Meteor shower forecasting
for spacecraft operations

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Overview

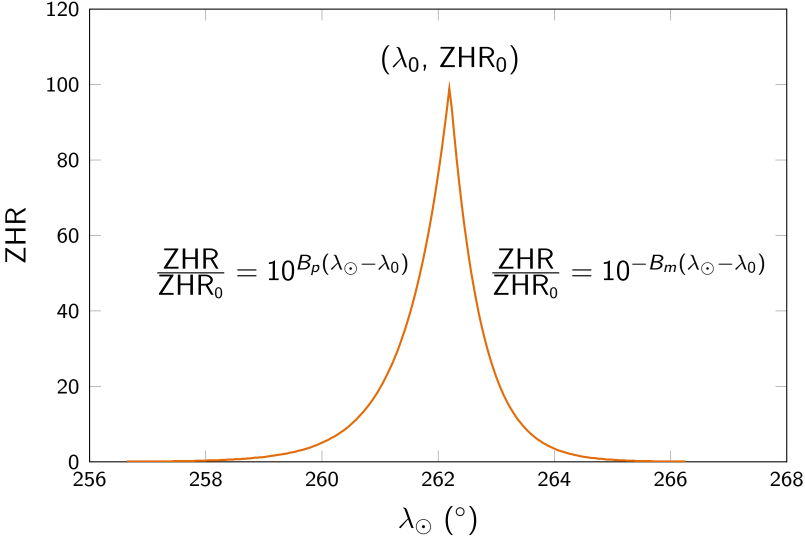
Forecast outputs
- Shower flux
- Baseline flux
- Enhancement factors

Shower activity profiles
- Background
- Data
- Fitting algorithm
- Improved profiles

Summary

Shower fluxes are computed from ZHR

Shower activity profile



Shower fluxes are computed from ZHR

Koschack & Rendtel (1990; KR90)

1. Calculate magnitude-limited flux from ZHR:

$$f_{6.5} = \frac{\mathrm{ZHR}_0 \cdot (13.1r - 16.5)(r - 1.3)^{0.748}}{37200\ \mathrm{km}^2}$$

2. Convert to milligram-or-larger flux (faster = brighter):

$$f_{\mathrm{mg}} = f_{6.5} \cdot r^{9.775 \log_{10}\left(\frac{29\ \mathrm{km/s}}{v_{100\ \mathrm{km}}}\right)}$$

3. Scale to desired mass:

$$\frac{f_m}{f_{\mathrm{mg}}} = \left(\frac{m}{1\ \mathrm{mg}}\right)^{1-s}$$

where $s = 1 + 2.3 \log_{10} r$ is the mass index.

Shower flux

- We report fluxes to 4 limiting particle kinetic energies.

KE_{ref} (J)	m_{ref} (g)	d_{ref} (cm)
6.7	3.35×10^{-5}	0.04
104.7	5.24×10^{-4}	0.1
2827.	1.41×10^{-2}	0.3
104720.	5.24×10^{-1}	1.0

- For each shower, we calculate the appropriate limiting mass:

$$m_{lim} = m_{ref} \times \left(\frac{20 \text{ km/s}}{v_{400 \text{ km}}} \right)^2$$

Shower flux

Gravitational focusing and shielding

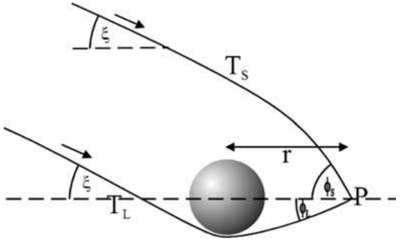


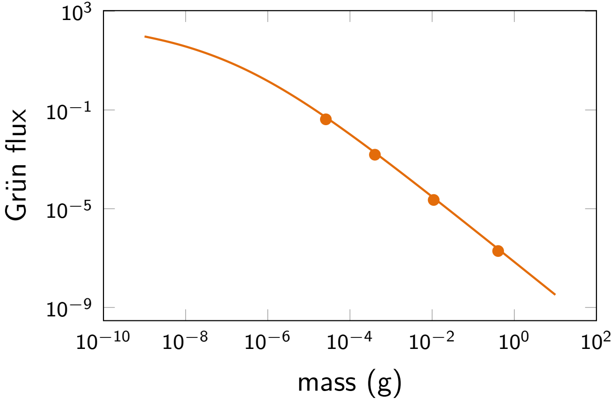
Diagram from Jones & Poole, 2007

- Earth's gravity enhances the meteoroid flux near Earth
- The Earth also physically blocks some meteoroids

- Shower fluxes include gravitational focusing but *not* shielding.
- Reflects a "worst-case" scenario in which a spacecraft element is fully exposed to the shower.

