Meteoroid environment modeling: the Meteoroid Engineering Model and shower forecasting

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Outline

Sporadics: Meteoroid Engineering Model (MEM)
  Description
  Future improvements

Showers: Shower forecasting
  Description
  Recent improvements
Stand-alone software
 Computes meteoroid environment relative to spacecraft
 Does not include temporal variations such as showers
 Most appropriate during design phase
MEM generates trajectory-specific environment

- MEM takes spacecraft trajectory into account
- Also accounts for influence of Earth or Moon in sub-models
- Earth’s gravity enhances the meteoroid flux near Earth
- The Earth also physically blocks some meteoroids
- MEM computes both effects at the spacecraft’s location

Diagram from Jones & Poole, 2007
Meteoroid directionality is not isotropic
Meteoroid velocity is not uniform

\[ \langle v \rangle \neq \sqrt{\langle v^2 \rangle} \]
Pillars of MEM

Damage done by a meteoroid impact depends on:
- mass
- velocity/impact angle
- density (currently 1 g/cc)

We are revisiting each of these components for the next version of our Meteoroid Engineering Model (MEM).

Meteoroid impact crater on shuttle window. Image provided by the NASA/JSC Hypervelocity Impact Technology (HVIT) Team.
Velocity distribution improvements
Improved de-biasing and “sharpening”

Brown et al. (2004)
Moorhead et al. (2017)
de-biased and sharpened
We fit log-normal distributions to the two density groups:

- \( T_J < 2 \) – HTCs, NICs – apex and toroidal
- \( T_J > 2 \) – JFCs, asteroids – helion/antihelion
MEM Recap

- **MEM**: a stand-alone piece of software, describes meteoroid environment along user-supplied spacecraft trajectory.

- Currently working to revise model:
  - **Velocity** distribution is:
    - derived from radar (CMOR) observations,
    - de-biased using modern ionization efficiency, and
    - sharpened to remove uncertainty smoothing.
  - **Density** distribution is based on Kikwaya et al. (2011) and links density to dynamical class.

- Future work: revisit flux(mass) and characterize uncertainties.
MEM’s environment is time-invariant

MEO shower forecast provides time-dependent shower fluxes

These are derived from hourly rates (ZHRs)

\[ \propto 10^{B_p(\lambda_\odot - \lambda_0)} \]

\[ \propto 10^{-B_m(\lambda_\odot - \lambda_0)} \]
We use the Grün meteoroid flux as a point of comparison.

Reference speed is 22.75 km s\(^{-1}\) at 400 km altitude (due to grav focusing).
Flux comparison

Example Fluxes

- 0.04 cm
- 0.10 cm
- 0.30 cm
- 1.00 cm

Flux (m$^{-2}$ hr$^{-1}$)

UT Date

Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Enhancement factors

The forecast reports fluxes on a flat plate facing the shower radiant vs.

This is a “worst-case scenario” for shower exposure. Although typically showers are a small fraction (0.9% - 15%) of the baseline flux, the risk enhancement can be significant for a fully exposed element.
Example Enhancement Factors

- **UT Date**
- **Flux Enhancement (%)**
- **0.04 cm**
- **0.1 cm**

Enhancement factors for various months are shown with specific increase factors for certain dates.
Activity profiles in the annual forecast
Original forecast parameters from Jenniskens (1994)

Plots from Jenniskens (1994)
Visual observations in both the northern and southern hemispheres.
14 years of CMOR data
Arietids
Arietids

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Improved showers

In the end, we were able to improve the activity profiles for 12 showers:
Shower forecast recap

- The MEO generates annual meteor shower forecasts that report:
  - Shower fluxes (based on ZHR and other shower parameters)
  - Baseline fluxes
  - Enhancement factors (to support risk assessments)
- More recent, we revised many shower activity profiles.
  - We used 14 years of fluxes from CMOR (advantageous for daytime showers in particular)
  - We were able to improve the profiles of 12 major meteor showers.
- We plan to expand this in the future to include additional data and constrain mass indices.