

MEM in the Cloud Overview

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NASA Meteoroid Environment Office

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Overview

- Attributes of the Meteor Engineering Model (MEM)
 - Spacecraft and the meteoroid environment
 - Technical limitations of MEM
- MEM in the Cloud
 - User interface
 - Output files
- Summary

Attributes of the Meteoroid Engineering Model

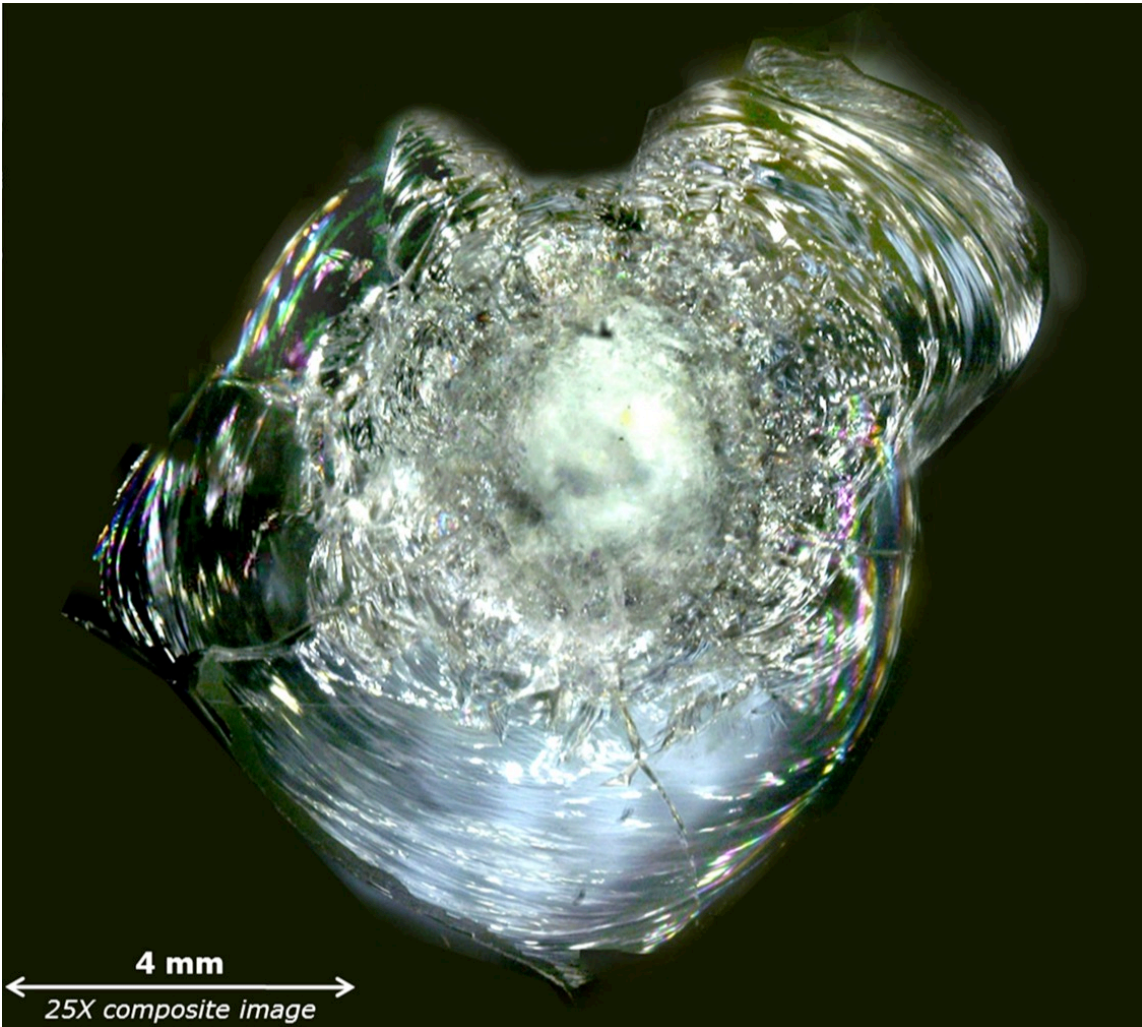


MEM Characterizes Meteoroid Environment

- The meteoroid environment can damage both spacecraft and astronauts.

diameter	KE	damage
🔫 BB gun		
0.04 cm	7 J	spacesuit
0.1 cm	105 J	delicate components
🎳 bowling ball		
0.3 cm	3 kJ	sturdier components
🍈 watermelon at terminal velocity		
1 cm	105 kJ	mission-critical
🏗️ small wrecking ball		

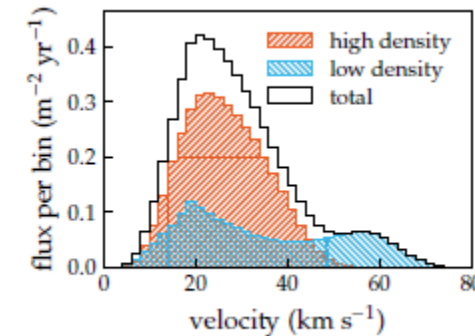
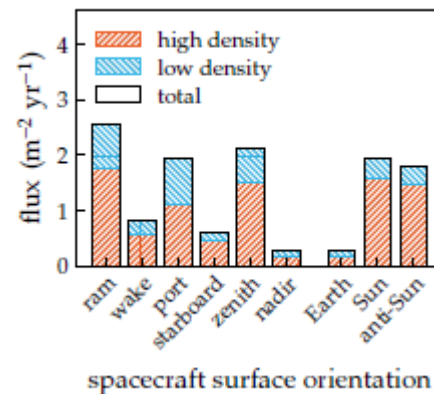
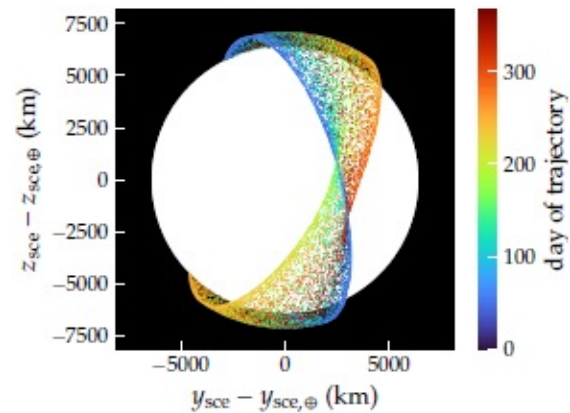
table by Althea Moorhead from NASA Meteoroid Environment Office (MEO)
grade stainless loose ball bearings by Oleksandr Panasovskyi from the Noun Project
strike by Randomhero from the Noun Project
watermelon by Blaise Sewell from the Noun Project
wrecking ball crane by Gan Khoon Lay from the Noun Project



meteoroid impact crater image provided by the NASA/JSC Hypervelocity Impact Technology (HVIT) Team

Meteoroid Engineering Model

- MEM is a physics-based model.
- Only sporadic meteors are included in the model.
- To calculate the possible damage from this environment, engineers require “rate of impacts...speeds, densities, and direction of motion of meteoroids” (Moorhead, 2019).



Trajectory and MEM output Plots for Aqua, a NASA research satellite

Charts by Althea Moorhead from NASA MEO

<https://fireballs.ndc.nasa.gov/mem/library/aqua.html>

Meteoroid Orbits

- MEM's meteoroid orbits are derived from comets.
- Jones (2004) found a relation between comet orbits and meteoroid populations:
 - Helion/anti-helion meteoroids originate from short-period comets.
 - Apex meteoroids originate from long-period comets.
 - Toroidal meteoroids originates from Halley-type comets.

