Effects of meteor head plasma distribution on radar cross sections and derived meteoroid masses

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Introduction

The problem of determining the meteoroid mass flux input to Earth's atmosphere has persisted for decades [1]; two orders of magnitude separate the high and low ends of the commonly-cited estimates. These differences arise due to different observational methods, but also due to a large number of uncertainties in assumed parameters for each method.

We focus herein on estimates derived from meteor head echoes observed with high-power, large-aperture (HPLA) and other radars. Meteor head plasma and radar cross section (RCS) are regularly detected by these ground-based radars. However, because of the plasma nature of the meteor head, the relationship between the measured RCS and the meteor plasma parameters is not straightforward. Close et al. [2] and others relate the meteor head RCS to the electron line density q in the meteor, and then relate the line density to the meteoroid mass as $qv\mu = \beta dm/dt$. It is assumed that the velocity v is measured, and the mean molecular mass μ is assumed. The ionization potential β is summarized by [3] as a function of velocity, but is also a function of composition. The line density q is thus left to be determined.

In this paper, we present numerical calculations to relate the meteor head plasma distribution to the RCS; the line density q is trivial to compute from the distribution. We use a forward model of radar scattering from meteor plasma using a finite-difference time-domain (FDTD) model of the electromagnetic wave interaction with the plasma. This model computes the meteor head RCS for a given meteor plasma distribution, specified with a peak plasma density and a characteristic size. We then relate measured RCS values to the input size and density parameters to better characterize the meteor plasma. We present simulation results that show that the RCS is directly related to the overdense meteor area; that is, the area of the meteor inside which the plasma frequency exceeds the radar frequency. This provides a direct estimate of the meteor plasma size from a given RCS measurement.

Next we investigate the effect of the assumed plasma distribution. We relax that assumption of a Gaussian or parabolic exponential distribution and explore different distribution shapes, including a new distribution derived from analytical calculations of meteor ablation; we call this the Dimant distribution. Comparing the different calculated RCS from these different distributions to three-frequency head echo data from the CMOR radar, we show that the Dimant distribution provides the best fit to the data. However, given uncertainties in the data, we cannot conclude that any distribution is the most valid. In addition, we show that the choice of distribution assumed can alter the resulting line density by an order of magnitude for the same data. We thus show that the in addition to μ and β above, the line density q is similarly difficult to ascertain, even with state-of-the-art measurements of the radar cross section.

References

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