Institute of Aerospace Systems

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Modeling the Space Debris Environment with MASTER-2009 and ORDEM2010

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Outline

- ESA MASTER-2009 Population Generation
  (**M**eteoroid **a**nd **S**pace Debris **T**errestrial **E**nvironment **R**eference)
- NASA ORDEM2010 Population Generation
  (**Or**bital **D**ebris **E**ngineering **M**odel)
- (Software Feature Comparison)

MASTER-2009
Population Generation Process

Object Data Acquisition & Processing

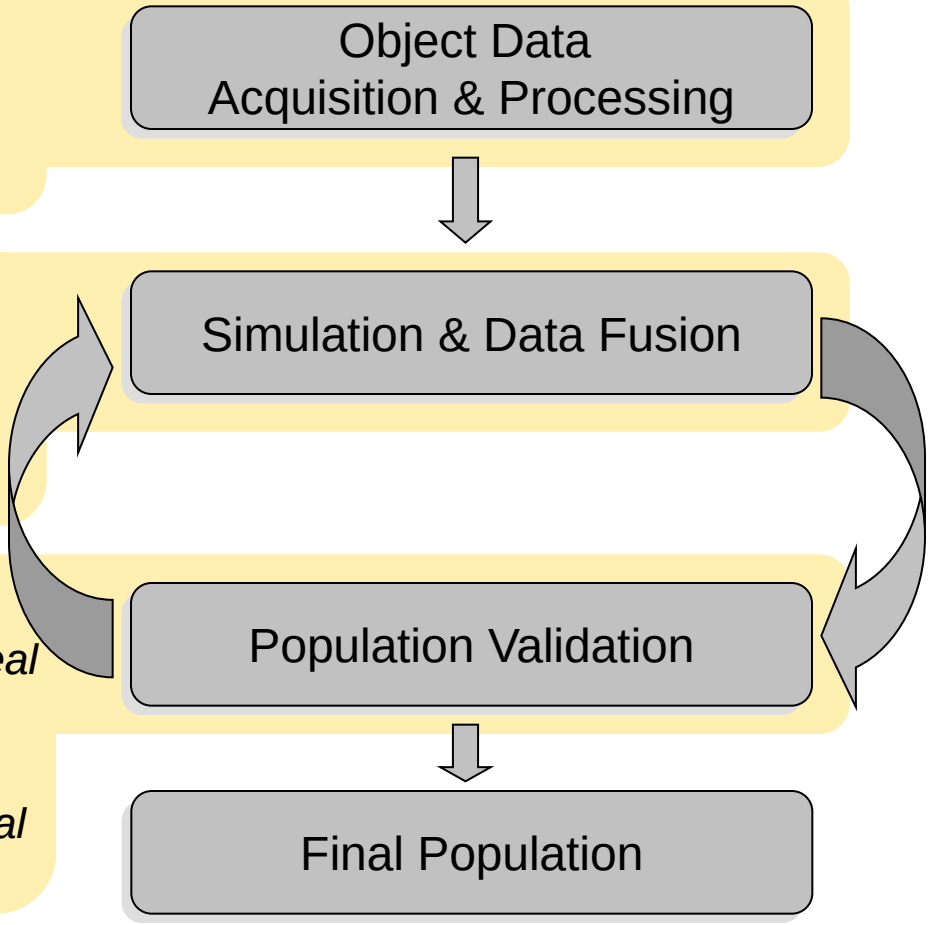
- Data for tracked objects is collected from multiple sources & brought into unified format

Simulation & Data Fusion

- All debris sources are simulated
- Simulation results are fused with data for tracked objects

Population Validation

- Large objects > ~10 cm: comparison of *real* and *simulated* measurement campaigns (*PROOF*)
- Small objects < ~1 mm: comparison of *real* and *simulated* impact craters (*MASTER*)



MASTER-2009
Object Data Acquisition & Processing

Acquisition of object bulk:

Input: Two-Line Elements (USSTRATCOM)
Acquired data: single mean orbit parameters
Output: Quarterly orbit snapshots between 1957 and 2009

