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Electrical Conductivity of the Stratosphere

Kamsali Nagaraja,[*] S D Pawar,[†] P Murugavel[‡] and
V Gopalakrishnan[§]

Abstract

Ionic conductivity of the stratosphere is one of the important parameters for understanding the electrical state of the region. This parameter is sensitive to the presence of aerosols and thus, aerosol loading on the stratosphere has a bearing on the conductivity. Preliminary efforts were made to study the behaviour of stratospheric ion conductivity and its variation under enhanced aerosol conditions by making use of an Ion-aerosol model. The aerosol ion-small ion recombination coefficient obtained from the model determines the extent to which aerosols can alter the conductivity of the stratosphere. This necessitates the requirement of experimental measurements of attachment and recombination coefficient along with simultaneously measured aerosol density to have the proper information on electrical conductivity of the region.

Keywords: Aerosols, conductivity, stratosphere, model studies

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[*] Department of Physics, Bangalore University, Bangalore-560 056; kamsalinagaraj@bub.ernet.in

[†] Indian Institute of Tropical Meteorology, Pune-411 008; pawar@tropmet.res.in

[‡] Indian Institute of Tropical Meteorology, Pune-411 008; pmvelu@tropmet.res.in

[§] Indian Institute of Tropical Meteorology, Pune-411 008; gopal@tropmet.res.in

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1. Introduction

The Ion-aerosol model studies are important in the field of atmospheric research for better understanding of the electrical state of the atmosphere as related to aerosols in the region. The stratospheric ion conductivity is sensitive to the presence of aerosols. Thus, aerosol loading on the stratosphere, lies between tropopause (~10 km) and stratopause (~50 km), has a bearing on the corresponding electrical conductivity. The aerosols reduce the stratospheric conductivity by:

a) converting the highly mobile small ions into less mobile aerosol ions through ion-aerosol attachment (coefficient β).

b) 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, Rosen *et al.* [4] have analyzed the effect of aerosols on conductivity through simultaneous measurements of aerosol number density 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 aerosols and conductivity. Variation of conductivity is primarily governed by the corresponding mobility of small ions and coefficients are dependent on size distribution of aerosols [5]. 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. Using these as input to the model, the electrical conductivity of the region is computed and presented.

2. Ion-aerosol model

The ion-aerosol model used in this study is shown in Fig. 1, whereas the details of this model for surface level conductivity near to the earth's surface under enhanced aerosol conditions is described by Nagaraja *et al.* [6] and variation of small ions by

Nagaraja *et al.* [7]. 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 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. It is found that the results of this study are not altered by this assumption.

The steady state small ion and aerosol ion densities are given by the basic equations as:

$$q - \alpha_i N_{\pm}^2 - \beta Z N_{\pm} - \alpha_s N_{\pm} A_{\pm} = 0 \tag{1}$$

$$\beta Z N_{\pm} - \alpha_s N_{\pm} A_{\pm} - \alpha_a A_{\pm}^2 = 0 \tag{2}$$

where q is cosmic ray ion production rate, α_i is ion-ion recombination coefficient, $N_{\pm}$ and $A_{\pm}$ are concentrations of positive or negative molecular and aerosol ions, respectively.

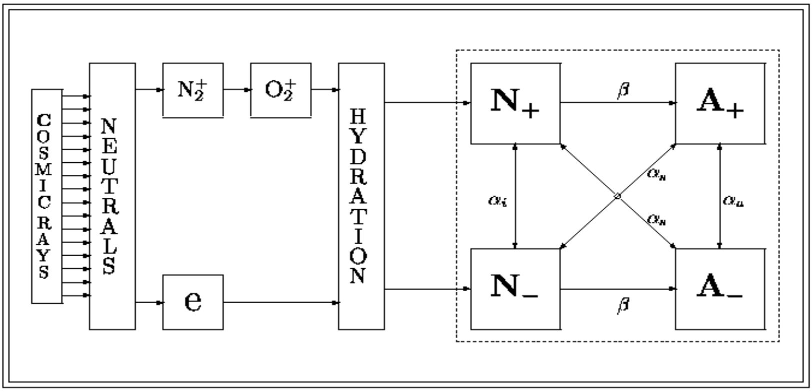

Fig 1 Simplified ion-aerosol model used in this study for the stratospheric region

Steady state molecular ion density N_0 in absence of aerosols is:

