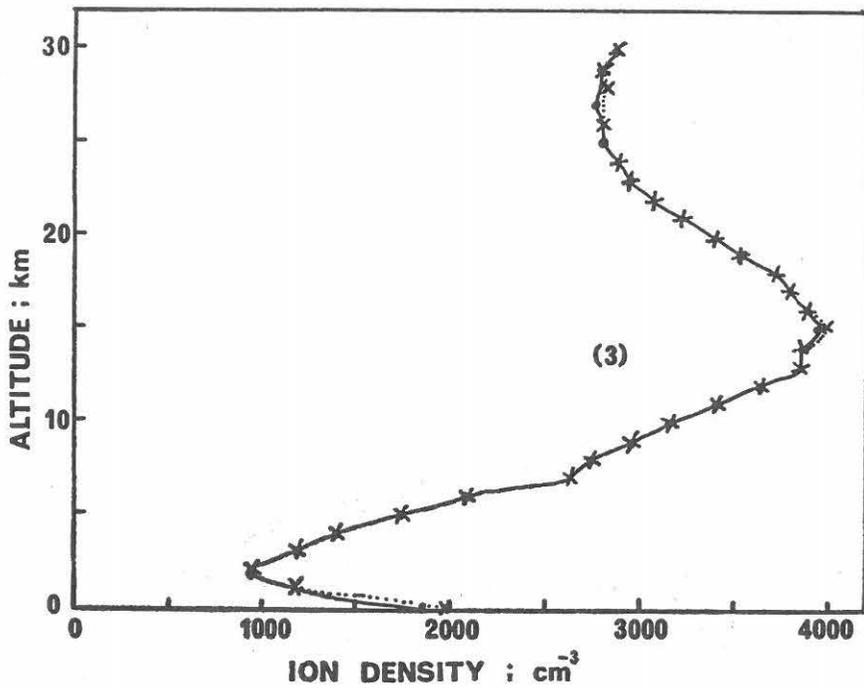


Fig. 5. The ion density profile corresponding to the profile (3) in Fig. 2.

15 km in altitude. As we can see it in equation (8), the aerosol factor is proportional to the total density of aerosols and attachment coefficient of ions to aerosols. Thus the influence of the aerosol existence on the small ion density is rather weak in the stratosphere so far as we assume a low total aerosol density such as that given by Junge et al. (1961). On the other hand, the attachment coefficients are approximately proportional to the square of radius of aerosols, and to the number p of elementary charge on them. Therefore one of the reasonable assumptions to be made will be that we consider the existence of large sized aerosols of low number density in the balloon altitude. The assumption is consistent with the generally acceptable conception of low number aerosol density in the balloon altitude and interpretes the deviation of the observed ion density profile from what is expected from a small ion equilibrium theory in the balloon altitude.

4. Conclusions

Closely to inquire in to one of the possibilities of interpreting the deviation of the observed ion density profile from a profile expected from small ion equilibrium theory in the balloon altitude we have solved the equation of ion equilibrium taking into account the aerosol factor using an electronic computer system and investigated the influence of aerosols on the ion density in the stratosphere. The results of our computation shows that the effect is rather small or negligibly small above 15 km altitude, so far as we accept the total density of aerosols given by Junge et al. (1961) based on their balloon observations. Therefore we suggest, as one of the possible accounting for the deviation of our observed profile from the theoretical profile, the presence of large sized aerosols, though very low in number density, in the stratosphere.

However the idea of large sized aerosols with multiple elementary charges on it, can not seem to exclude the other possibilities. In this respect, the photochemical effect of atmospheric ozones on the ion density in the upper atmosphere will likely be very significant and should be present in the future.

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