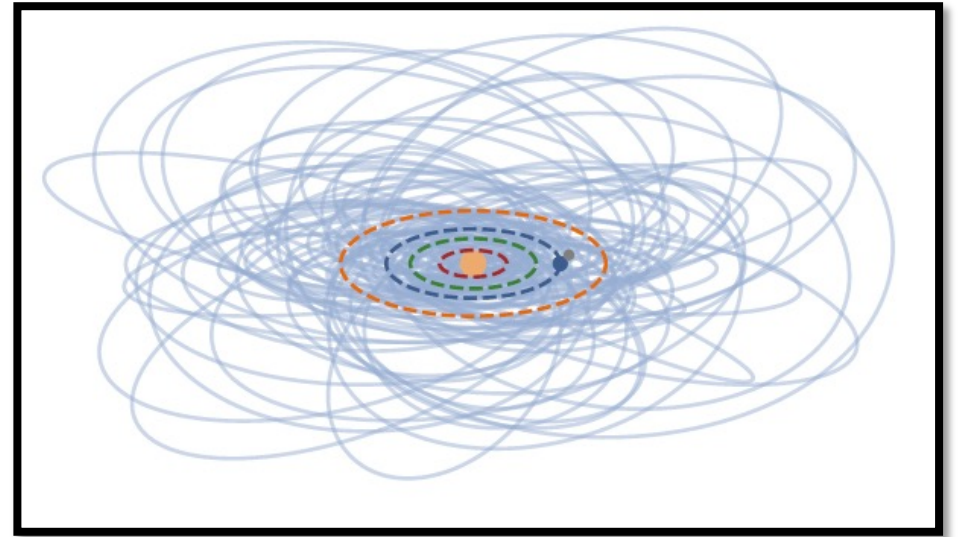
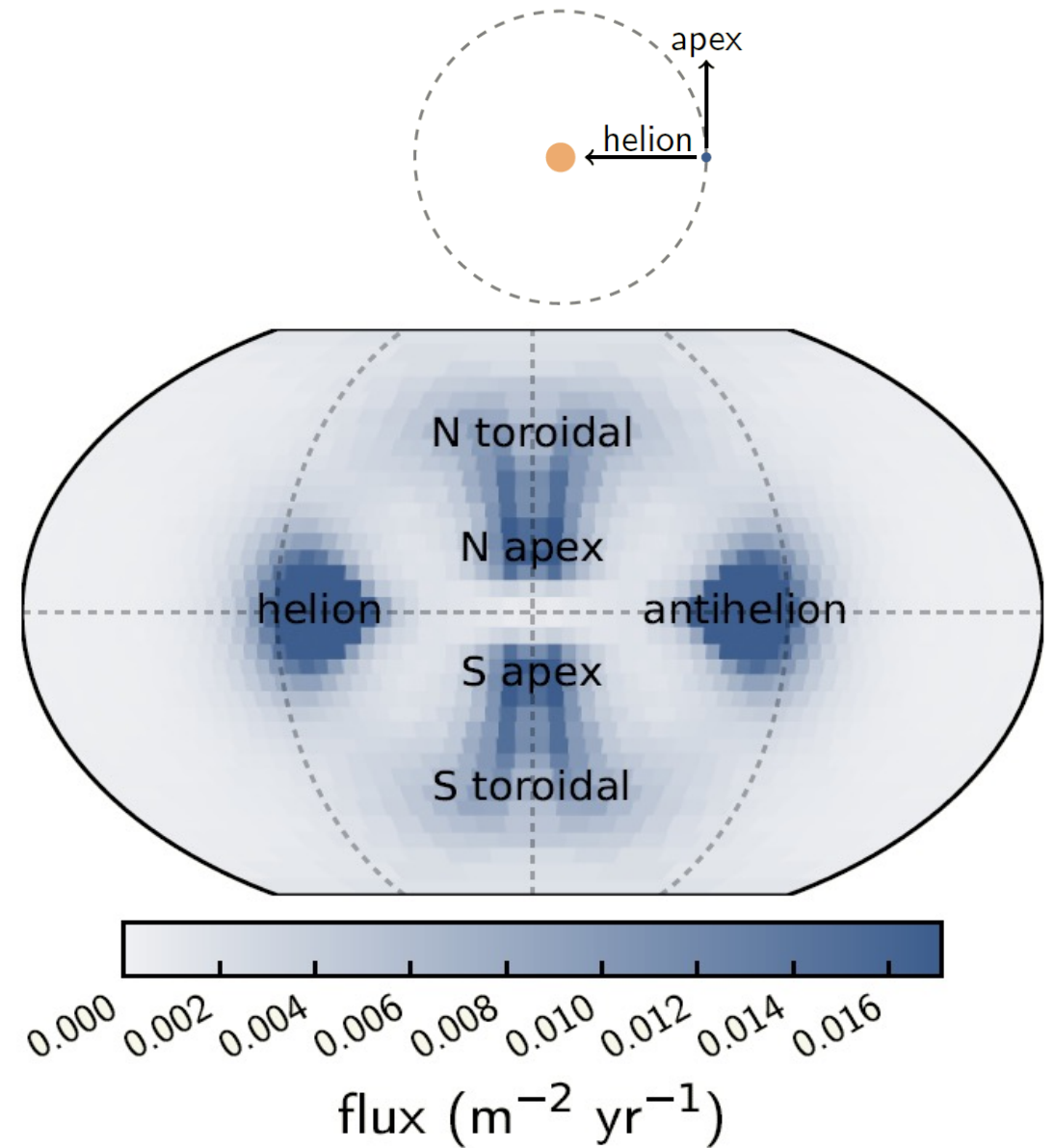


Image by Althea Moorhead from NASA MEO

Directional Distribution of Meteors

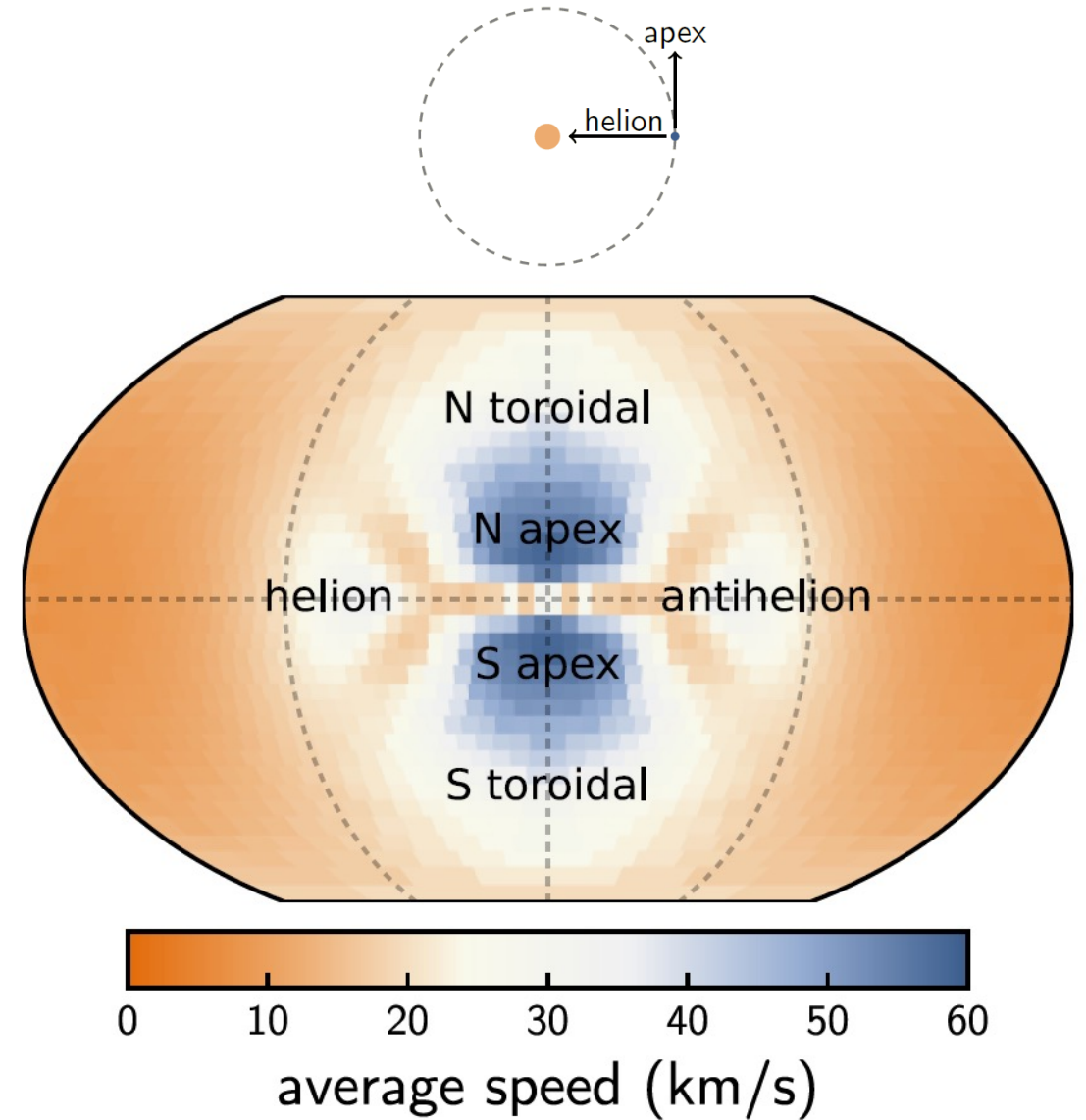
- The meteoroid environment is not isotropic.
- Three meteor orbit populations divided into six concentrations are shown in the directional map.