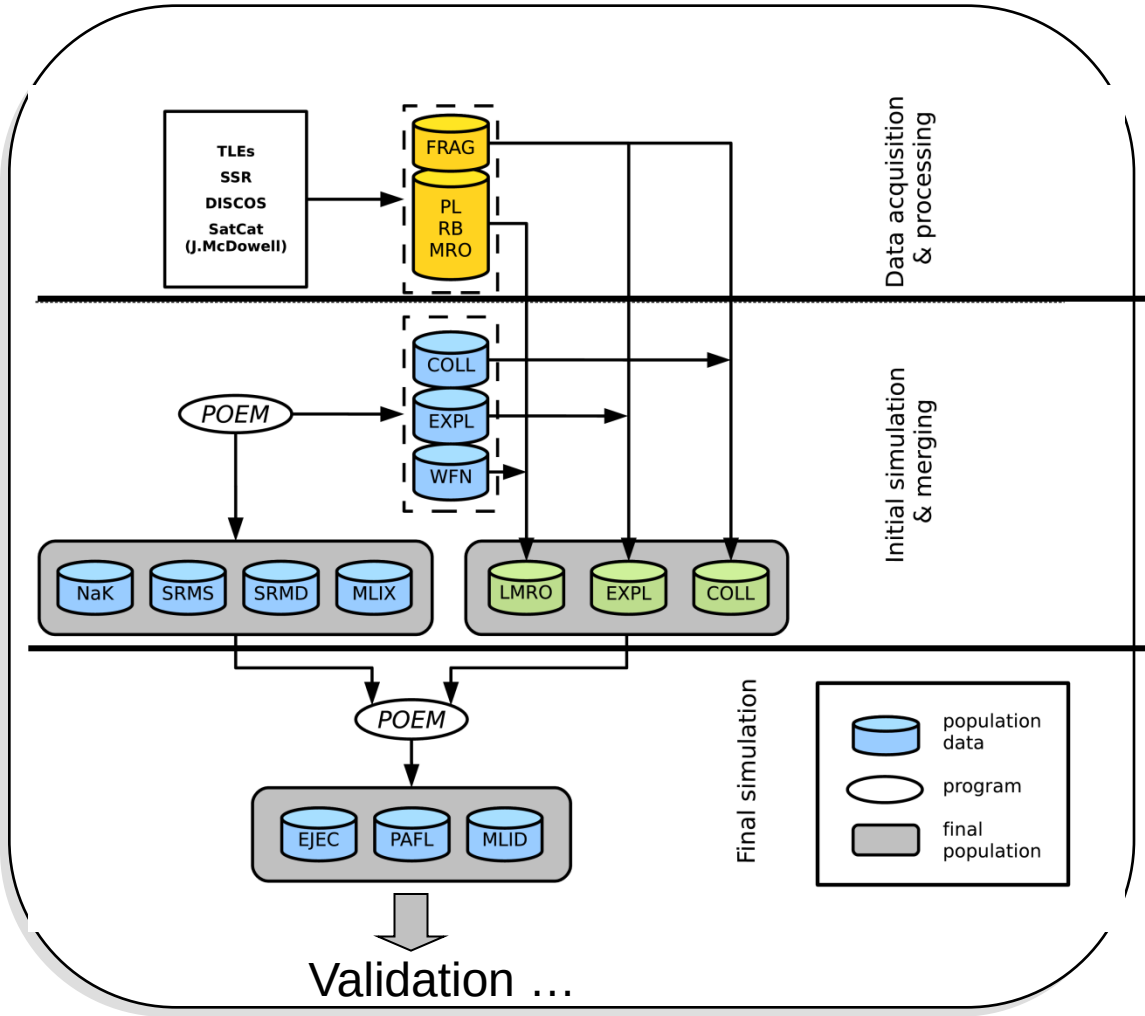
Additional objects:

Input: Satellite Catalog (Jonathan McDowell)
Acquired data: Objects not included with TLE data
Output: Extended quarterly orbit snapshots

Object properties:

Input: Database and Information System Characterising Objects in Space (ESA: DISCOS) & Satellite Situation Report (USSTRATCOM)
Acquired data: Object size, mass and mass-to-area ratio
Output: Quarterly population snapshots subdivided into fragments & launch- and mission related objects (payloads, rocket bodies and mission debris)

MASTER-2009
Simulation & Data Fusion



POEM (Program for Orbital Debris Environment Modeling)

- Compendium of individual debris models for each source

List based debris sources:

- Individual events are simulated
- List data includes e.g.:
  event epoch, orbit location, event magnitude

