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NASA Orbital Debris Engineering Model ORDEM 3.0 - User's Guide

Orbital Debris Program Office

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Acronyms

2-D .... two dimensional
CPU .... Central Processing Unit
FY-1C .... Fengyun 1-C
GEO .... Geosynchronous Orbit
GOST .... GOsudarstvennyy STandart
GTO .... Geosynchronous Transfer Orbit
GUI .... graphical user interface
HAX .... Haystack AuXiliary radar
HVIT .... (NASA) Hypervelocity Impact Technology (Group)
ISS .... International Space Station
LEGEND .... LEO-to-GEO Environment Debris Model
LEO .... low Earth orbit
MASTER .... Meteoroid and Space Debris Terrestrial Environment Reference
MODEST .... Michigan Orbital Debris Survey Telescope
NaK .... Sodium potassium eutectic coolant for RORSAT reactors
NASA .... National Aeronautics and Space Administration
ODPO .... (NASA) Orbital Debris Program Office
ORDEM .... Orbital Debris Engineering Model
RAM .... random-access memory
RAAN .... right ascension of the ascending node
RORSAT .... Radar Ocean Reconnaissance SATellite
SBRAM .... (NASA ODPO) Satellite Breakup Risk-Assessment Model
S/C .... spacecraft
SOCIT .... Satellite Orbital Debris Characterization Impact Test
SSN .... Space Surveillance Network
STS .... Space Transportation System
SUA .... Software Usage Agreement
TLE .... Two-Line Element

Symbols

a .... semi-major axis
AP, ω .... argument of perigee
az .... azimuth
ECC, e .... eccentricity
el .... elevation
h_a .... apogee altitude
h_p .... perigee altitude
INC, i .... inclination
MM, n .... mean motion
RAAN, Ω .... right ascension of the ascending node
σ .... standard deviation
vr .... relative velocity

1.0 Introduction

This National Aeronautics and Space Administration (*NASA) Orbital Debris Engineering Model (ORDEM) 3.0 User's Guide* accompanies delivery of the latest upgraded Orbital Debris Engineering Model (ORDEM 3.0). The user's guide also provides a top-level program description and a list of capabilities. It includes appendixes with descriptions of runtime error and information codes (Appendix A), descriptions of input/output file formats (Appendix B), how to use uncertainty files (Appendix C), and descriptions of typical runtimes for different orbit configurations (Appendix D).

Another document, the *ORDEM 3.0 Technical Document*, will be released later. It will contain a detailed description of the program (finite element model, coding structure, and applications), an overview of all data measurement sources, a data analysis section that describes the use of those data sources, and a description of statistical tools, theory, and model data.

ORDEM 3.0 supersedes the previous NASA Orbital Debris Program Office (ODPO) model – ORDEM2000 (Liou, *et al.* 2002). The availability of new sensor and *in situ* data, the re-analysis of older data, and the development of new analytical techniques has enabled the construction of this more comprehensive and sophisticated model. An upgraded graphical user interface (GUI) is integrated with the software. This upgraded GUI uses project-oriented organization and provides the user with graphical representations of numerous output data products. These range, for example, from the conventional average debris size (or altitude bin) vs. flux for chosen analysis orbits (or views) to the more complex color-contoured, two-dimensional (2-D) directional flux diagrams in local spacecraft elevation and azimuth.

Finally, the sequential numbering scheme has been adopted to sever upgrades from simple calendar accounting and to emphasize major advances in the model design and supporting data analysis. Also this scheme will allow for quicker interim model upgrades than have previously been accomplished. The current model is ORDEM 3.0. This permits the older models ORDEM96 and ORDEM2000 to be retroactively referred to as ORDEM 1.0 and ORDEM 2.0, respectively.

1.1 Requirements of an Orbital Debris Engineering Model

The primary requirement for any engineering model is to provide the user with accurate results expediently. The two main types of ORDEM users are spacecraft designers and operators, and debris researchers. (A third user group includes mission planners and analysts using the ODPO Debris Assessment Software package, which implements ORDEM populations in calculations for spacecraft damage probability.)