Baseline flux

- 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).



Baseline flux

Gravitational focusing and shielding

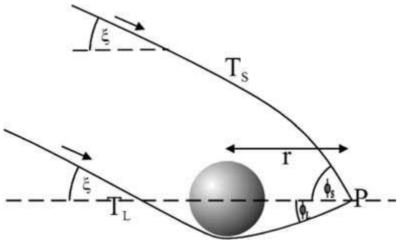
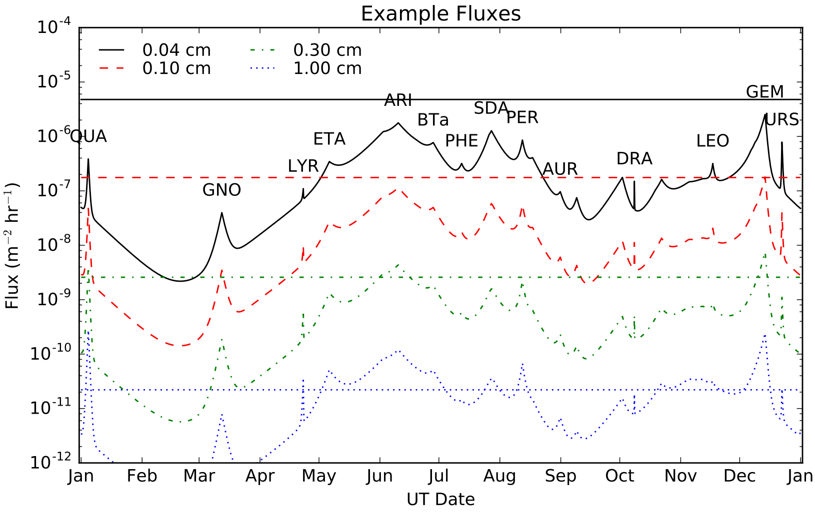


Diagram from Jones & Poole, 2007

- Earth's gravity enhances the meteoroid flux near Earth
- The Earth also physically blocks some meteoroids

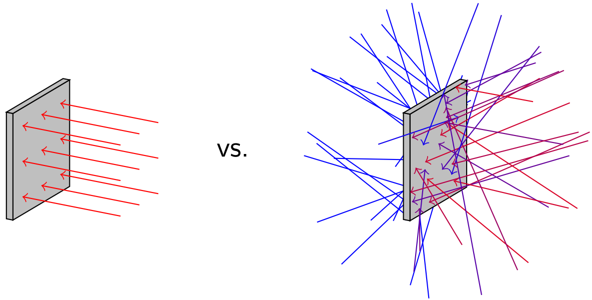
- Baseline flux includes gravitational focusing *and* shielding.
- A portion of the sporadic flux will be blocked by the Earth.