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

Fractional depletion (η) of small ions due aerosols are:

$$\eta = \frac{A_{\pm}}{N_0} = \frac{N_0 - N_{\pm}}{N_0} \tag{4}$$

Solving equations (1) and (2) simultaneously and using equations (3) and (4), one can write the expressions for βZ and α_s as:

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

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

The conductivities σ_o and $\sigma_{\pm}$ of the stratosphere at any altitude in the absence and presence of aerosols, respectively, are given by:

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

where e is elementary charge, $b_{\pm}$ is molecular ion mobility and is given by [8]:

$$b_{\pm} = \frac{b_0 P_0 T}{T_0 P} \tag{8}$$

where T and P are, respectively, the temperature and pressure at the altitude of interest. The parameters b_o, P_o and T_o refer to their respective values at sea level.

3. Methodology

Modeling of the stratospheric conductivity shown schematically in Fig. 1 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 [9] and α_i is found to be height dependent, varying from about 4×10^{-6} to 5×10^{-8} cm^{3}s^{-1} in the height range of 10-60 km [2, 3]. For singly charged aerosols, the relative magnitudes of α_a and α_s are such that $\alpha_a \le \alpha_s \le \alpha_i$ [10]. Several difficulties encountered in the modeling of stratospheric conductivity using background aerosols, where large values of α_a and α_s are used in the model. This problem can be overcome by analytically determining α_a or α_s for an assumed background aerosol size distribution and is employed in the present study. However, the results of this study showing $\alpha_s \geq \alpha_i$ is to be interpreted in view of multiple charging of aerosols.

Initially, with a suitable assumed value of α_a, value of η is computed from Eq. (5). Then the value of α_s is computed by using Eq. (6). It is noted that, ina this step, α_s becomes negative if the assumed value of α_a is unrealistically large. In the present computations α_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 $A_\pm$ and hence $\sigma_\pm$ are computed. These computations are repeated for various assumed effective sizes r and the conductivity profiles were obtained.

4. Results and discussion

The conductivity-profiles were computed for different r = 0.001, 0.004, 0.008, 0.02, 0.06, 0.1, 0.4 and 0.8 μm, however, the profiles for r = 0.001 – 0.02, 0.1, 0.4 and 0.8 μm only shown in Fig. 2(a) to 2(d) for clarity.

The input parameters such as ionization rate [11], temperature and pressure [12] and mobility derived from temperature and pressure that were used to obtain the electrical conductivity from Ion-aerosol model are shown in Fig. 1. As height increases the ionization rate (Fig. 1a) drops and attains constant beyond 25 km, where as temperature (Fig. 1b) decreases in the beginning and attains constant values between 15–25 km and then raises because of enhancement of ozone in the middle of the stratosphere. However, the pressure (Fig. 1c) decreases and becomes constant after 25 km and follows the trend of temperature. The mobility profile obtained from temperature and pressure shown in Fig. (1d) increase slowly below tropopause and the steep is large beyond 25 km. With these inputs the model runs with large number of iterations to obtain different attachment and recombination coefficients that have a great importance in determining the electrical nature of the atmosphere.

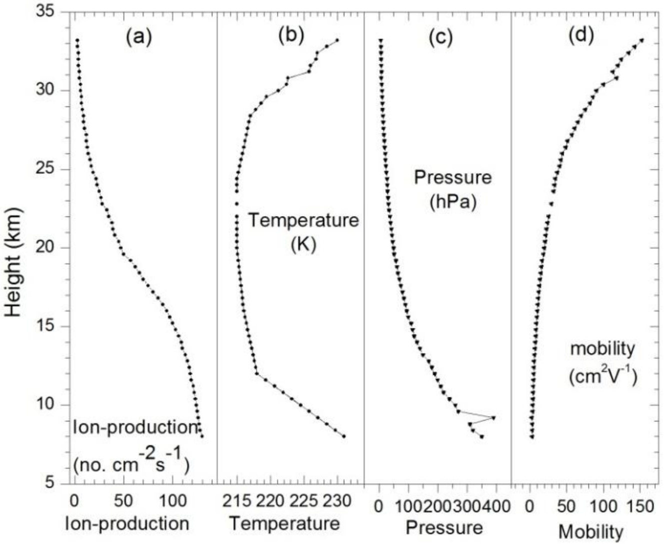

Fig. 2. Profiles of a) ionization rate b) temperature c) pressure and d) mobility for stratospheric region from 8 to 33 km.