The requirements of each user group differ somewhat, though they share many common requirements. To facilitate implementation of cost-effective shielding, the designer of an oriented spacecraft requires detailed estimates of the particle flux as a function of local azimuth/elevation. (Such detail is not required for a randomly tumbling spacecraft.) To determine this flux accurately, the user must carefully assess the debris size and orbit distribution. Because of the long lead times in new satellite designs, the temporal behavior of the debris environment over a satellite's lifetime is also important.

When an observer is planning a debris observation campaign, predicted fluxes are used to ensure that the experiment planning and design can accommodate the quantity and rate of data collection. Ultimately, measurements will be compared to the model predictions and will be the final figure of merit of the model's veracity. Predicted fluxes will depend upon the inclination and altitude distribution of resident space objects visible from the ground-based sensor location. Additionally, an observer must consider whether the sensor is fixed in its orientation or is steerable in azimuth and elevation. When bistatic radars use parallax, the altitude distribution becomes crucially important due to common field-of-view constraints.

Thus, any such model must include, at a minimum, an accurate assessment of the orbital debris environment as a function of altitude, latitude, and debris size. ORDEM 3.0 is an engineering model that is consistent with this requirement. It is based on debris populations with various altitude, inclination, and size distributions. The model provides a complete description of the environment, including debris flux, onto spacecraft surfaces or the debris detection rate observed by a ground-based sensor.

1.2 Limitations of an Orbital Debris Engineering Model

Some studies are beyond the scope of the ORDEM series. For example, the series cannot reliably evaluate the short-term collision risk between fragments from recent breakup events and an orbiting satellite. Such an assessment requires highly accurate orbital positioning and propagation – a task that the NASA ODPO Satellite Breakup Risk-Assessment Model (SBRAM) accomplishes. The long-term impact of various mitigation measures on the debris environment must rely on a debris evolution model that includes effects such as the solar activity cycle (affecting atmospheric density and hence the decay rate of objects in low Earth orbit [LEO]), the growth of the space vehicle population, and a projected fragmentation rate. The NASA ODPO LEO-to-GEO Environment Debris Model (LEGEND) is applicable for examining the consequences of such phenomena.

1.3 A Historical Overview of Orbital Debris Engineering Models

The first debris engineering model was developed for the Space Station Program Office in 1984 (Kessler 1984). Later models were assembled for the Strategic Defense Initiative Organization, for various LEO spacecraft programs (Kessler 1989), and for the Space Station Program Office (Kessler 1991). Each of these portrayed the environment as curve fits to describe the distributions of large objects (the Space Surveillance Network [SSN] – a catalog of objects larger than approximately 10 cm) and small objects (as recorded by the inspection of surfaces exposed to and returned from space). Both periodic (solar cycle) and secular (launch traffic and fragmentation growth rate) effects were included explicitly. A significant requirement of these models was that they be easily executed by a programmable calculator or be capable of manual manipulation within a reasonable time.

The need to better define the debris environment eventually outgrew this latter requirement. ORDEM 1.0, formerly ORDEM96, (Kessler 1996) was the first model that required a personal computer for effective implementation. ORDEM 1.0 pioneered the use of debris population ensembles characterized by altitude, eccentricity, inclination, and size. ORDEM 2.0, formerly ORDEM2000, (Liou, *et al.* 2002) adopted a similar approach, but it replaced the final remnants of curve fitting, as used by all previous NASA engineering models, with a finite element model to represent the debris environment.

Engineering models are not limited to the NASA models mentioned above. For example, the European Space Agency Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) (Sdunnus 2001) series of models performs similar functions, as did the former Soviet Union's three-population (orbital debris, micrometeoroids, and "Earth-orbiting meteoroids") GOST (GOsudarstvennyy STandart – meaning state standard) engineering model. MASTER-2005 and MASTER-2009 (Oswald 2006) and (Flegel, *et al.* 2010) are similar to the latest in the ORDEM series of models (ORDEM 2.0 and ORDEM 3.0), whereas the Soviet model is similar to the earlier NASA models.

