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EFFECT OF AEROSOL LOADING ON THE CONDUCTIVITY OF THE STRATOSPHERE

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Abstract

The stratospheric ion conductivity for an enhanced aerosol condition is estimated using a simple ion-aerosol model. For analyzing the effect of aerosols on conductivity the aerosol number density alone is not sufficient. It is found that the aerosol ion-small ion recombination coefficient determines the extent to which aerosols can alter the conductivity of the stratosphere. This emphasizes the requirement of measurement of aerosol number density and conductivity in the region.

Introduction

The conductivity of the stratosphere is one of the most important parameter for understanding the electrical state of the region. This parameter is known to be very sensitive to the presence of aerosols and thus the aerosol loading on the stratosphere has a bearing on the conductivity. The influence of aerosols on ionic conductivity has been modelled by several researchers [Datta et al (1987), Srinivas and Prasad (1993, 1996)]. However, most of these works are not for enhanced aerosol condition of the stratosphere. Rosen et al (1985) 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, they have highlighted the absence of correlation between the measured profiles of Z and conductivity, $\sigma_{\pm}$, and concluded that aerosols may not alter the conductivity at all. Thus it is clear that, in order to analyze the effect of aerosols on ionic conductivity, a parameter which is a function of ionic mobility and aerosol size distribution may be required.

The aerosols in the region 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 simple ion aerosol model

The simple ion-aerosol model (Nagaraja et al, 2006) is used to estimate the conductivity of the region. 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 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.

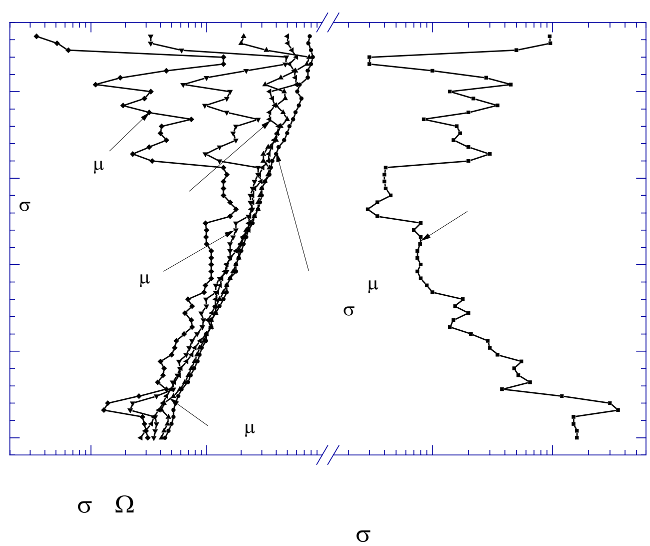
Methodology

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 (1985) is available. Thus, in the present computations, an effective size (*r)* for the aerosols is assumed.

Modelling 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 (Smith and Adams, 1982) 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 [Srinivas and Prasad (1993, 1996)]. From theoretical considerations, Hoppel (1985) 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 (1993) have shown the difficulties encountered in the modelling of stratospheric conductivity using background (unperturbed) 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.

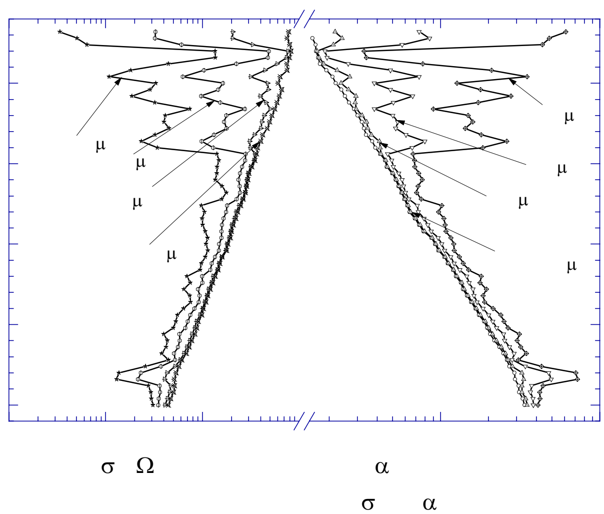
Results and discussion

The computations involve 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 for clarity.



In Fig. 1, the input *Z*-profile and the model $\sigma_\pm$-profiles are shown along with the $\sigma_\pm$-profile measured simultaneously with *Z* by Rosen et al (1985). 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 (1985) to a conclusion that the aerosols may not have influence on the conductivity of the stratosphere. However, an careful examination of *Z* and model $\sigma_\pm$-profiles in the plot 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 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.

The model computed α_s-profiles for various assumed values of r and Z (not shown here) show that the fluctuations in Z cause similar fluctuations in the corresponding α_s only for larger r values. It is to be noted 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 and validates the condition that at all heights $\alpha_s \geq \alpha_i$. Thus, the aerosol ion-small ion recombination is seen to be 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 the 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 Fig. 2, where α_s and model $\sigma_\pm$-profiles are shown for various values of r. The absence of fluctuations in the experimental $\sigma_\pm$-profile with respect to Z in Fig. 1 indicates that the effective size corresponding to the Z-profile as given by Rosen et al (1985) 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 (1985). Therefore, for estimating the effect of aerosols on the conductivity at any height, knowledge of α_s is important and the information about Z alone may not be sufficient.



In Fig. 2, it is also be observed that at all heights $\alpha_s \geq \alpha_i$, whereas the theoretical considerations dictate the condition $\alpha_s \leq \alpha_i$ (for singly charged aerosols) at any height. Thus, the observation in Fig. 2 (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 these 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.

Conclusion

A simple ion-aerosol model is employed to study the effect of aerosols on the stratospheric ion conductivity during an enhanced aerosol condition. Variations in the 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 understanding the relationship between aerosols and conductivity. Further, the model derived values of α_s indicate a need to extend this study from the point of view of multiple charging of aerosols under enhanced condition.

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