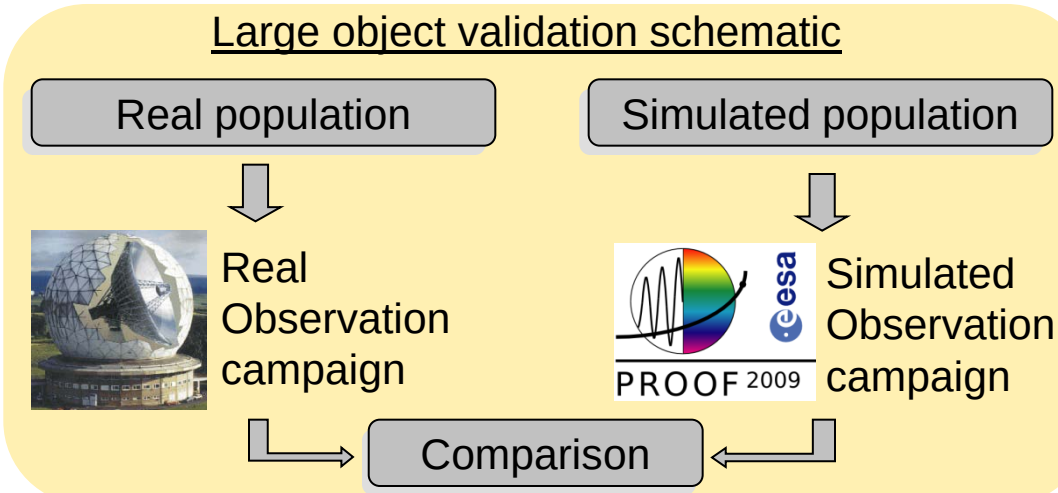
Continuous debris sources:

- All LMRO are analysed wrt. paint flakes, delaminated MLI and ejecta which they would have produced

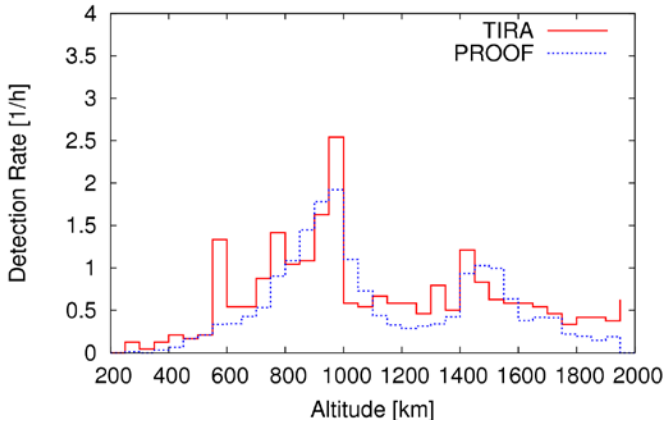
MASTER-2009
Large Object Validation

- Detection campaigns offer information on the number of objects, RCS or magnitude and orbit properties
- *PROOF* (ESA **Pr**ogram for **R**adar and **O**ptical **O**bservation **F**orecasting) applies filters for:
  - geometry (e.g. field of view, viewing direction)
  - performance (e.g. radar: wavelength, power; optical: CCD type, integration time)