1.4 Point of Contact

The official point of contact for ORDEM 3.0 at the NASA ODPO is:

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2.0 ORDEM 3.0 Model

Since ORDEM 2.0 was released, new debris data have become available and analysis techniques have matured to more currently reflect the debris environment.

Based on these data and techniques, NASA established a number of mandates for the new engineering model, ORDEM 3.0. With the singular events that occurred near the end of the last decade (Fengyun-1C [FY-1C] anti-satellite test and Iridium/Cosmos collisions), the mandates for ORDEM 3.0 have expanded to:

- extend the model to geosynchronous orbit (GEO) with the addition of Michigan Orbital Debris Survey Telescope (MODEST) data and modeling techniques to include GEO objects down to 10 cm,
- investigate and account for Molniya-type orbits with fixed arguments of perigee,
- continue to include radar detections of debris (SSN, Haystack AuXiliary radar [HAX], Haystack, and Goldstone) in the model and make use of these larger data sets to apply model fiducial points at half-decade sizes,
- use the NASA Hypervelocity Impact Technology (HVIT) group's Space Transportation System (STS) microdebris impact database (STS 71-135 listing over 600 impacts), which includes crater dimension, chemical composition, and derived damage equations on STS aluminum radiator panels and windows,
- assign small fragment (<10 cm) material density based on the Satellite Orbital Debris Characterization Impact Test (SOCIT) laboratory impact test results and on-orbit STS returned surface impactor analysis,
- model the Radar Ocean Reconnaissance SATellite (RORSAT) sodium potassium (NaK) coolant droplet population with radar measurements,
- include specific, major debris-producing events that have been thoroughly observed (i.e., the remnants of the FY-1C on 11 January 2007, and the accidental collision of Iridium 33 and Cosmos 2251 on 10 February 2009) and add to the general population,
- include long-term, debris-producing events that have been surmised from LEO high-altitude radar data (i.e., SNAPSHOT, Transit, and 56° inclination-debris shedding activity) and add to the general population,
- fully develop the Bayesian statistical model for population derivation,
- include debris population uncertainties,
- provide "igloos" with equal-angle elements for full surrounding visualization of debris flux on spacecraft, and
- build the ORDEM 3.0 GUI to accommodate the full-angle views (i.e. 4π steradian views) of the large yearly input files.

Table 2-1 compares ORDEM 3.0 top-level output features to those of ORDEM 2.0. These are detailed in output file formats and graphics in Section 2.4 and Appendix B. The new model input populations are pre-derived directly from the data sources listed in Table 2-2. These consist of *in-situ* sources, for debris ranging from 10 μm to less than 1 mm, and remote sensors, for debris ranging from 1 mm to over 1 m. These data are applied to ORDEM 3.0 in a maximum likelihood estimation and a Bayesian statistical process, respectively, in which the NASA ODPO models listed in Table 2-3 form the *a priori* conditions. Those modeled debris populations are reweighted in number to be compatible with the data in orbital regions where the data are collected. By extension, model debris populations are reweighted in regions where no data are available (e.g., all sizes in low latitudes and sub-millimeter sizes at altitudes above the International Space Station [ISS]).

Table 2-1: Feature Comparison of ORDEM 2.0 and ORDEM 3.0

Parameter	ORDEM 2.0	ORDEM 3.0
Spacecraft & Telescope/Radar analysis modes	Yes	Yes
Time range	1991 to 2030	2010 to 2035
Altitude range with minimum debris size	200 to 2000 km (>10 μm) (LEO)	100 to 40,000 km (>10 μm)* (LEO to GTO) 34,000 to 40,000 km (>10 cm) (GEO)
Orbit types	Circular (radial velocity ignored)	Circular to highly elliptical
Model population breakdown by type & material density	No	Intacts Low-density (1.4 g/cc) fragments Medium-density (2.8 g/cc) fragments & microdebris High-density (7.9 g/cc) fragments & microdebris RORSAT NaK coolant droplets (0.9 g/cc)
Model cumulative size thresholds (*fiducial points*)	10 μm, 100 μm, 1 mm, 1 cm , 10 cm, 1 m	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
Flux uncertainties	No	Yes
Total input file size	13.5 MB	1.25 GB
Meteoroids	No	No**