Plot by Althea Moorhead from NASA MEO

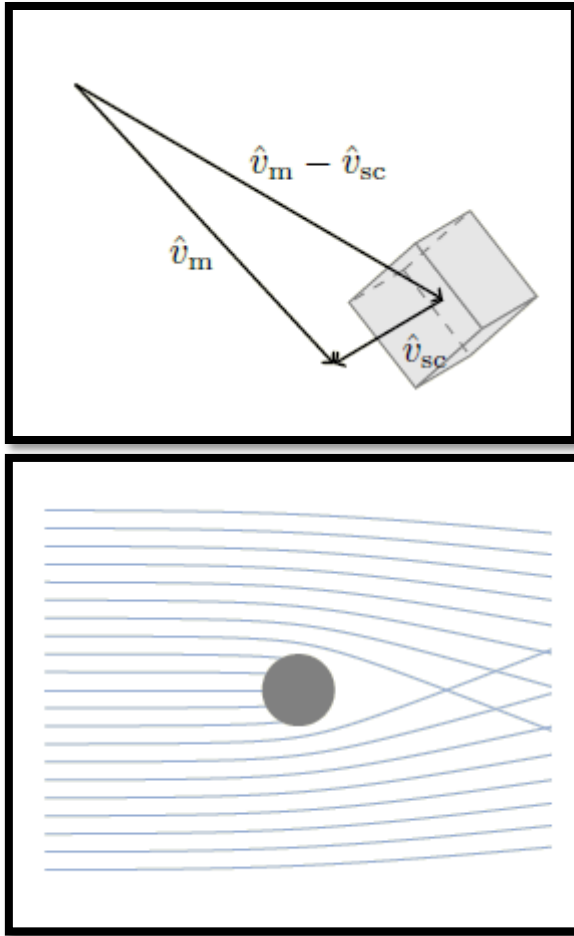
Speed Distribution of Meteors

- Meteor directionality and speed are not independent.
- Each of the three orbit populations have different average speeds with apex meteors possessing greater speeds.



Plot by Althea Moorhead from NASA MEO

Spacecraft Motion and Gravitational Protection

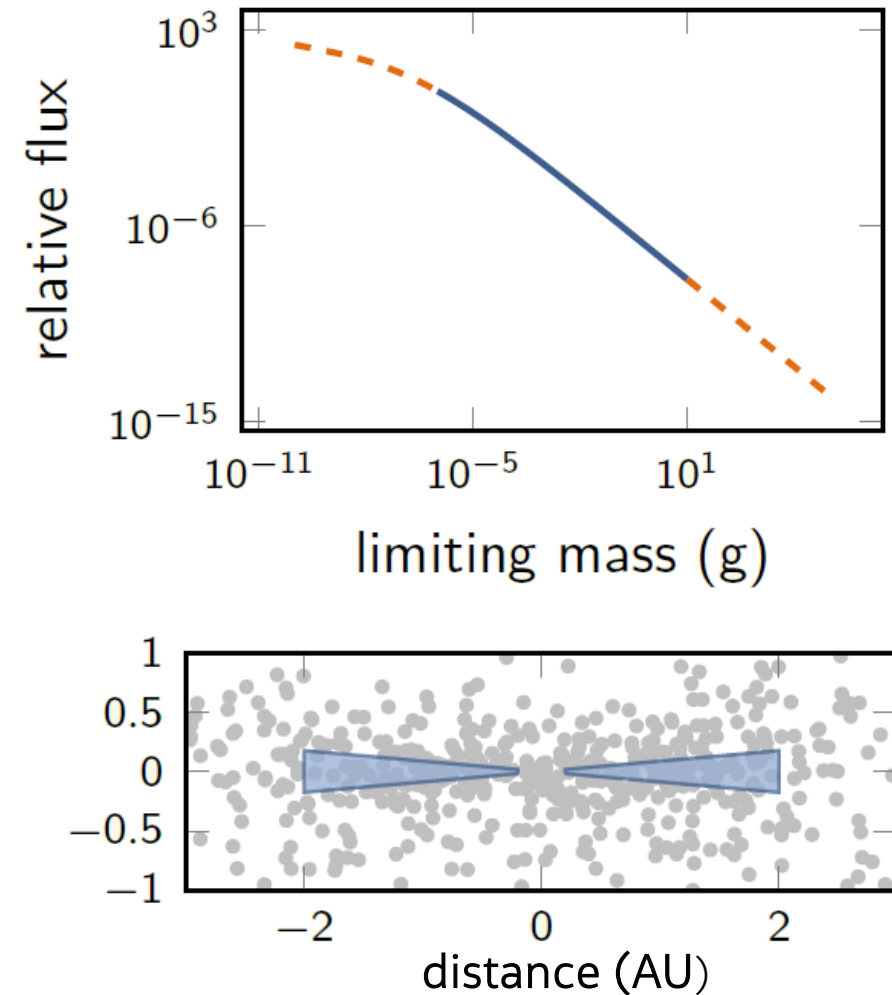


Images by Althea Moorhead from NASA MEO

- MEM incorporates the spacecraft's relative motion.
- MEM also includes gravitational shielding and focusing.

Location and Mass Limits

- MEM is currently limited to the inner solar system:
 - 0.2 – 2.0 AU
 - 5° of the ecliptic
- MEM is limited to meteoroids with a mass of $10^{-6} - 10^1 \text{g}$.