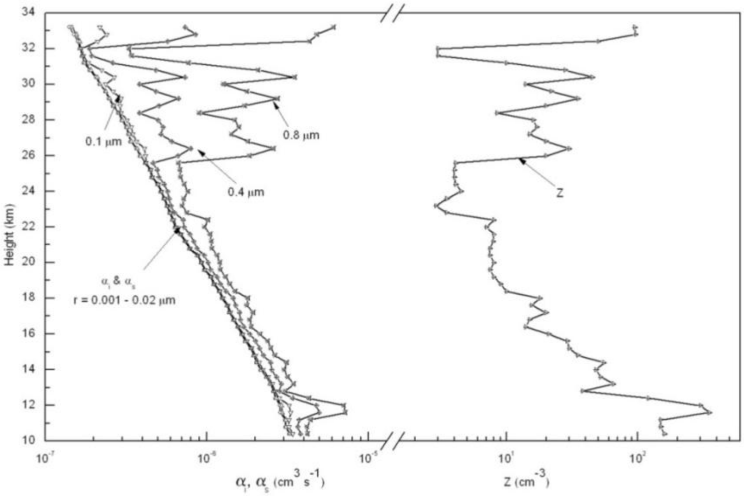

Fig. 3. Profiles of input *Z*, α_i and computed α_s-profiles for various aerosol sizes

The model computed α_s-profiles for various assumed values of *r* are shown along with α_i and Z used in this study in Fig. 3. The fluctuations in aerosols cause similar fluctuations in corresponding α_s only for larger *r* values. It is noted that the reduction in conductivity by aerosols is because of the ion depletion due to ion-aerosol attachment and aerosol ion-small ion recombination. In Fig.

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 aerosols, the variations in α_s represent the possible reduction and/or variations in the atmospheric conductivity due to the presence of aerosols.

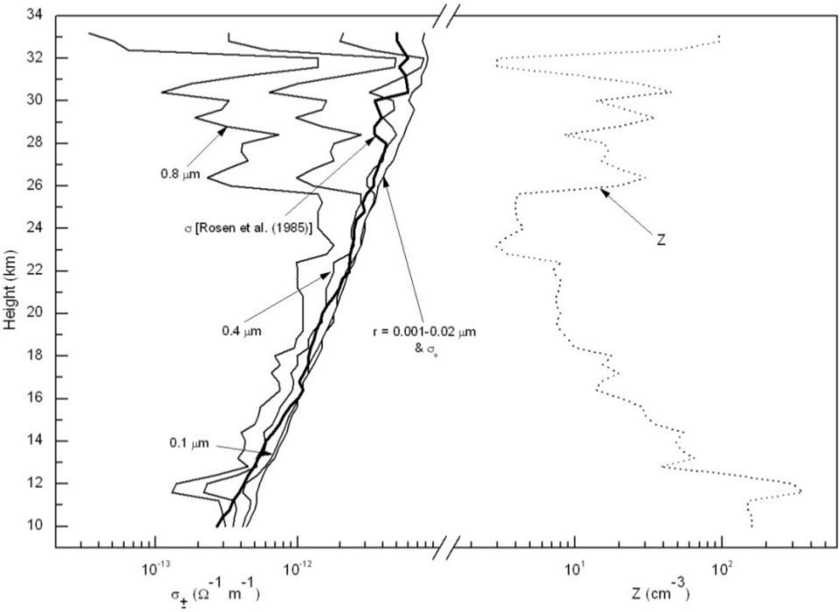

Fig. 4. Profiles of model conductivity along with measured aerosol and conductivity

The input Z and model predicted $\sigma_{\pm}$-profiles is shown in Fig. 4 along with the $\sigma_{\pm}$-profile measured simultaneously by Rosen *et al.* [4]. It may be observed that the fluctuations in aerosol values do not cause any considerable fluctuations in the measured $\sigma_{\pm}$-profiles, particularly, at lower heights. However, an examination of Z and model $\sigma_{\pm}$-profiles 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 4 to the variations of Z is large at higher altitudes. The absence of fluctuations in experimental $\sigma_{\pm}$ -profile with respect to aerosols 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, for estimating the effect of aerosols on conductivity at any height, knowledge of α_s is important and information about Z alone may not be sufficient. The model computed conductivity values agrees well with experimental values at greater heights.

5. Conclusion

Ion-aerosol model is employed to study the effect of aerosols on stratospheric ionic 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 α_i) indicate a need to extend this study from the point of view of multiple charging of aerosols under enhanced condition. The model predicted conductivity values agrees well with experimental values at greater heights.

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