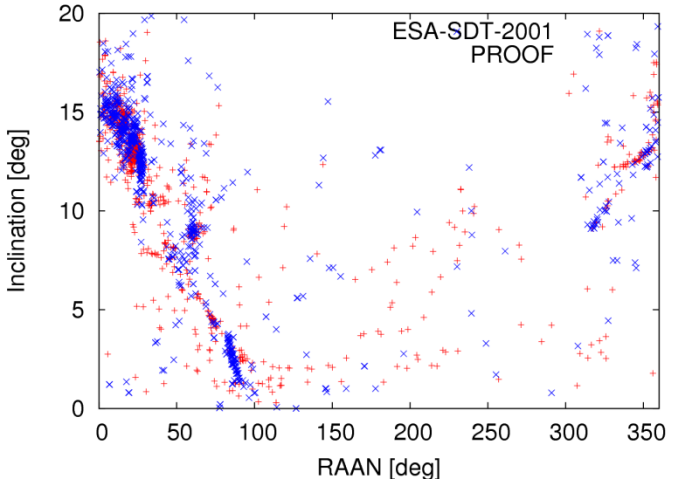
Large object validation schematic



Validation of amount of debris



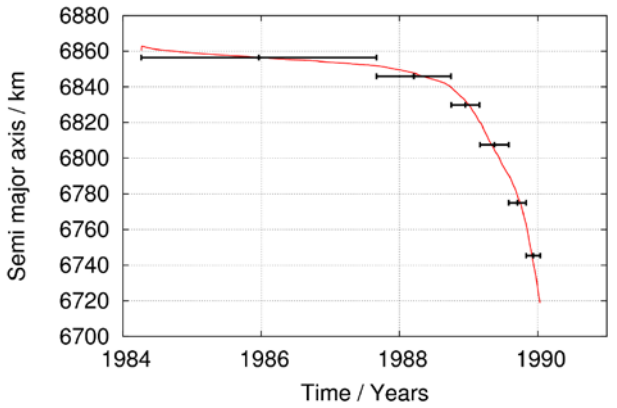
Validation of orbit distribution



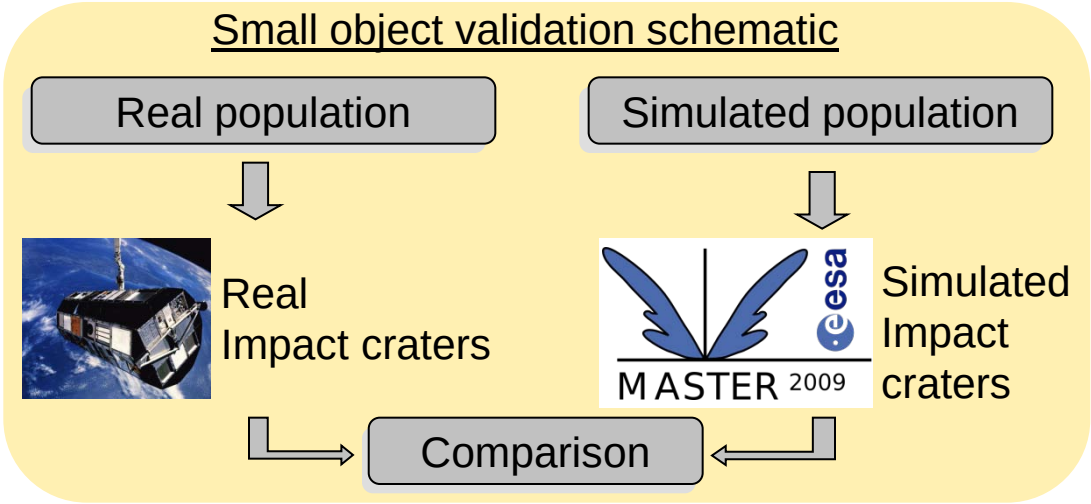
MASTER-2009
Small Object Validation

- Impact craters offer information on the impactor size/impact velocity, impact direction and total number of objects
- *MASTER* applies filters for e.g.:
  - target orbit evolution/maneuvers
  - rotation of target orbit line of apsides and line of nodes
  - target surface orientation
  - damage equations

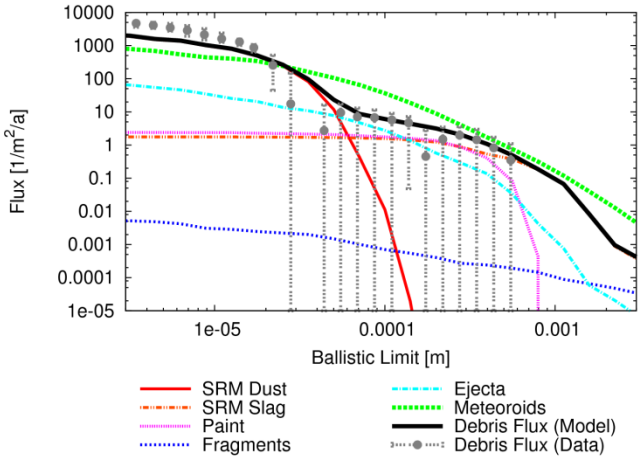
Simulating mission parameters



Small object validation schematic



Validation of impact fluence



ORDEM2010

- The Orbital Debris Engineering Model, ORDEM2010, includes,
  - **High-fidelity population file structure of the yearly debris populations from 1995 - 2035**
    - Sizes 10 μm - 1 m (LEO - GTO) ; sizes 10 cm - 1 m (GEO)
    - Stable orbital elements (i.e., those that do not randomize on a sub-year timescale)
      - LEO – GTO → Hp, Ecc, Inc ; GEO → MM, ECC, Inc, RAAN
    - Debris material density
  - **High-fidelity spacecraft analysis program compares the populations with a spacecraft-encompassing 'igloo' to achieve a 3-D output of flux on the spacecraft**
  - **Advanced graphical user interface (GUI) allows visualization of spacecraft flux in 2-D and 1-D**

Parameter	**ORDEM2010**
Spacecraft and Telescope/Radar analysis modes	YES
Time range	1995 to 2035
Altitude range with minimum debris size	200 to 34,000 km (>10 μm)* ; 34,000 to 38,000 km (>10 cm)
Model population breakdown	Intacts, Low-density fragments ; Medium-density fragments and degradation/ejecta ; High-density fragments and degradation/ejecta ; RORSAT NaK coolant droplets
Population material density breakdown	Low-density (<2 g/cc) ; Medium-density (2-6 g/cc) High-density (>6 g/cc) ; RORSAT NaK coolant (0.9 g/cc)
Population cumulative size thresholds	10 μm, 31.6 μm, 100 μm, 316 μm, 1 mm, 3.16 mm, 1 cm, 3.16 cm, 10 cm, 31.6 cm, 1 m
Population storage	LEO-to-GTO bins - Hp, Ecc, Inc , GEO bins - MM, Ecc, Inc, RAAN
Population extension	Bayesian statistics with ODPO models
Model S/C flux analysis method	Igloo surrounding S/C
Model T/R flux analysis method	Segments along line-of-sight