Plots by Althea Moorhead from NASA MEO

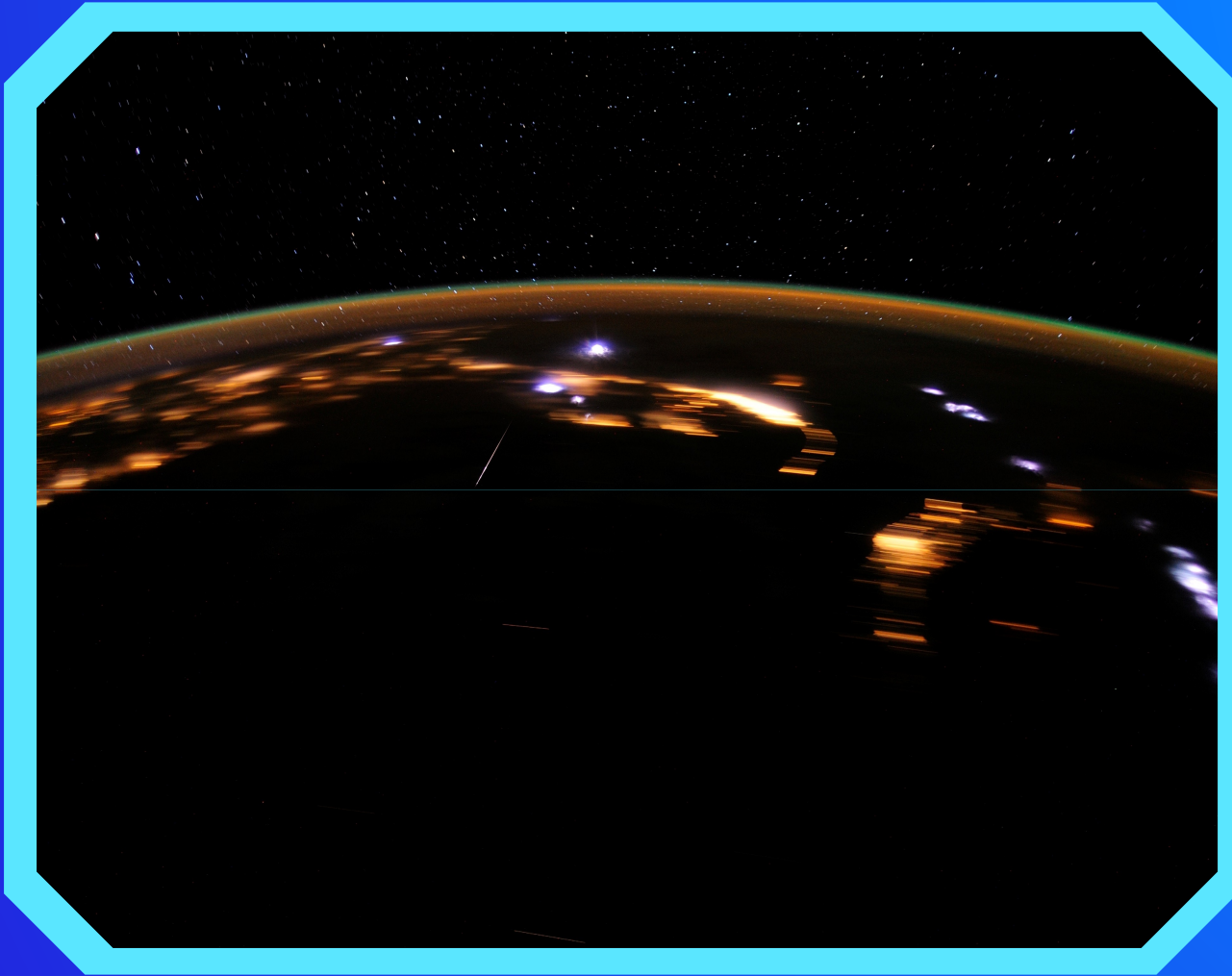
System Requirements of MEM

- While no formal system minimum requirements have been determined, MEM is known to work on:
 - Windows 7/10.
 - MacOS versions Catalina through Sonoma.
- Linux distributions are currently unavailable.

Technical Limitations of MEM

- How the user interacts with MEM is not necessarily the same across operating systems:
 - Windows OS provides greater flexibility in that the end user can run via a graphical user interface (GUI) or command line (CL).
 - MacOS only run via command line.
- Additionally, the efficiency of the program can vary based on the hardware. Newer versions of MEM include parallel processing to improve the rate of computation.

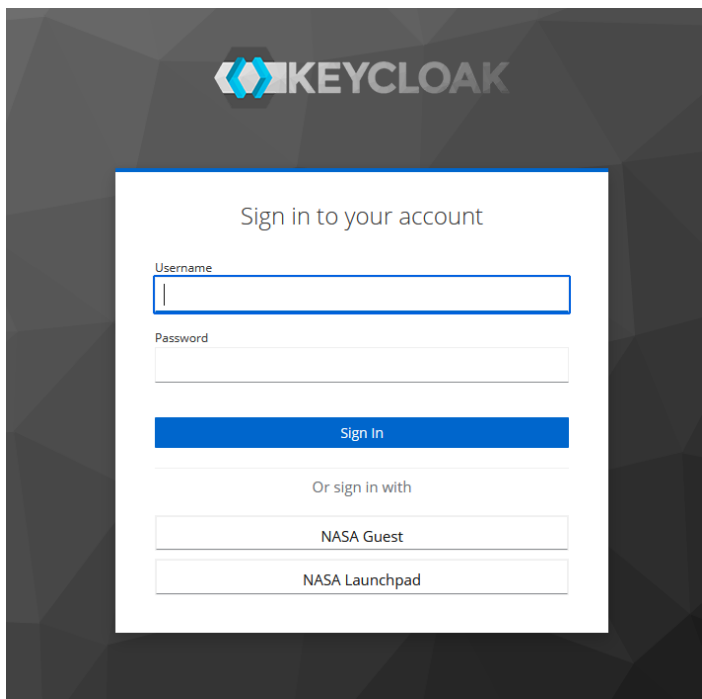




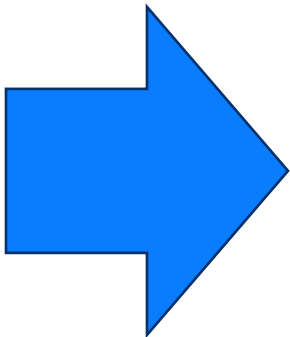
Attributes of MEM in the Cloud

Login required

- MEM in the Cloud requires a NASA Guest log in.



<https://mem.mmod.appdat.jsc.nasa.gov/>



MEM 3 Web Application

Help

Form not working? Please check that Javascript is enabled.
Hover over form fields below for usage tips.
[user guide \(PDF\)](#)
[example runs](#)

Input options

upload trajectory:

Browse...

No file selected.
file size cannot exceed 500 MB

input origin:

Earth

input axes:

equatorial

Run options

vectors used:

all

vector count (n):

limiting mass:

-6

enter log base 10 of mass in grams

high-fidelity mode:

☐

Output options

output origin:

Earth

output axes:

body-fixed

angular resolution:

5°

velocity resolution:

1 km/s

intermediate files:

☐

igloo flux files:

☐

standard deviation files:

☐

Check options

Start run

Submitted runs:

Help Section – Overview

MEM 3 Web Application

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☐

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☐

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☐

Check options

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Help

Form not working? Please check that Javascript is enabled.
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[user guide \(PDF\)](#)
[example runs](#)

Help Section – User Guide

Home

1 Introduction

1.1 History

1.2 Requirements

1.3 Limitations

1.4 Version history

2 The environment

2.1 Flux

2.2 Directionality

2.3 Velocity

2.4 Density

3 Application use

3.1 Interface

3.2 Input

3.3 Output

4 Interpretation

4.1 Coordinate frames

4.2 Flux reporting

4.3 Density distributions

4.4 Mass scaling and risk

5 Uncertainty

Meteoroid Engineering Model (MEM)

Web Application User Guide

1 Introduction

The Meteoroid Engineering Model (MEM) version 3 is NASA's most current and accurate model of the meteoroid environment. MEM 3 supersedes all Release 1.0c (MEMR1c), and previously internally controlled and released versions of MEMCvP v2.0 and LunarMEM v2.0. Earlier versions of MEM supported the use of the Meteoroid Engineering Model (MEM) and its derivative, Technical Memo 4527 (Smith, 1994; hereafter abbreviated as TM 4527).¹

1.1 History

Prior to the establishment of the NASA Meteoroid Environment Office (MEO), NASA's meteoroid environment models relied on a simple empirical expression and later in TM 4527.³ This expression describes the meteoroid flux incident on a flat plate near 1 au. TM 4527 assumes an isotropic environment, many factors to account for the reduction in flux occurring when the Earth shields the spacecraft from a portion of the meteoroid environment and the enhanced flux from the Earth's atmosphere. TM 4527 also introduced a crude, piecewise meteoroid speed distribution with an average velocity of 19 km/s for an orbiting spacecraft based on Kessler's model. Dust particles smaller than 10^{-6} g have a density of 2 g/cm³, micrometeoroids between 10^{-6} g and 0.01 g have a density of 1 g/cm³, and meteoroids larger than 0.01 g have a density of 3 g/cm³. The model presented in TM 4527 was assembled from multiple independent sources.

