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Impact of aerosols on conductivity of the stratosphere

S.Chandramma[1]*, K.Nagaraja[2]

[1]Department of Physics, Yuvaraja's College, University of Mysore, Mysore - 570 005, (INDIA)

[2]Department of Physics, Bangalore University, Jnanabharathi, Bangalore - 560 056, (INDIA)

E-mail : s_chandramma@yahoo.com

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ABSTRACT

Ionic conductivity is one of the important parameters for understanding the electrical state of the environment and is known to be sensitive to the presence of aerosols. Thus, aerosol loading on the stratosphere has a bearing on the conductivity. A preliminary effort is made to study the behaviour of ionic conductivity of the stratosphere. For analyzing the effect of aerosols on conductivity, the aerosol number density alone is not sufficient and requires a parameter which is a function of ionic mobility and as well as aerosol size distribution. Therefore, the aerosol ion-small ion recombination coefficient determines the extent to which aerosols can alter the conductivity of the stratosphere. This necessitates the requirement of experimental measurements of aerosol ion-small ion recombination coefficient along with simultaneously measured aerosol density and electrical conductivity in the region. Comparison of α_s-profiles with that of the ion-ion recombination coefficient α_i indicate that it may be necessary to incorporate multiple charged aerosols in the ion-aerosol model studies of conductivity of stratosphere under enhanced aerosol conditions such as volcanic eruption, a feature not seen in the usual model studies of the stratospheric conductivity.

KEYWORDS

Ions;
Aerosols;
Electrical conductivity;
Stratosphere;
Atmosphere.

INTRODUCTION

Ion-aerosol model studies of stratospheric conductivity are an important area of atmospheric research for understanding the electrical state of the atmosphere as related to aerosols in the region. The stratospheric ion conductivity is known to be very sensitive to the presence of aerosols in the region. Thus, aerosol loading on the stratosphere has a bearing on the corresponding conductivity in the region. The aerosols reduce the stratospheric conductivity by (i) converting the highly mobile small ions into less mobile aerosol ions through ion-aerosol attachment (coefficient β) and (ii) neutralizing the small ions through the aerosol ion-small ion recombination (coefficient α_s). Another process which makes the ion-aerosol attachment rate faster is the charged aerosol-aerosol recombination (coefficient α_a). However, α_a is small compared to β and α_s. The influence of aerosols on ionic conductivity has been modeled by several research workers[1-3]. However, most of these works are not for enhanced aerosol condition of the stratosphere. Rosen *et al*.[4] have analyzed the effect of aerosols on the conductivity through simultaneous measurements of aerosol number density, *Z*, and ion conductivity during enhanced aerosol condition of the stratosphere. Further, Rosen *et al*.[4] have highlighted the absence of correlation between their measured profiles of *Z* and conductivity, σ±, and conclude that aerosols may not alter the conductivity at all. Srinivas and Prasad[2] have shown in their model study that the height variation of σ± is primarily governed by the corresponding mobility of small ions. Further, they have emphasized the need of computing at least one of the coefficients α_s and α_a from the model. Further, these coefficients are shown to be aerosol size distribution dependent[3]. Thus it is clear that, in order to analyze the effect of aerosols on the ionic conductivity, a parameter which is a function of ionic mobility and aerosol size distribution may be required.

ION-AEROSOL BALANCE EQUATION

The ion-aerosol model[5,6] used in this study is shown in Figure 1. The two types of β for the attachment of positive and negative ions with the neutral aerosols are considered to be equal. Similarly, the two

