Numerical Modeling of Radio Wave Scattering from Meteor Head Plasma

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We have developed a 3-dimensional Finite-Difference Time-Domain (FDTD) model of scattering of radar waves from meteor head plasma. The model was developed with the goal of better characterizing meteor observations in ground-based High-Power, Large Aperture (HPLA) radars; in particular, the relationship between the measured radar cross section (RCS) and the physical properties of the meteor plasma. This relationship was characterized by Close et al [2004, Icarus 168] using an analytical expression of the radio wave scattering in the meteor plasma; however, our numerical model eliminates a number of assumptions that were made in that work, including the requirement that the meteor is small compared to the radar wavelength.

The FDTD model treats the meteor head plasma as a cold, collisional, magnetized plasma, and solves Maxwell's equations and the Langevin equation simultaneously and self-consistently in and around the plasma. We use this model to investigate scattering of radar waves from a meteor head (the "head echo") under a range of plasma densities, meteor sizes and shapes, and incident radio wave frequencies, ranging from 50 MHz (i.e., the Jicamarca Radio Observatory) to 450 MHz (i.e, the Poker Flat Incoherent Scatter Radar). The numerical model uses an incident plane wave and maps the scatter fields to the far field using a Near-to-Far (NTF) Field Transformation, allowing us to calculate the RCS of an input meteor. In this way we relate the RCS to the variable input parameters of meteor size, density, shape, and radio wave frequency. We find that computed RCS disagrees with previous analytical theory [Close et al, 2004] at certain meteor sizes and densities, in some cases by over an order of magnitude. We find that the calculated meteor head RCS is monotonically related to the "overdense area" of the meteor, defined as the cross-section area of the part of the meteor where the plasma frequency exceeds the wave frequency. In particular, the meteor RCS closely matches the theory for a conducting sphere with this area, exhibiting Rayleigh and optical scattering regimes, but no resonance regime. This results provides a physical measure of the meteor size and density that can be inferred from measured RCS values from ground-based radars.