Although TM 4527 was the first effort to build a comprehensive model of the meteoroid environment, it was never formally peer-reviewed and does not represent the current state of knowledge. As a result, TM 4527 underrepresents the risk of meteoroid impacts posed to spacecraft in low Earth orbit. The subsequent review of NASA's meteoroid models, which whose flux and speed were consistent with the observations and physics. This model forms the basis of MEM and is briefly described in [section 2](#).

- The Meteoroid Environment Office (MEO) has converted a user guide to HTML from NASA/TM—2020–220555 for MEM which goes into detail how to use MEM and, in turn, MEM in the Cloud.

<https://fireballs.ndc.nasa.gov/mem/guide/>

Help Section – Example Runs

Home

1 About

2 Earth

2.1 ISS

2.2 Aqua

2.3 GOES-14

2.4 JWST

3 Moon

3.1 LADEE

3.2 NRHO

4 Mercury

4.1 MESSENGER

5 Venus

5.1 Venus Express

6 Mars

6.1 MRO

6.2 MAVEN

7 Interplanetary

7.1 MAVEN transfer

Aqua

Sun-synchronous orbit (SSO)

Files

Click [here](#) to download the trajectory.

Click [here](#) to download the run options file.

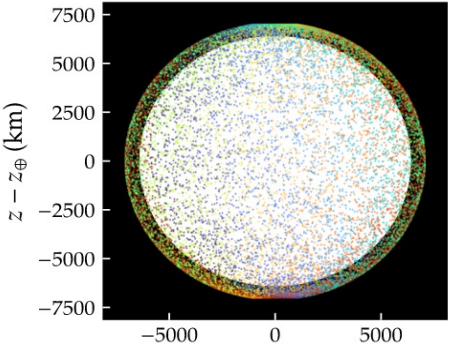
Description

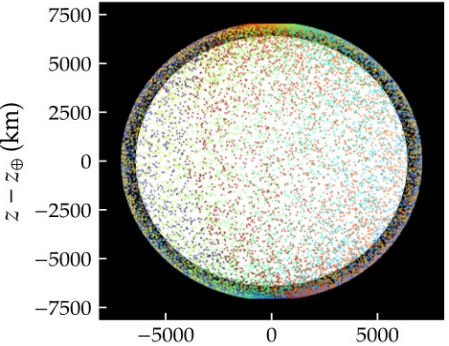
Aqua is part of NASA's Earth Observing System (EOS), a group of satellites that observe the Earth's surface and biosphere. These satellites are in Sun-synchronous orbit (SSO). Their orbits are nearly polar such that each orbit precesses once per year, allowing the satellites to observe the Earth's surface at a consistent illumination angle. This means that the orbit tends to preserve a similar orientation with respect to the Sun.

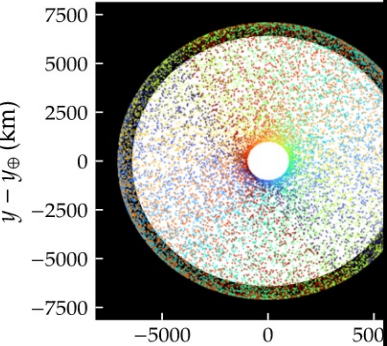
SSO is a category of low Earth orbit (LEO), and thus the meteoroid environment encountered by Aqua will be similar in magnitude to that of the ISS. However, the apparent directionality will differ due to the orbital inclination between these spacecraft and, more importantly, to the fact that Aqua maintains a similar orbital orientation relative to the sporadic meteoroid sources while the ISS does not.

Graphics

Trajectory in inertial frame







- The MEO provides several example trajectories and MEM configuration options

<https://fireballs.ndc.nasa.gov/mem/library/>

Input Option Section

MEM 3 Web Application

Help

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[user guide \(PDF\)](#)
[example runs](#)

Input options

upload trajectory:

Browse...

No file selected.

file size cannot exceed 500 MB

input origin:

Earth

input axes:

equatorial

Run options

vectors used:

all

vector count (n):

limiting mass:

-6

enter log base 10 of mass in grams

high-fidelity mode:

Output options

output origin:

Earth

output axes:

body-fixed

angular resolution:

5°

velocity resolution:

1 km/s

intermediate files:

igloo flux files:

standard deviation files:

Check options

Start run

Submitted runs:

Input options

upload trajectory:

Browse...

No file selected.

file size cannot exceed 500 MB

input origin:

Earth

input axes:

equatorial

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Input Option Section

- Upload trajectory – Select the trajectory file.
- Input origin – Center of the input trajectory. Valid selections are Earth, Sun, Moon, Mercury, Venus, or Mars.
- Input axes – The axis alignment associated with the input trajectory. Valid options are equatorial (Earth) and ecliptic.

Input options

upload trajectory:

Browse...

No file selected.
file size cannot exceed 500 MB

input origin:

Earth ▼

input axes:

equatorial ▼

Run Options Section

MEM 3 Web Application

Help

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[example runs](#)

Input options

upload trajectory:

Browse... No file selected.
file size cannot exceed 500 MB

input origin:

Earth

input axes:

equatorial

Run options

vectors used:

all

vector count (n):

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enter log base 10 of mass in grams

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☐

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☐

Check options

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enter log base 10 of mass in grams

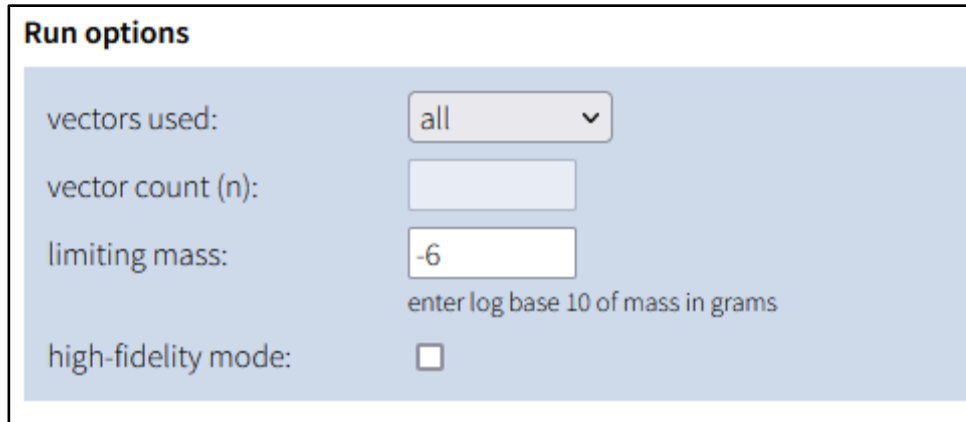
high-fidelity mode:

☐

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Run Options Section



The screenshot shows a 'Run options' panel with a light blue background. It contains four settings:

- vectors used:** A dropdown menu with 'all' selected and a downward arrow.
- vector count (n):** An empty text input field.
- limiting mass:** A text input field containing '-6', with a label below it that reads 'enter log base 10 of mass in grams'.
- high-fidelity mode:** An unchecked checkbox.

- MEM gives the option to use:
 - all state vectors in the trajectory file.
 - the first n vectors of the trajectory file.
 - random selection of n vectors of the trajectory file.
- The vector count refers to the number of state vectors used if not using the entire set.
- Limiting mass – Larger meteoroids will produce a smaller flux.
- High-fidelity mode – Produces files corresponding to each state vector.

Output Options Section

MEM 3 Web Application

Help

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[example runs](#)

Input options

upload trajectory:

Browse... No file selected.
file size cannot exceed 500 MB

input origin:

Earth

input axes:

equatorial

Run options

vectors used:

all

vector count (n):

limiting mass:

-6

enter log base 10 of mass in grams

high-fidelity mode:

Output options

output origin:

Earth

output axes:

body-fixed

angular resolution:

5°

velocity resolution:

1 km/s

intermediate files:

igloo flux files:

standard deviation files:

Check options

Start run

Submitted runs:

Output options

output origin:

Earth

output axes:

body-fixed

angular resolution:

5°

velocity resolution:

1 km/s

intermediate files:

igloo flux files:

standard deviation files:

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Output Options Section

- MEM gives the option to choose a different origin and axes than the input.
- MEM also allows the user to choose the angular and velocity resolutions of the output files.
- Intermediate files will produce flux files for each state vector.
- Igloo flux files provide alternative descriptions of the environment in quasi-equal area angular bins.
- Standard deviation files for the flux can be produced.