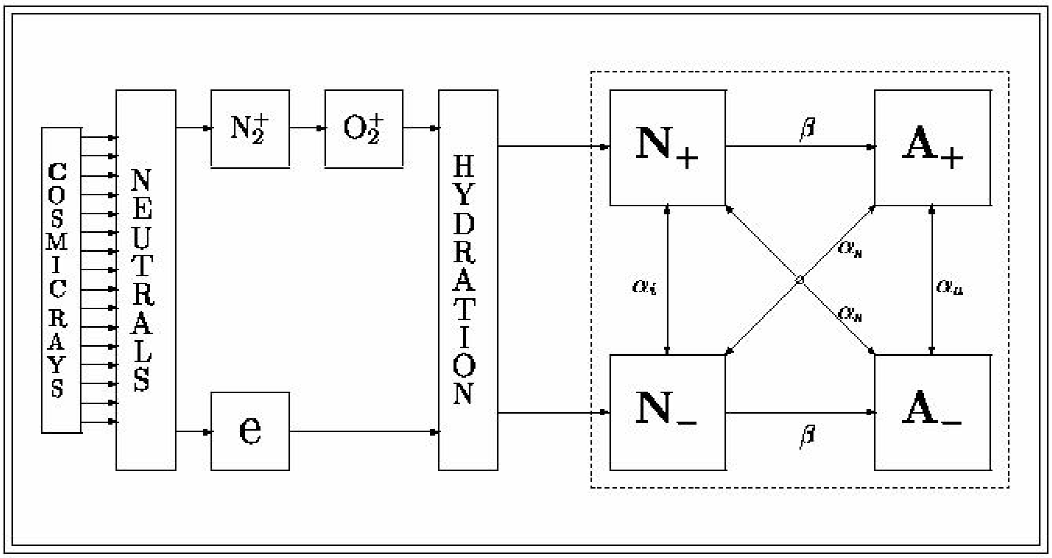

Figure 1 : Simplified ion-aerosol model used in this study

types of α_s are also assumed to be equal in the present study, although these two types of α_s are known to be slightly different[3]. It is found that the results of this study are not altered by this assumption. The conductivities of the stratosphere at any altitude in the absence and presence of aerosols is estimated and analyzed. The steady state small ion and aerosol ion densities are given by the basic equations as:

$$q - \alpha_i N_\pm^2 - \beta Z N_\pm - \alpha_s N_\pm A_\pm = 0 \quad (1)$$

$$\beta Z N_\pm - \alpha_s N_\pm A_\pm - \alpha_a A_\pm^2 = 0 \quad (2)$$

where *q* - Cosmic ray ion production rate

α_i - Ion-ion recombination coefficient

N± and *A*± - Steady state concentrations of positive or negative molecular and aerosol ions, respectively.

The steady state molecular ion density N_o in the absence of aerosols is given by

$$N_0 = \left[\frac{q}{\alpha_i}\right]^{\frac{1}{2}} \quad (3)$$

The fractional depletion η of small ions due to the presence of aerosols is defined as

$$\eta = \frac{A_\pm}{N_0} = \frac{N_0 - N_\pm}{N_0} \quad (4)$$

Solving Eqs. 1 and 2 simultaneously and using Eqs. 3 and 4 we can write the following expressions for β*Z* and α_s as:

$$\beta Z = N_0 \eta \left\{\frac{\alpha_i (2-\eta) + \alpha_a \eta}{2(1-\eta)}\right\} \quad (5)$$

$$\alpha_s = \left\{\frac{\alpha_i (2-\eta) - \alpha_a \eta}{2(1-\eta)}\right\} \quad (6)$$

The conductivities σ_o and σ± of the stratosphere at any altitude in the absence and presence of aerosols, respectively, are given by

$$\sigma_0 = N_0 e b_{\pm} \quad \text{and} \quad \sigma_{\pm} = (1-\eta)\sigma_0 \qquad (7)$$

$$b_{\pm} = \frac{b_0 P_0 T}{T_0 P} \qquad (8)$$

where e - Elementary charge $b\pm$ - Molecular ion mobility at the altitude of interest is given by[7]

T and P are, respectively, the temperature and pressure at the altitude of interest

b_o, P_o and T_o refer to their respective values at sea level

METHODOLOGY

The atmospheric temperature, pressure, neutral density, ionization rate due to cosmic rays, aerosol number density is the input parameters to the model. It is noted that no effective size or the size distribution corresponding to the *Z*-profile as given by Rosen et al[4] is available. Thus, in the present computations, an effective size (*r)* for the aerosols is assumed. Estimation of the stratospheric conductivity requires a knowledge of recombination coefficients α_i, α_a and α_s. Parametric formulae for α_i have been used in the stratospheric model studies[8] and is found to be height dependent, varying from about 4×10^{-6} to 5×10^{-8} cm^3s^{-1} in the height range of 10–60 km[2,3]. From theoretical considerations, Hoppel[9] has shown that for singly charged aerosols the relative magnitudes of α_a and α_s are such that $\alpha_a \leq \alpha_s \leq \alpha_i$. Srinivas and Prasad[2] have shown the difficulties encountered in the modelling of stratospheric conductivity using background aerosols, where large values of α_a and α_s [with $(\alpha_a,\alpha_s) \geq \alpha_i$] are used in the model. This problem can be overcome by analytically determining α_a or α_s for an assumed aerosol size distribution. The computations are repeated for various assumed effective sizes *r* and the conductivity profiles so obtained are analyzed against the $\sigma\pm$ profile measured simultaneously.