*While the geosynchronous transfer orbit (GTO) is not as well observed as LEO, the orbital dynamic forces and mechanisms for fragmentation are considered to be similar. The ODPO therefore allows for > 10 μm fluxes through GTO. For GEO the dynamics (including perturbation forces and impact velocities) as well as the size and structure of satellites are unique, though GTO and GEO physically overlap. The ODPO provides GEO debris fluxes for 10 cm and larger only. This is based on the SSN (1 m and larger), the MODEST uncorrelated target data (30 cm – 1 m) and the MODEST uncorrelated targets extended to 10 cm. Any fluxes below that 10 cm threshold at altitudes above LEO altitudes are solely due to GTO objects.

**The ODPO has decided that the meteoroid environment will not be included in ORDEM. The user must include a separate meteoroid model to create the total space debris environment.

Table 2-2: Contributing Data Sets

Observational Data	Role	Region/Approximate Size
SSN catalog (radars, telescopes)	Intacts & large fragments	LEO > 10 cm, GEO > 1 m
HAX (radar)	Statistical populations	LEO > 3 cm
Haystack (radar)	Statistical populations	LEO > 5.5 mm
Goldstone (radar)	Statistical populations	2 mm < LEO < 8 mm
STS windows & radiators (returned surfaces)	Statistical populations	10 µm < LEO ≤ 1 mm
MODEST (telescope)	GEO data set	GEO > 30 cm

Table 2-3: Contributing Models (with Corroborative Data)

Model	Usage	Corroborative Data
LEGEND	LEO Fragments > 1 mm GEO Fragments > 10 cm	SSN, Haystack, HAX, MODEST, SSN
Degradation/Ejecta	10 µm < LEO ≤ 1 mm	STS windows & radiators

The ORDEM 3.0 input debris populations are binned in the quasi-orthogonal orbital elements in Table 2-4 for non-GEO objects and in Table 2-5 for GEO objects. Bin sizes are chosen to complement actual population distributions. The final files are from the direct yearly input database of ORDEM 3.0.

The binned input populations are accessed via the Spacecraft and Telescope/Radar modes; where the former uses the encounter igloo method and the later uses a segmented bore-sight vector for computation of flux. This process is described more fully in the following sections and will be discussed in depth in the *ORDEM 3.0 Technical Document*.

Table 2-4: Input File Population Bins for LEO to GTO

Parameter	Binning Intervals	Total No. of Bins
Perigee altitude, h_p	$100 \le h_p < 2000$ km → 33.33 km bins $2000 \le h_p < 10{,}000$ km → 100 km bins $10{,}000 \le h_p < 40{,}000$ km → 200 km bins	287
Eccentricity, e	$0 \le \sqrt{e} < 0.02666$ → 0.02666 bin $0.02666 \le \sqrt{e} < 1$ → 0.01333 bins	74
Inclination, i	$0° \le i < 180°$ → 0.75° bins	240

Table 2-5: Input File Population Bins for GEO

Parameter	Binning Intervals	Total No. of Bins
Mean Motion, n	$0.5 \le n < 0.95 \rightarrow 0.01$ rev/day bins $0.95 \le n < 1.05 \rightarrow 0.001$ rev/day bins $1.05 \le n < 1.80 \rightarrow 0.01$ rev/day bins	220
Eccentricity, e	$0 \le \sqrt{e} < 0.5 \rightarrow 0.02$ bins	25
Inclination, i	$0° \le i < 0.2° \rightarrow 0.2°$ bins $0.2° \le i < 1.0° \rightarrow 0.8°$ bins $1° \le i < 25° \rightarrow 1°$ bins	26
Right ascension of ascending node, Ω	$0° \le \Omega < 360° \rightarrow 5°$ bins	72