Output options

output origin:	Earth ▾
output axes:	body-fixed ▾
angular resolution:	5° ▾
velocity resolution:	1 km/s ▾
intermediate files:	☐
igloo flux files:	☐
standard deviation files:	☐

Submitted Runs Section

Submitted runs:

trajectory	status	progress	time left	
nrho.txt	running		21m 43s	<button>Abort</button>
AquaExample.txt	failed			<button>Details</button> <button>Delete</button>
ISSEExample.txt	complete			<button>Download</button> <button>Delete</button>

*please note that runs are retained for only 3 weeks

- Trajectory – The name of the trajectory file.
- Status – The status of the run:
 - Queued
 - Running
 - Failed
 - Complete
 - Deleted
- Progress – Progress bar marking approximately how long until the run is complete.

Submitted Runs Section

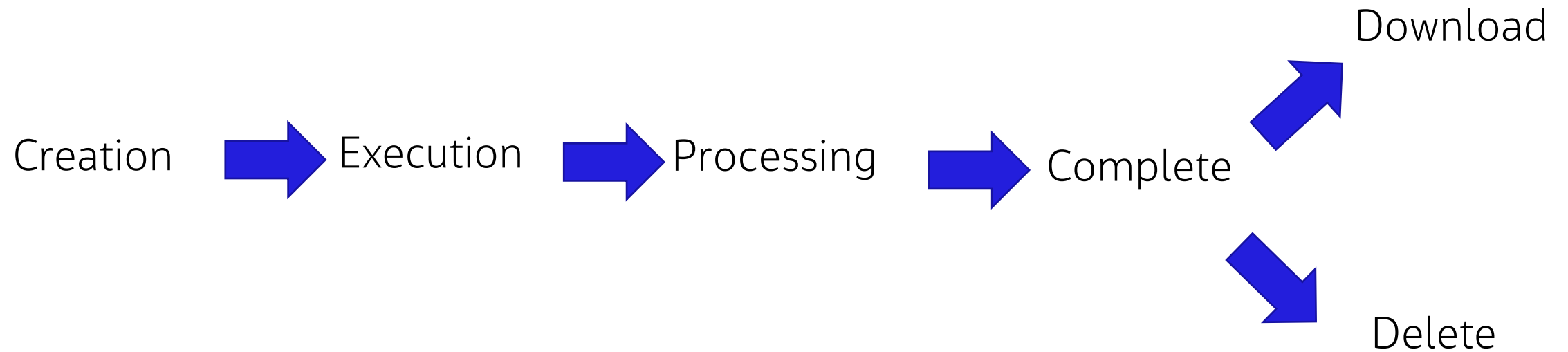
Submitted runs:

trajectory	status	progress	time left	
nrho.txt	running		21m 43s	<button>Abort</button>
AquaExample.txt	failed			<button>Details</button> <button>Delete</button>
ISSEExample.txt	complete			<button>Download</button> <button>Delete</button>

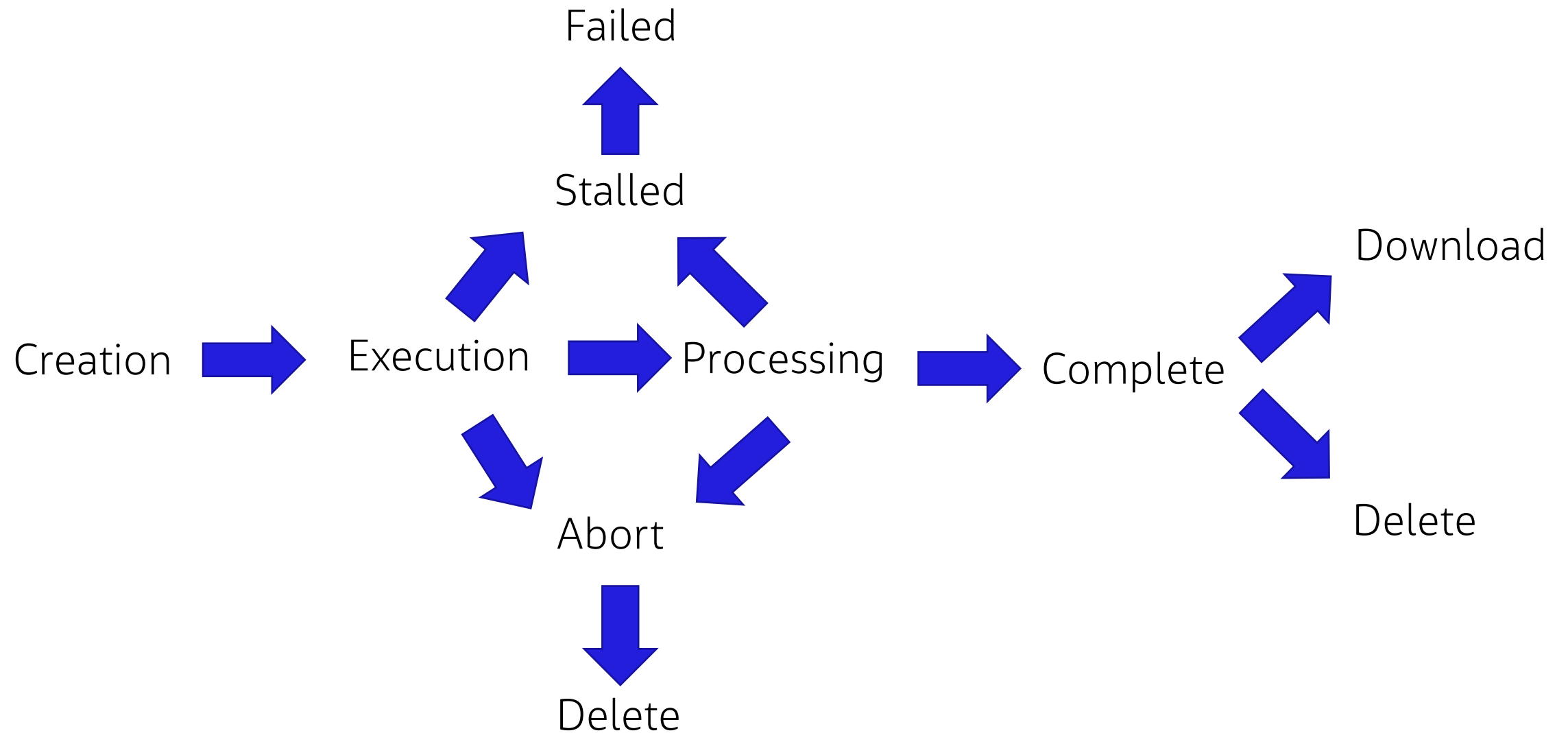
*please note that runs are retained for only 3 weeks

- Time left for the run to complete.
- Action buttons at various stages include:
 - Abort, which cancels the run.
 - Details, which displays the log.
 - Download, which downloads the zip files.
 - Delete, which deletes the run from the database.

The Lifecycle of A Successful Run



The Possible Lifecycle of A Run



Failed Executions

- Users can see the details of any failed run.
- This report includes:
 - MEM version
 - Start time and date
 - Error description

user log:

```
meteoroid engineering model (mem) version 3.0.2c  
run started at 15:35:23 pm 07/23/24
```

```
-----  
error: predicted total output file size exceeds limit
```

Storage

- It was discovered that past runs were sometimes lost once the user left the interface. There was no guarantee that the same instance would be accessed if the user returned.
- The solution was to use Google Cloud Storage (GCS) as it:
 - maintains a cloud backup.
 - automatically restores runs found in the GCS if it is not found in the instance.
 - limits access to the user's past runs.

Output Files - Overview

- Once a run is complete, the user can download a zip file containing all the output files.
- The name of this file is a unique hash number containing the trajectory and run options.