Initially, with a suitable assumed value of α_a, the value of η is computed from Eq. 5. Then the value of α_s is computed by using Eq. 6. It is noted that, in this step, α_s becomes negative if the assumed value of α_a is unrealistically large. In the present computations $\alpha_a = 10^{-7}$ cm^3s^{-1} is found to be suitable. From the values of η obtained from Eq. 5, the values of $N\pm$ and $A\pm$ [Eq. 4] and hence $\sigma\pm$ and $\Delta\sigma\pm$ (=$A\pm eb\pm$) are computed. These computations are repeated for various assumed effective sizes *r* and the conductivity profiles so obtained are analyzed against the $\sigma\pm$ profile measured simultaneously with *Z* by Rosen *et al*[4].

RESULTS AND DISCUSSION

In the present study we have computed the $\sigma\pm$-profiles for *r* = 0.001, 0.004, 0.008, 0.02, 0.06, 0.1, 0.4 and 0.8 μm. But the profiles for *r* = 0.001 – 0.02, 0.1, 0.4 and 0.8 μm are only shown in Figures 2-4 for clarity. The input *Z*-profile, and the model $\sigma\pm$-profiles are shown in Figure 2 along with the $\sigma\pm$-profile measured simultaneously with *Z* by Rosen *et al*[4]. It may be observed that the fluctuations in *Z* values do not cause any considerable fluctuations in the measured $\sigma\pm$-profiles, particularly, at lower heights. Such observations lead Rosen *et al*.[4] to a conclusion that the aerosols may not have influence on the conductivity of the stratosphere. However, an examination of *Z* and model $\sigma\pm$-profiles in Figure 2 reveals that the anti-correlation between *Z* and model $\sigma\pm$ is apparent only for larger *r* values, and is very small for *r* = 0.001 – 0.02 μm. Further, the sensitivity of the model $\sigma\pm$-profiles in Figure 2 to the variations of *Z* is large at higher altitudes. Thus, in order to appreciate the effect of aerosols on the conductivity, comparison of $\sigma\pm$-profiles with the corresponding *Z*-profile alone may not be sufficient.

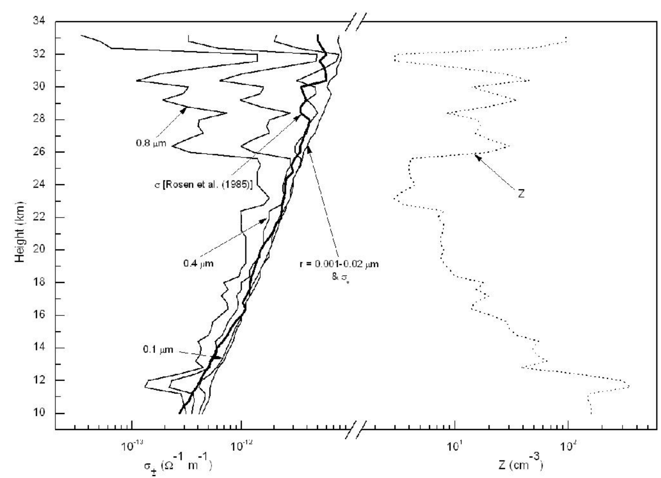

Figure 2 : Profiles of experimental *Z* and conductivity $\sigma_{\pm}$ from Rosen *et al*.

The model computed α_s-profiles for various assumed values of *r* are shown along with α_i[8] used in this study and Z in Figure 3. It may be observed that the fluctuations in Z cause similar fluctuations in the corresponding $_s$ only for larger r values. We note that the reduction in the $\sigma\pm$ by aerosols is because of the ion depletion due to ion-aerosol attachment and aerosol ion-small ion recombination. In Figure 3 it is observed that at all heights $\alpha_s \geq \alpha_i$. Thus, the aerosol ion-small ion recombination is seen to be very important in the studies of ion depletion due to aerosols, particularly, under enhanced aerosol condition. The coefficient, α_s, is dependent on the aerosol size distribution as well as on the small ion mobility. Thus, the relatively smaller fluctuations of α_s with respect to Z at lower altitudes as compared to those at higher heights are due to the relatively smaller ionic mobilities at lower altitudes. It is evident that the ion depletion levels are directly reflected in the α_s values at any height. Hence, it is clear that, rather than variations in Z, the variations in α_s may represent the possible reduction and/or variations in the atmospheric conductivity due to the presence of aerosols. This point is demonstrated in Figure 4, where α_s and model $\sigma\pm$-profiles are shown for various values of r. The absence of fluctuations in experimental $\sigma\pm$-profile with respect to Z in Figure 2 indicates that the effective size corresponding to the Z-profile as given by Rosen *et al*.[4] may be small (< 0.01 μm). The model predicted conductivity profiles for $r < 0.1$ μm agree well with the $\sigma\pm$-profile of Rosen *et al*.[4]. Thus it is to be noted that, for estimating the effect of aerosols on the conductivity at any height, knowledge of α_s is important. Information about Z alone may not be sufficient.