ORDEM2010
Population Generation Process

- Bayesian statistical approach to debris population analysis
  - **Ten additional years of data including,**
    - Catalog datasets → SSN
    - Statistical datasets → Haystack, HAX radars
    - Individual event datasets → FY-1C anti-satellite test, Iridium 33/Cosmos 2251 from SSN radar observation
  - **NASA Orbital debris Program Office (ODPO) models used as prior conditions**
    - LEGEND 3-D debris long-term environment model replaces the 1-D EVOLVE
    - NaK Module for RORSAT sodium potassium droplets
    - Degradation/Ejecta (D/E) for sub-millimeter particles

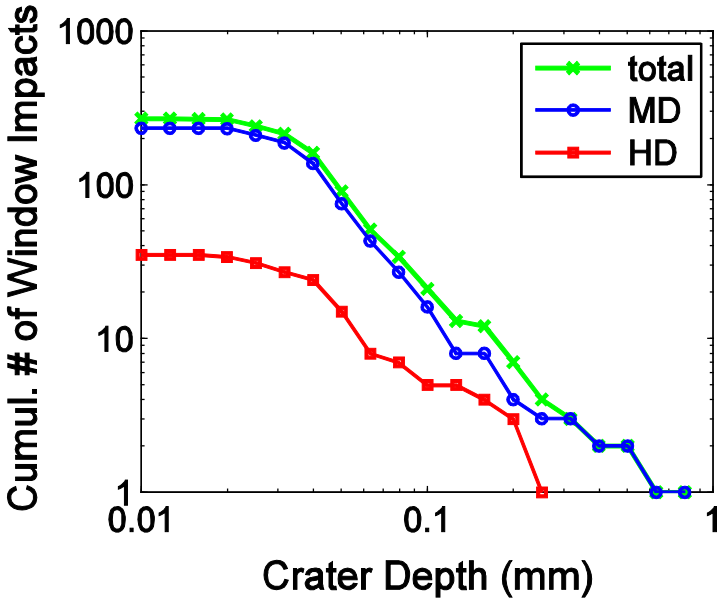
Model	Usage	Corroborative Data
LEGEND	LEO Fragments > 1mm ; GEO Fragments > 10cm	Haystack, HAX, SSN ; MODEST
NaKModule	NaK droplets > 1 mm	Haystack
Degradation/ejecta model	1mm > Degradation/ejecta > 10μm	STS windows & radiators

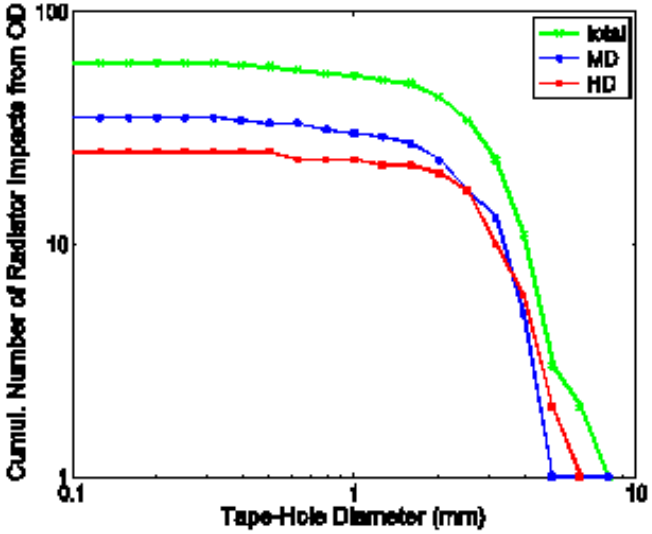
ORDEM2010
Population Validation (1)

- Large object (>1mm) validation is ongoing.
- Small object (<1mm) validation
  - **A degradation/ejecta source model is constructed to provide the desired reference populations for the micro-debris population derivations.**
  - **Catalog (>10 cm) objects are taken as parent bodies of the small micron-sized particles.**
    - Number of micro-debris objects created by a surface degradation process is proportional to the surface area of a parent body.
    - Micro-debris objects created in a surface degradation process share the same orbit with its parent body *at the creation time*. Every orbit of the degradation/ejecta particles is propagated independently under the influence of solar radiation pressure and atmospheric drag, in addition to gravitational perturbations.
  - **The production rates of micro-debris are honed to be compatible with data.**