Flux comparison



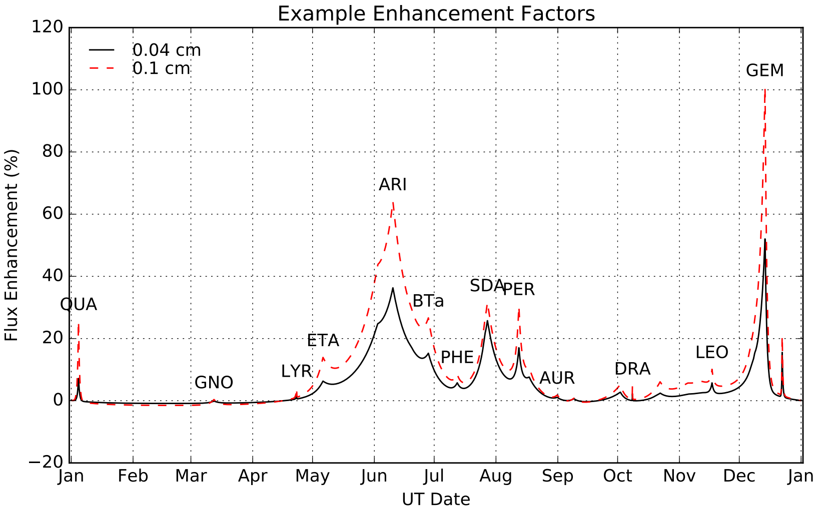
Enhancement factors

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



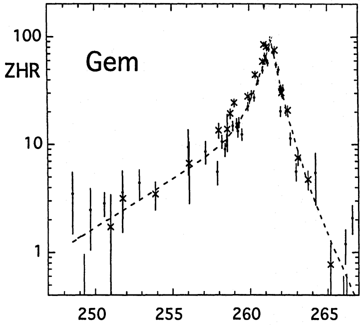
This is a “worst-case scenario” for shower exposure. Although typically showers are a small fraction (0.9% - 15%) of the baseline flux, the risk enhancement can be significant for a fully exposed element.

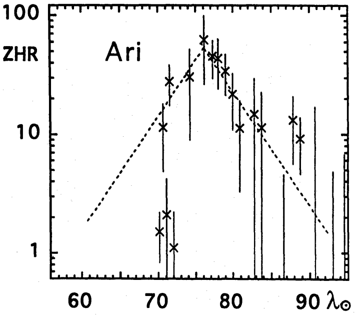
Enhancement factors



Activity profiles in the annual forecast

Original forecast parameters from Jenniskens (1994)



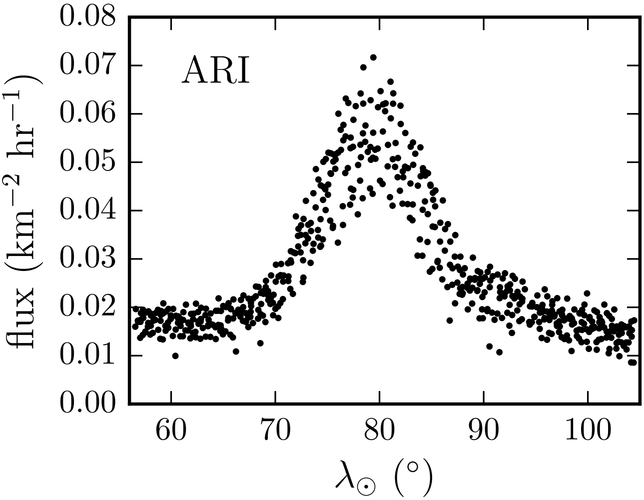


Plots from Jenniskens (1994)

Visual observations in both the northern and southern hemispheres.

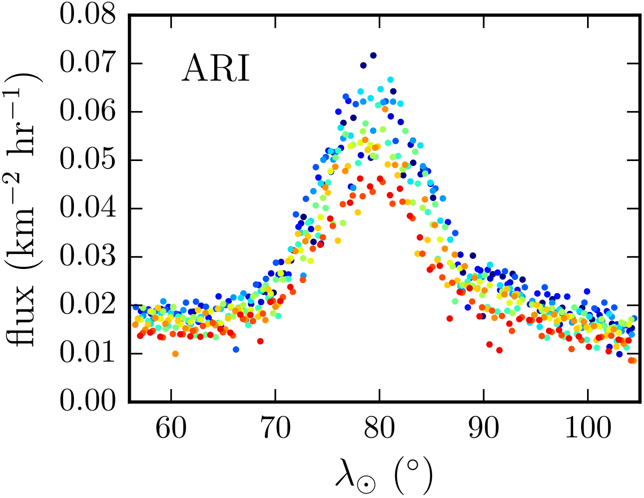
14 years of CMOR data

Arietids



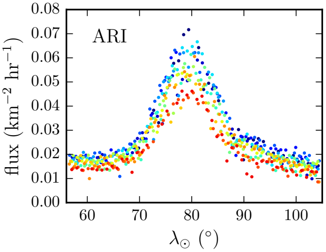
14 years of CMOR data

Arietids: color-coded by year

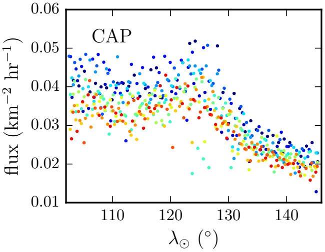


Challenges

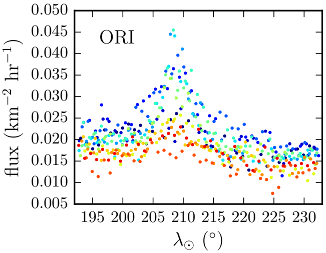
background varies by year:



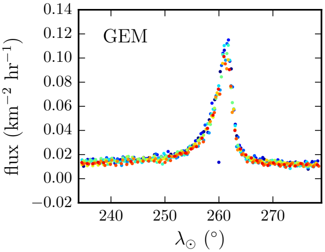
trends in background:



sensitivity varies by year:



outliers:



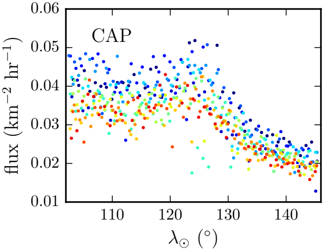
Step 1: Fit trend to background

I weight the data away from the peak more:

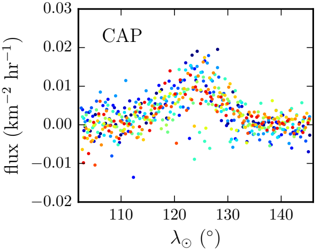
$$w_i = (\lambda_{\odot,i} - \lambda_0)^2 \tag{1}$$

And fit a linear trend:

$$f_{bg} = a\lambda_{\odot} + b_{yr} \tag{2}$$



$\longrightarrow$

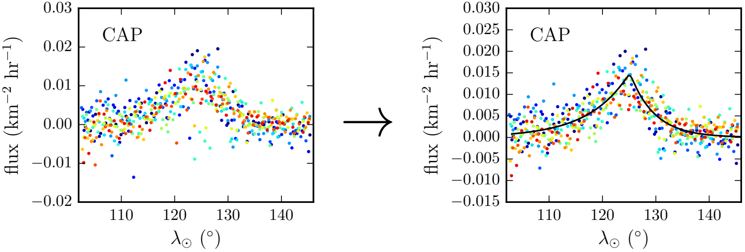


Step 2: Initial fit to data

Next, I fit for f_0, B_p, B_m, and λ_0

$$f = f_0 \cdot \begin{cases} 10^{+B_p(\lambda_\odot - \lambda_0)} & \lambda_\odot < \lambda_0 \\ 10^{-B_m(\lambda_\odot - \lambda_0)} & \lambda_\odot > \lambda_0 \end{cases}$$

I clip 5-σ outliers and iterate until there are none.

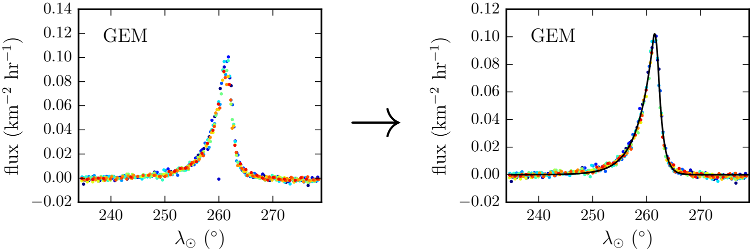


Step 2: Initial fit to data

Next, I fit for f_0, B_p, B_m, and λ_0

$$f_1 = f_0 \cdot \begin{cases} 10^{+B_p(\lambda_\odot - \lambda_0)} & \lambda_\odot < \lambda_0 \\ 10^{-B_m(\lambda_\odot - \lambda_0)} & \lambda_\odot > \lambda_0 \end{cases}$$

I clip 5-σ outliers and iterate until there are none.

