Estimation of Pre-Atmospheric Meteoroid Mass and Velocity using SAAMER-OS Observations

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Introduction

Earth is constantly being bombarded by meteoroids that undergo ablation in the upper atmosphere. This processes causes them to lose both mass and velocity before they're detected by ground-based systems, resulting in uncertainty about their pre-atmospheric conditions. We present a novel methodology for estimating a meteoroids physical parameters prior to encountering Earth's atmosphere using observations from SAAMER-OS and discuss the detection of different ablation regimes.

Methodology

The Southern Argentina Agile Meteor Radar Orbital System (SAAMER-OS) is a multistatic meteor radar located in Tierra del Fuego, Argentina. For each meteor detected, SAAMER-OS measures velocity ($\mathbf{v_z}$), altitude ($\mathbf{z_z}$), and entry angle ($\boldsymbol{\alpha}$), as well as linear and circular signal polarizations ($\boldsymbol{\Phi}$).

To find pre-atmospheric meteoroid conditions, these measurements are fed into a Full-Wave Scattering Model (FWSM) to determine trail electron line density ($\mathbf{q_z}$) at the time of detection [1].

These values are then interpolated across pre-computed ablation profiles produced with the Electron Line Density (ELINDEN) model, part of the University of Leed's Chemical Ablation Model (CABMOD), to determine a best fit for the pre-atmospheric conditions of each meteoroid [2].

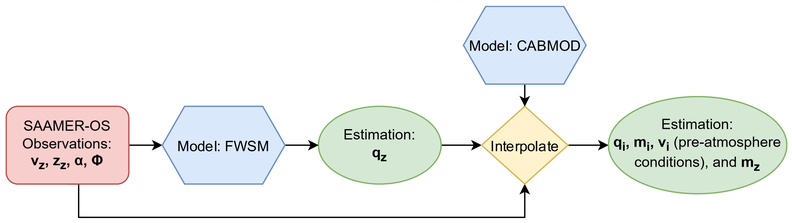

Figure 1: Workflow to generate estimates for the pre-atmospheric conditions of observed meteoroids.

Methodology Continued

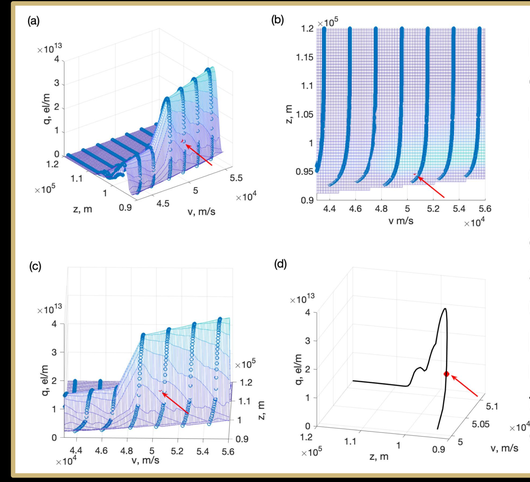

Figure 2: A visual depiction of how the meteoroid ablation profiles (produced by CABMOD) can be interpolated across electron density (**q**), altitude (**z**) and velocity (**v**). This allows for a profile that best matches an observation to be used to determine conditions at 500 km [2].

Results and Discussion

Meteors observed over three time periods were used to demonstrate the functionality of this methodology, Aug. 15th – Sept. 20, Oct. 23 – Nov. 21, and Dec.3 – Dec. 31, 2024. In total, the pre-atmospheric conditions for **4803** unique meteoroids were obtained.

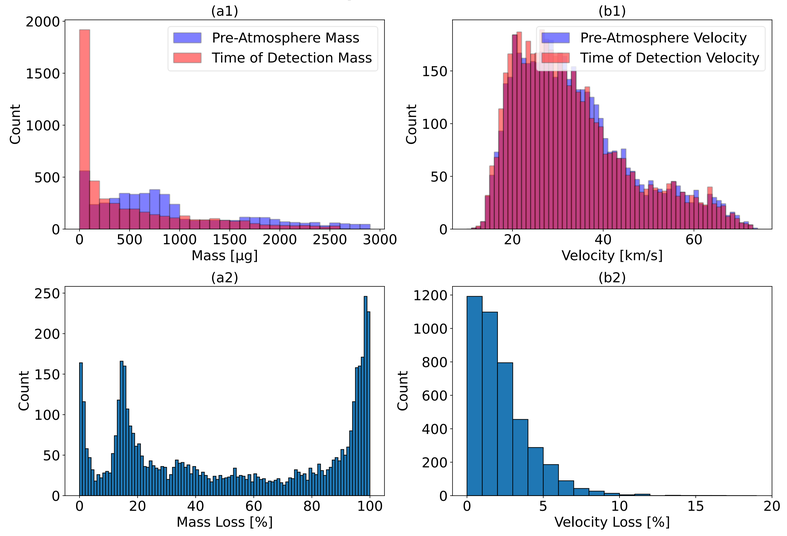

Figure 3: Distributions of the pre-atmospheric and time of detection **(a1)** mass and **(b1)** velocity of meteoroids observed by SAAMER-OS, and the percentage **(a2)** mass lost and **(b2)** velocity lost by meteoroids prior to detection. This figure includes the total population of 4803 meteoroids across all sample periods.

Results and Discussion Continued

As seen in **Figure 3 (a2)**, applying this methodology to real meteor data reveals the presence of three populations of meteoroids with distinct ablation characteristics, loosing ~1, 15, and 99% of their initial mass. These likely belong to families of meteoroids with different compositions and volatilities, possibly stemming from distinct sources.

Figure 3 (b2) shows that, despite distinct ablation populations being present, nearly all meteoroids lost < 10% of their initial velocity, indicating that meteoroid deceleration processes share commonality across compositions.

While these preliminary results are interesting, they are not yet fully representative of the environment. The use of pre-computed tables requires several simplifying assumptions that limit the number of events that are successfully processed, including a Carbonaceous Ivuna (CI) meteoroid composition and isothermal meteoroids.

Conclusions

A methodology for determining the pre-atmospheric conditions of meteoroids was demonstrated on a sample population of 4803 meteors. Analysis revealed the presence of three distinct ablation regimes, where mass loss peaked at 1, 15, and 99%. These populations indicate the presence of different compositional families of meteoroids. Additionally, it was found that most meteoroids lost <10% of their velocity prior to detection. A larger sample is currently being processed to improve statistics.

References:
[1] Stober et al. (2023), Polarization dependency of transverse scattering and collisional coupling to the ambient atmosphere from meteor trails, Planet. Space Sci., 237, 105768.
[2] Dawkins et al. (2023), A novel methodology to estimate pre-atmospheric dynamical conditions of small meteoroids, Planet. Space Sci., 238, 105796.
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