ORDEM2010
Population Validation (2)

- Window and radiator impact data from 38 STS missions. Window data is identified by the metric crater depth, radiator data by metric tape-hole diameter.
- Impactor are identified by material density when available. MD = medium density (aluminum, paint). HD = high density (steel)

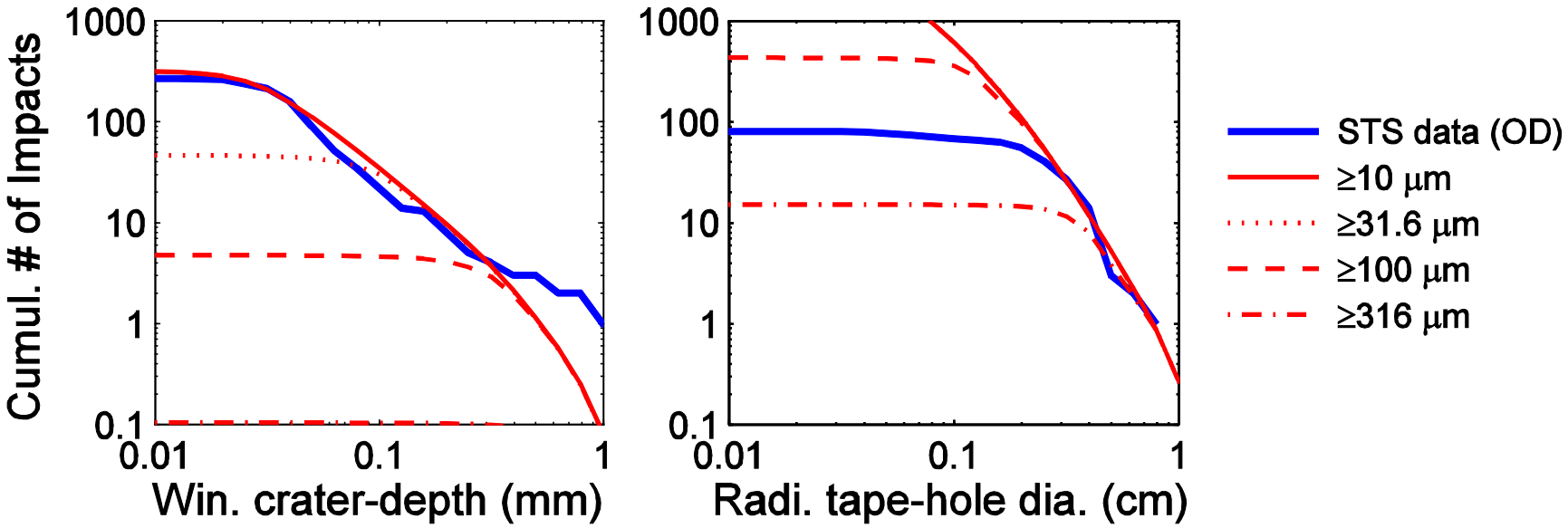




ORDEM2010
Population Validation (3)

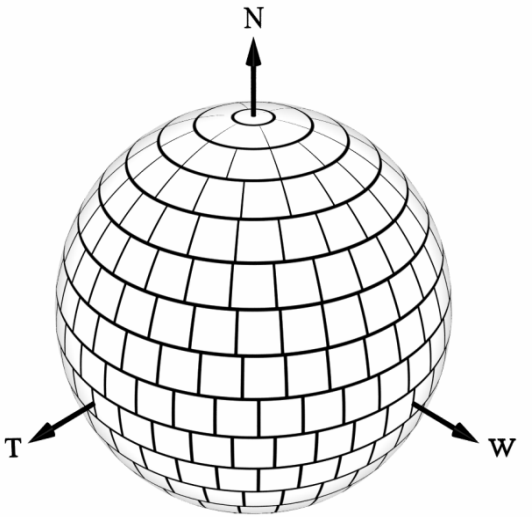
- Degradation/ejecta model medium density population is adjusted to both window data and radiator data simultaneously.