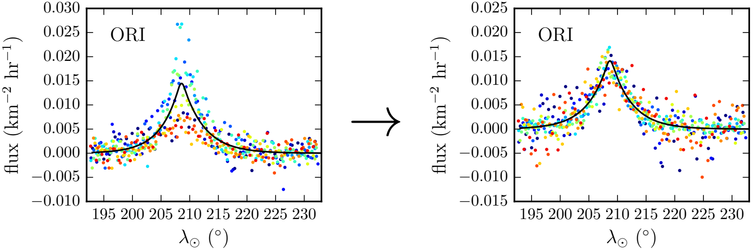


Step 3: Fit amplitudes

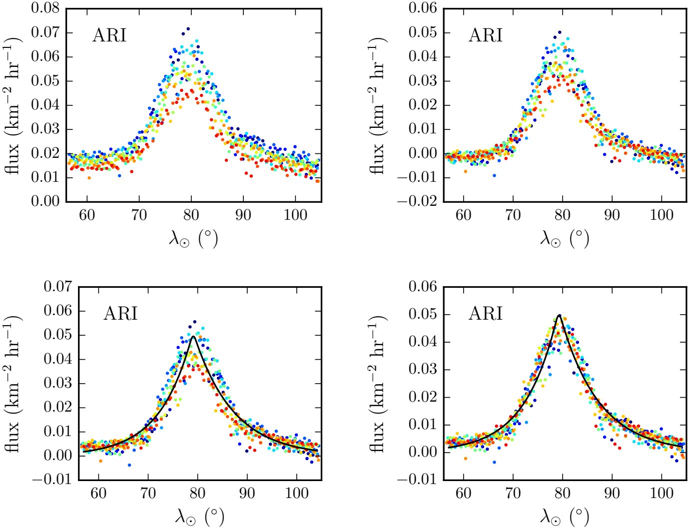
Using $f_1(\lambda_\odot)$ from Step 2, I allow the amplitude to vary by year:

$$f_i = \sum_{yr} f_1(\lambda_i) * a_{yr} + b_{yr}$$

I use these a and b values to normalize the data, and then again fit for the shape parameters.

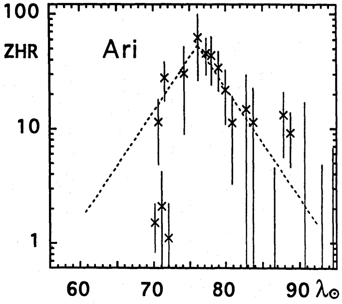


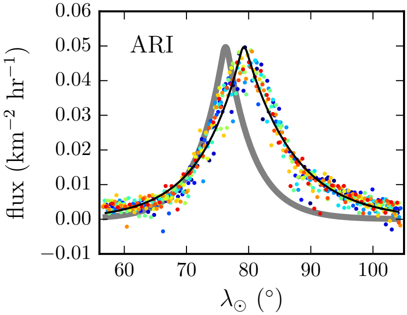
Arietids


ARI
ARI
ARI
ARI
flux (km^{-2} hr^{-1})
$\lambda_\odot$ (°)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
−0.01
−0.02
60
70
80
90
100

Arietids

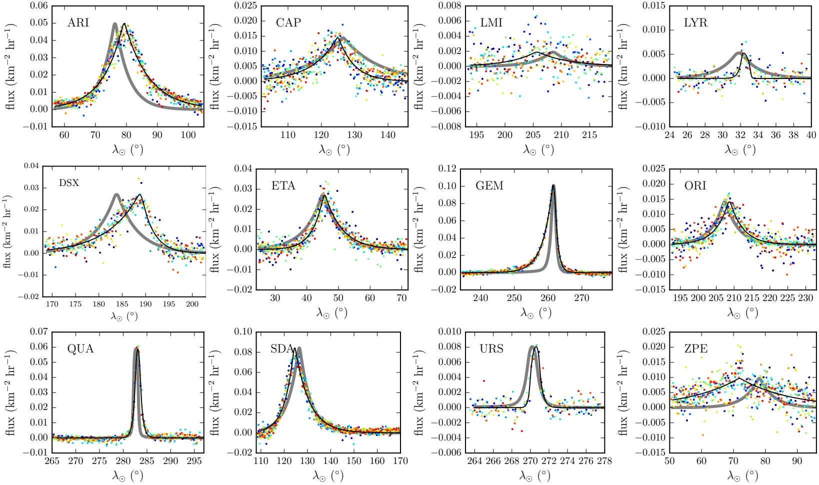
- Comparing Jenniskens (1994) with this work (right).
- Previous forecast profiles appears in gray (peak amplitude matched)





Improved showers

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



Summary

- 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.