In Figure 4, it may also be observed that at all heights $\alpha_s \geq \alpha_i$, whereas the theoretical considerations[9] dictate the condition $\alpha_s \leq \alpha_i$ (for singly charged aerosols) at any height in the stratosphere. Thus, clear observation in Figure 4 (i.e., $\alpha_s \geq \alpha_i$) is possible if aerosols can become multiply charged, since in this simplified model study α_s is an effective coefficient for the recombination between charged aerosols and small ions. This emphasizes the importance of α_s in the studies of ion depletion due to aerosols, particularly, under enhanced aerosol conditions. Therefore, there is a need to include channels for the formation of multiply charged aerosols in the ion-aerosol model studies of the region. Also evident from the results is the requirement of experimentally determined values of α_s for analyzing the effect of aerosols on the stratospheric conductivity. However, if aerosols have multiple charges then analysis will be complicated.

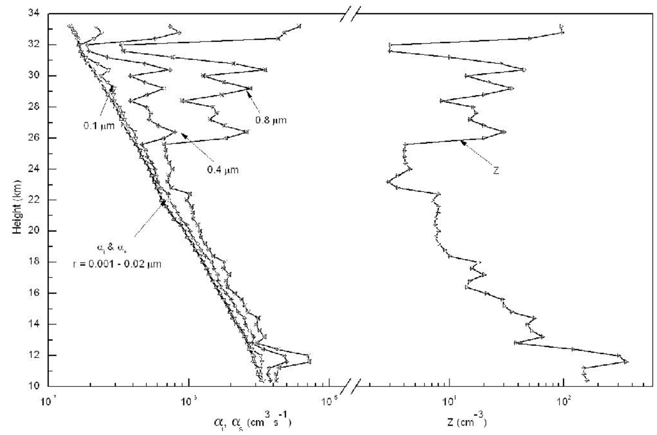

Figure 3 : Height profiles of input Z, α_i and computed α_s-profiles for various aerosol sizes

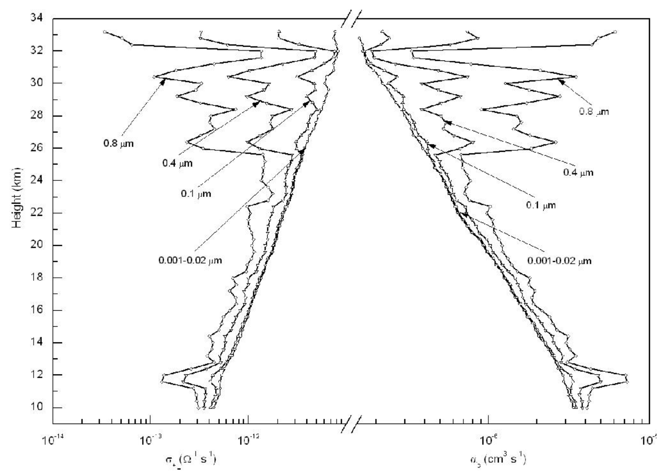

Figure 4 : Height profiles of α_s and $\sigma\pm$ for various aerosol sizes

SUMMARY

An ion-aerosol is employed to study the effect of aerosols on the stratospheric ion conductivity. Variations in aerosol concentration need not bring about similar variations in the corresponding conductivities. But the aerosol ion-small ion recombination coefficient, α_s, is seen to directly represent the reduction in the conductivity of the stratosphere due to aerosols. Therefore, knowledge about α_s is essential for understanding the effect of aerosols on the stratospheric conductivity. This, in turn, requires the knowledge of the aerosol size

distribution. Information about *Z* alone may not be sufficient for predicting/understanding the relationship between aerosols and conductivity. Further, the model derived values of α_s (in relation to $_i$) indicate a need to extend this study from the point of view of multiple charging of aerosols under enhanced condition.

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