- **Detailed presentation, 'Simulation of Micron-Sized Debris Populations in Low Earth Orbit' will be given later at this conference, by Dr. Yu-Lin Xu.**



ORDEM2010
Spacecraft Analysis Program

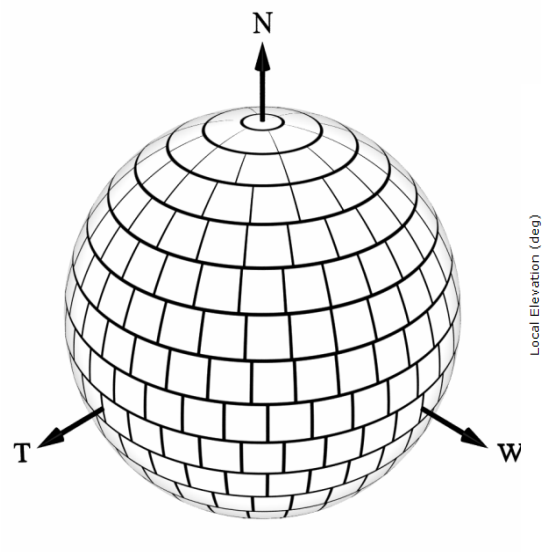
- ORDEM2010 spacecraft encounters debris flux via a spacecraft-encompassing 3-D igloo
  - **Population flux is tested for each igloo element in an igloo coordinate system of debris size, velocity, azimuth, and elevation with respect to spacecraft ram direction**
  - **Flux is summed within an element, all element fluxes are summed together for the total yearly spacecraft encounter**
  - **Highest fidelity igloo presently in ORDEM2010 is 10˚x10˚x1km/s (Az x EL x Vel)**



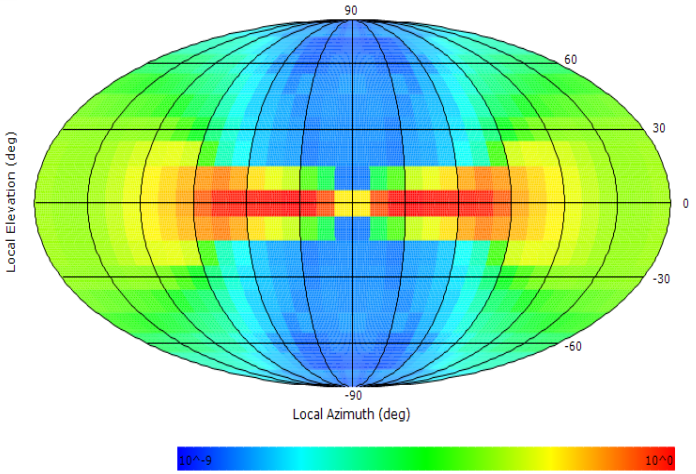
equal-area
spacecraft-encompassing igloo

ORDEM2010
Graphical User Interface (GUI)

- This directional debris flux calculation is supported by an updated graphical user interface (GUI) package designed for ORDEM2010 that includes a 2-D directional flux chart (a.k.a. Mollweide projection, pseudo-cylindrical equal-area map projection used for global or sky maps)



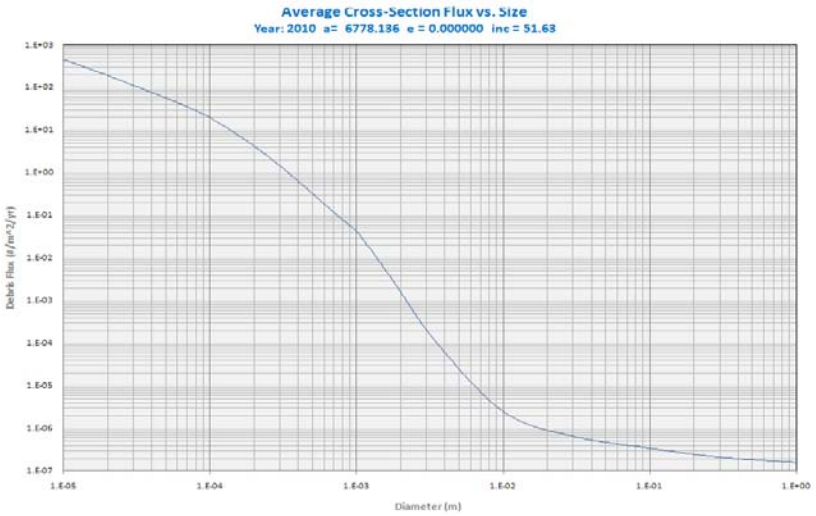
equal-area
spacecraft-encompassing igloo