Name	Type	Compress
 HiDensity	File folder	
 LoDensity	File folder	
 hidensity.txt	TXT File	
 info.txt	TXT File	
 ISSEExample.txt	TXT File	
 lodensity.txt	TXT File	
 log.txt	TXT File	
 options.txt	TXT File	
 progress.txt	TXT File	

Output Files – Trajectory file

- The <trajectory>.txt file is a copy of the original input trajectory file.

```
# Aqua
# input origin: Earth
# input axes: equatorial
#
#      JD (TDB)      x (km)      y (km)      z (km)      vx (km/s)      vy (km/s)      vz (km/s)
#
2458849.508239      2890.64113      -2831.58146      -5821.11524      2.95761156      -5.49466886      4.14328808
2458849.508365      2922.64717      -2891.21026      -5775.62488      2.92232129      -5.45992769      4.21387416
2458849.514132      3916.47230      -5096.04224      -2987.64047      0.97284274      -3.18296603      6.71782012
2458849.534092      -103.77288      -1615.16575      6884.45156      -4.26127168      6.03045887      1.34673254
2458849.562836      -1872.34999      4187.34547      -5403.84643      3.76880810      -4.41843983      -4.73420407
2458849.565428      -984.02902      3090.41872      -6303.28493      4.12730943      -5.33180838      -3.26113047
2458849.580975      3714.54786      -4520.80393      -4001.22224      1.65249841      -4.03253831      6.09767194
2458849.593613      2925.00372      -5306.82035      3659.62209      -2.93716389      2.76189833      6.33063861
2458849.595047      2536.96253      -4919.93057      4410.13162      -3.31771630      3.47442262      5.76691221
2458849.612714      -3246.07275      3503.52038      5219.28054      -2.53139219      5.04526133      -4.94915249
2458849.622781      -3864.10232      5909.25834      -570.15287      1.21238113      0.08906777      -7.40405923
2458849.637104      109.56160      1607.42223      -6903.73987      4.26148755      -6.01070970      -1.33334031
2458849.637649      310.00945      1322.52214      -6957.95765      4.25049057      -6.08751540      -0.96900758
2458849.653808      4035.58489      -5608.37491      -1573.44024      0.07598956      -1.96617288      7.23708005
2458849.656507      3930.66306      -5892.03658      144.91878      -0.97148276      -0.45398527      7.42536291
2458849.660772      3285.80869      -5611.56408      2800.99801      -2.48400862      1.95710639      6.80619863
2458849.663596      2577.20906      -4952.77172      4349.80123      -3.29189080      3.41278425      5.81827222
2458849.663719      2542.06281      -4916.19017      4411.35525      -3.32243753      3.47167193      5.76585657
2458849.679635      -2826.97030      2696.42860      5896.84613      -3.05388322      5.56891853      -4.00183199
2458849.683782      -3693.73149      4452.12648      4076.20732      -1.72578651      4.11290623      -6.03841175
2458849.694480      -3409.93886      5702.50456      -2461.50483      2.28841866      -1.62501159      -6.95486756
2458849.700534      -1161.00500      380.01700      5805.80000      3.00011051      6.00000000      1.00000000
```

Output Files – Log and Progress Files

```
Meteoroid Engineering Model (MEM) version 3.0.2c  
Run started at 15:31:57 PM 07/17/24
```

```
-----  
  
Execution terminated successfully
```

```
100% complete, execution completed in 8s
```

- The log.txt file provides information regarding the run, including the version of MEM used, the time the program began running, and whether the program ran successfully.
- The progress file shows the percentage that MEM was able to run and the run time, if applicable.

Output Files – Options File

- The options.txt file contains the MEM run options used.
- A header gives a description of each line below the divide.

```
#####
Options file for MEM 3, contains the following lines:
#
# Line 1 - name of input file
# Line 2 - input origin: (su)n, (ea)rth, (mo)on, (me)rcury, (ve)nus, (ma)rs
# Line 3 - input axes: (eq)uatorial or (ec)liptic
# Line 4 - use (a)ll state vectors, a (r)andom selection, or the (f)irst n
# Line 5 - integer number of state vectors to be used (ignored if using all)
# Line 6 - log10 of the desired minimum particle mass, within [-6, 1]
# Line 7 - high fidelity run (y for yes)
# Line 8 - directory within which results will be placed
# Line 9 - run name (will be used to name results folder)
# Line 10 - output origin : (su)n, (ea)rth, (mo)on, (me)rcury, (ve)nus, (ma)rs
# Line 11 - output axes : (eq)uatorial, (ec)liptic, or (bo)dy-fixed
# Line 12 - desired output resolution in degrees (1, 2, 3, 4, or 5)
# Line 13 - desired output resolution in km/s (1 or 2)
# Line 14 - output intermediate files (y for yes)
# Line 15 - output igloo files (y for yes)
# Line 16 - output standard deviation files (y for yes)
#
#####
ISSEExample.txt
earth
equatorial
all
1
-6
n high fidelity
.
.
earth
body-fixed
5
1
n intermediate files
n igloo files
n standard deviations
```

Output Files – Info File

```
Meteoroid Engineering Model (MEM) version 3.0.2c
Run started at 15:31:57 PM 07/17/24

=====
INPUT FILES AND CHOICES

User's input file:   ISSExample.txt
Limiting mass:       10^-6 grams
State vectors used:  all 10
Output resolution:   5 degrees
High fidelity mode:  no

=====
BRIEF DESCRIPTION OF OUTPUT FILES

-----
FLUX FILES: These files report the meteoroid flux per bin of a three-dimensional
radiant-velocity grid.

- flux_avg.txt: reports the average flux for all state vectors used.

-----
CUBE FLUX FILES: These files report the flux and average speed of meteoroids
relative to a variety of surfaces. The first line of these files reports the
flux on a sphere of unit cross-sectional area. The third line reports the
average speed of meteoroids incident on each surface, and the fourth line
reports the flux on each surface. Subsequent lines break the flux down by speed.

WARNING: AVERAGE SPEEDS ARE TO BE USED FOR ROUGH ESTIMATES ONLY, AND MAY LEAD TO
AN UNDERESTIMATE OF VEHICLE RISK.

- cube_avg.txt: reports average flux and speeds for all state vectors used.
```

- The info.txt file contains an overview of the MEM options used with a description of the output files requested.

Output Files – LoDensity/HiDensity Files

- MEM segregates meteoroids into either a low-density or high-density population.
- The loDensity.txt and hiDensity.txt files provide the density distribution of the respective meteoroid population.

#	rho_min	rho_max	fraction
#	kg/m^3	kg/m^3	
	100.00	150.00	1.262e-09
	150.00	200.00	3.231e-07
	200.00	250.00	1.227e-05
	250.00	300.00	1.530e-04
	300.00	350.00	9.320e-04
	350.00	400.00	3.485e-03
	400.00	450.00	9.213e-03
	450.00	500.00	1.889e-02
	500.00	550.00	3.197e-02
	550.00	600.00	4.671e-02
	600.00	650.00	6.082e-02
	650.00	700.00	7.224e-02
	700.00	750.00	7.970e-02
	750.00	800.00	8.279e-02
	800.00	850.00	8.185e-02
	850.00	900.00	7.767e-02
	900.00	950.00	7.122e-02
	950.00	1000.00	6.346e-02
	1000.00	1050.00	5.519e-02
	1050.00	1100.00	4.702e-02
	1100.00	1150.00	3.937e-02
	1150.00	1200.00	3.247e-02
	1200.00	1250.00	2.644e-02
	1250.00	1300.00	2.130e-02
	1300.00	1350.00	1.700e-02
	1350.00	1400.00	1.346e-02
	1400.00	1450.00	1.058e-02
	1450.00	1500.00	8.271e-03
	1500.00	1550.00	6.433e-03
	1550.00	1600.00	4.982e-03
	1600.00	1650.00	3.844e-03