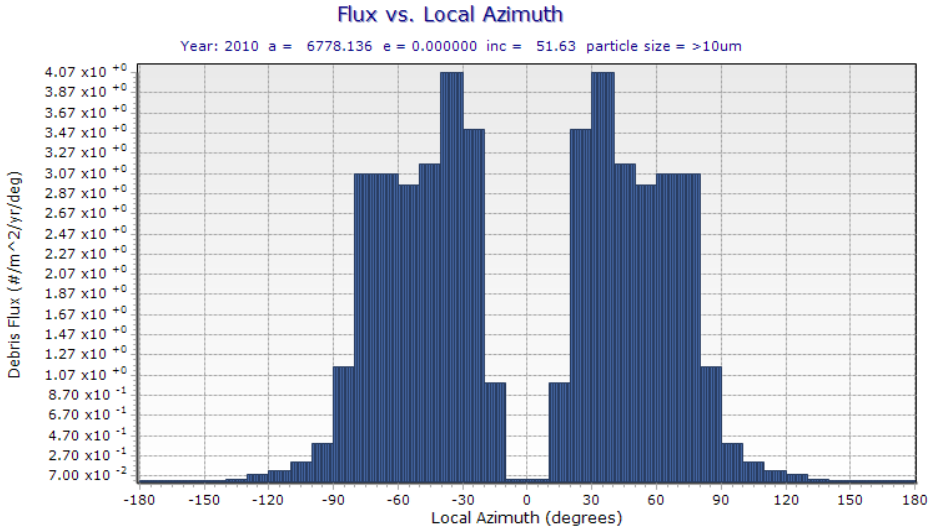


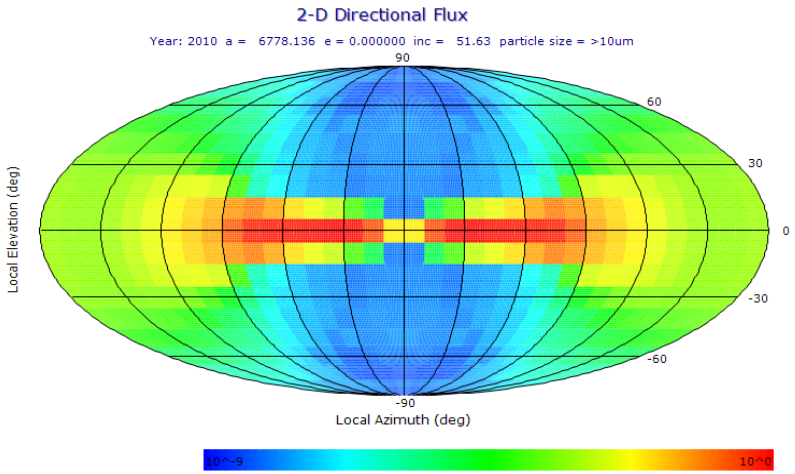
- Spacecraft velocity vector (ram direction) is defined by the azimuth, elevation coordinates (0°,0°)
- Anti-ram is defined where (180°,0°) and (-180°,0°) meet
- Zenith is defined at (0°,90°), and nadir at (0°,-90°).

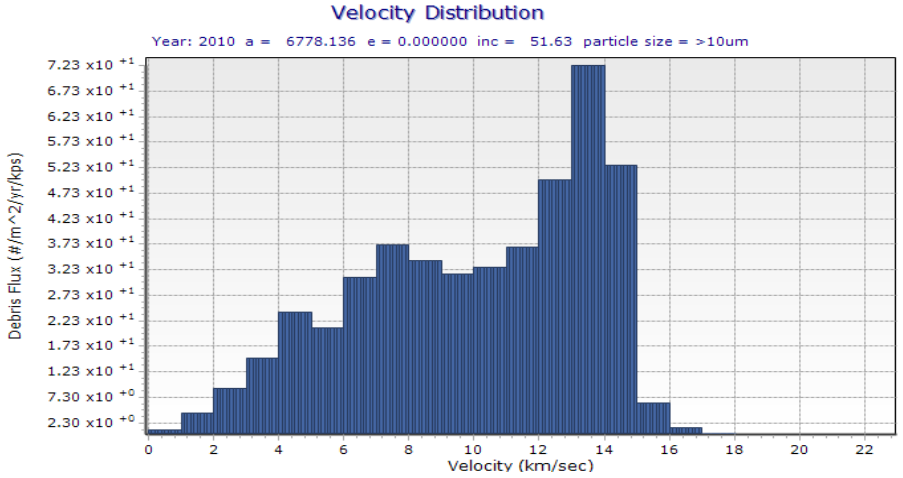
ORDEM2010
GUI Example

ISS ORDEM2010 GUI Outputs for Debris larger than 10 μm (Inc=51.63^0, Hp=Ha= 400 km, yr=2010)









Summary

- Spacecraft analysis using ORDEM2010 uses a high-fidelity population model to compute risk to on-orbit assets
- The ORDEM2010 GUI allows visualization of spacecraft flux in 2-D and 1-D
- The population was produced using a Bayesian statistical approach with measured and modeled environment data
- Validation of sizes < 1mm were performed using Shuttle window and radiator impact measurements
- Validation of sizes > 1mm is on-going

Summary

Backup Slide

MASTER-2009
Population Generation Process