Output Density Files – cube_*.txt

- Every MEM run will include a cube_avg.txt which contains meteoroid fluxes and velocities relative to a series of flat surfaces with different orientations.
- Additional intermediate cube files are named cube_n.txt, where n is the state vector number in the trajectory file.

```
# 80 rows of flux data
# 12 columns of flux data
#
# total cross-sectional flux 3.309200e+00 /m^2/yr
#
#
# average speed (km/s)      +x ram      -x wake      +y port      -y starboard      +z zenith      -z nadir      Earth      Su
# total flux (#/m2/yr) 1.758423e+00 1.524089e-01 4.400589e-01 3.668984e-01 2.169100e+00 4.379721e-02 4.379275e-02 2.726017e+00
# velocity (km/s)
0.5 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
1.5 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
2.5 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
3.5 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
4.5 0.000000e+00 1.095918e-04 2.805794e-06 2.792831e-05 1.466772e-05 1.018584e-05 1.018085e-05 0.000000e+00
5.5 0.000000e+00 1.292693e-03 1.000389e-04 4.143394e-04 3.770265e-04 1.167927e-04 1.167407e-04 2.613119e-04
6.5 0.000000e+00 4.427221e-03 5.031405e-04 1.881662e-03 2.022456e-03 4.029170e-04 4.027667e-04 3.910068e-04
7.5 0.000000e+00 8.116998e-03 9.866867e-04 4.781485e-03 4.397371e-03 7.625864e-04 7.622935e-04 1.150105e-03
8.5 1.086548e-05 1.050263e-02 1.355158e-03 8.029239e-03 6.358295e-03 1.265503e-03 1.265034e-03 2.249659e-03
9.5 6.608776e-05 1.205519e-02 1.979425e-03 1.119675e-02 8.037336e-03 1.734374e-03 1.733780e-03 3.190047e-03
10.5 4.347508e-04 1.210524e-02 2.688314e-03 1.430440e-02 1.016297e-02 2.229571e-03 2.228896e-03 5.123247e-03
11.5 1.251998e-03 1.236343e-02 3.158550e-03 1.754473e-02 1.271640e-02 2.501378e-03 2.500653e-03 7.380768e-03
12.5 3.694809e-03 1.157474e-02 3.998754e-03 2.192873e-02 1.869092e-02 2.729073e-03 2.728378e-03 1.316116e-02
13.5 5.369722e-03 1.100094e-02 5.110944e-03 2.080867e-02 1.856146e-02 2.835856e-03 2.835189e-03 1.462831e-02
14.5 1.004475e-02 9.588019e-03 7.864091e-03 2.362952e-02 2.388227e-02 3.075673e-03 3.075123e-03 2.173906e-02
15.5 1.504591e-02 8.218611e-03 1.122008e-02 2.251132e-02 2.569508e-02 3.284634e-03 3.284202e-03 2.686658e-02
16.5 2.210139e-02 8.193855e-03 1.485346e-02 2.404309e-02 3.354368e-02 3.090098e-03 3.089783e-03 3.713772e-02
17.5 3.023449e-02 7.010472e-03 1.848655e-02 2.193403e-02 3.786808e-02 2.773157e-03 2.772968e-03 4.681830e-02
18.5 4.097725e-02 5.295289e-03 2.144630e-02 1.526664e-02 4.040464e-02 2.328788e-03 2.328829e-03 5.699732e-02
19.5 5.904798e-02 4.564415e-03 2.510853e-02 1.516646e-02 4.931879e-02 2.118561e-03 2.118940e-03 7.467921e-02
20.5 7.066281e-02 3.961766e-03 2.467571e-02 1.353484e-02 5.439312e-02 2.129209e-03 2.129752e-03 8.516038e-02
21.5 8.049613e-02 3.439809e-03 2.432350e-02 1.269762e-02 5.983818e-02 1.927819e-03 1.928415e-03 9.502169e-02
22.5 8.631120e-02 2.888755e-03 2.366109e-02 1.184657e-02 6.688244e-02 1.581803e-03 1.582189e-03 1.039392e-01
23.5 8.811817e-02 2.323798e-03 2.251895e-02 1.076382e-02 7.141705e-02 1.220437e-03 1.220705e-03 1.086218e-01
```

Output Density Files – flux_*.txt

```
# 2592 rows of flux data
# 80 columns of flux data
#
# flux is distributed by angle and speed:
# angle values give minimum value of angular range (degrees)
# numeric column labels give midpoint of speed range (km/s)
#
# PHI1 THETA1      0.5      1.5      2.5      3.5      4.5      5.5
-90    0 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90    5 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   10 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   15 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   20 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   30 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   35 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   40 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   45 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   50 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   55 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   60 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   65 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   70 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   80 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   85 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   90 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90   95 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  100 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  105 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  110 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  115 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  120 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  125 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
-90  130 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00
```

- Every MEM run will include a flux_avg.txt which contains the flux within an azimuth, elevation and velocity grid, averaged over the trajectory.
- Additional intermediate flux files are named flux_n.txt, where n is the state vector number in the trajectory file.

Output Density Files – igloo_*.txt

- A MEM run requesting the igloo files described earlier will also include a igloo_avg.txt which is averaged over the trajectory.
- Additional intermediate igloo files are named igloo_n.txt, where n is the state vector number in the trajectory file.

```
# 1652 rows of flux data
# 80 columns of flux data
#
# flux is distributed by angle and speed:
# angle values give boundaries and center of angular bin (degrees)
# numeric column labels give midpoint of speed range (km/s)
#
# ID I J PHI1 PHI2 THETA1 THETA2 PHIavg THETAavg 0.5 1.5 2.5
1 1 1 -90.00 -85.00 0.00 120.00 -86.47 60.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
2 1 2 -90.00 -85.00 120.00 240.00 -86.47 180.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
3 1 3 -90.00 -85.00 240.00 360.00 -86.47 300.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
4 2 1 -85.00 -80.00 0.00 40.00 -82.10 20.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
5 2 2 -85.00 -80.00 40.00 80.00 -82.10 60.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
6 2 3 -85.00 -80.00 80.00 120.00 -82.10 100.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
7 2 4 -85.00 -80.00 120.00 160.00 -82.10 140.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
8 2 5 -85.00 -80.00 160.00 200.00 -82.10 180.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
9 2 6 -85.00 -80.00 200.00 240.00 -82.10 220.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
10 2 7 -85.00 -80.00 240.00 280.00 -82.10 260.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
11 2 8 -85.00 -80.00 280.00 320.00 -82.10 300.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
12 2 9 -85.00 -80.00 320.00 360.00 -82.10 340.00 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
13 3 1 -80.00 -75.00 0.00 22.50 -77.26 11.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
14 3 2 -80.00 -75.00 22.50 45.00 -77.26 33.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
15 3 3 -80.00 -75.00 45.00 67.50 -77.26 56.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
16 3 4 -80.00 -75.00 67.50 90.00 -77.26 78.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
17 3 5 -80.00 -75.00 90.00 112.50 -77.26 101.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
18 3 6 -80.00 -75.00 112.50 135.00 -77.26 123.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
19 3 7 -80.00 -75.00 135.00 157.50 -77.26 146.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
20 3 8 -80.00 -75.00 157.50 180.00 -77.26 168.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
21 3 9 -80.00 -75.00 180.00 202.50 -77.26 191.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
22 3 10 -80.00 -75.00 202.50 225.00 -77.26 213.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
23 3 11 -80.00 -75.00 225.00 247.50 -77.26 236.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
24 3 12 -80.00 -75.00 247.50 270.00 -77.26 258.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
25 3 13 -80.00 -75.00 270.00 292.50 -77.26 281.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
26 3 14 -80.00 -75.00 292.50 315.00 -77.26 303.75 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
27 3 15 -80.00 -75.00 315.00 337.50 -77.26 326.25 0.000000e+00 0.000000e+00 0.000000e+00 0.000000
```

Summary

- MEM is a physics based sporadic model used in spacecraft risk assessments to estimate the meteoroid environment.
- MEM in the Cloud expands the versatility of the stand-alone MEM program.
- Both MEM and MEM in the Cloud will continue to improve and develop to provide a reliable simulation of the meteoroid environment.

References

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- Jones. Meteoroid Engineering Model – Final Report. Contractor report.
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