2.1 Software Installation and Removal

The minimum system requirements to install ORDEM 3.0 are listed below:

- Microsoft Windows XP or later
- Microsoft .Net framework 4.0 or greater
- 512 MB random-access memory (RAM)
- 1.5 GB available disk space

NOTE: Depending on user inputs, ORDEM 3.0 runtimes will vary from 10 minutes (for low LEO circular orbits) to over 6 hours (for high apogee GTO orbits). A faster Central Processing Unit (CPU) will reduce runtime, but the computational method cannot take advantage of multiple CPUs/cores.

ORDEM 3.0 is distributed using an executable setup file. The setup will install the program's executable files and all necessary support files within the appropriate directories. To install the ORDEM 3.0 software, follow the procedure below:

1. If not already installed, obtain and install the Microsoft .NET framework 4.0 or greater (http://www.microsoft.com/net/Download.aspx).

2. Obtain the installation file for ORDEM 3.0 (ORDEM3.0_Install.exe) from the NASA ODPO Point of Contact.

3. Run the ORDEM 3.0 installer. This may require special user privileges (i.e., Administrator) depending on the computer's security settings.

The installer will set up the ORDEM 3.0 software, libraries, and extensive data files. The installer will also create Windows-based shortcuts to the ORDEM 3.0 GUI, User's Guide, and software uninstaller. By default, the shortcuts are located in the Windows-based Start menu under Programs → ORDEM 3.0.

Use the following steps to install the program:

1. If the installer detects that ORDEM 3.0 is already installed, it prompts the user to remove the installed version.

2. The **Welcome** window verifies that the installation of ORDEM 3.0 is desired. If not, select cancel.

3. The **Software Usage Agreement** verifies that the user agrees to accept the software license. The user may cancel the installation or may agree and proceed to the next step.

4. The Choose Users window allows the user to select whether to install ORDEM 3.0 for all users or for the current user only.

5. **Choose Install Location** defines the location where the application will be installed. The default location is the "Program Files (x86)" directory. A "Browse" button will enable the user to view the file structure to define a preferred location.

6. **Choose Start Menu Folder** defines a folder within the Windows-based **Start→Program** list where the application shortcuts will appear. The default setup will be provided, but another name can be defined or an existing program folder can be selected where this application will be loaded. Click "Next" to continue with installation.

7. The **Installing ORDEM 3.0** window is displayed. The progress bar displays information on the installation progress.

8. **Setup Complete** notifies the user that the setup has been completed and the system will not require rebooting. The user has the option to create a desktop shortcut to the ORDEM 3.0 GUI and to view the README.txt file.

9. If needed, verify that the installer added the NASA\ORDEM 3.0\model directory to the PATH environment variable.
   a. To verify PATH, right-click on **My Computer**, then select **Properties → Advanced System Settings → Environment Variables**. In the System Variables window, select the PATH option in the System Variables list and click the "Edit" button.

   b. If the NASA\ORDEM 3.0\model folder is not found in the PATH environment variable, the user can manually add this folder to PATH by typing the following in a command window:

      ```
      set PATH=<path-to-ORDEM3.0>\NASA\ORDEM 3.0\model;%PATH%
      ```

Do not remove or rename files and directories installed with ORDEM 3.0. Do not modify files within the ORDEM data directory ("ORDEM 3.0\data\"). Files and directories may be copied to another location if necessary, but ORDEM 3.0 requires the originally installed files to remain unaltered.

Removal:

ORDEM 3.0 includes an automatic removal ("un-installer") feature. To remove ORDEM 3.0, run the program "ORDEM 3.0-uninstall.exe", located in the "uninstall" folder of the ORDEM 3.0 application directory. This may require special user privileges depending on the computer's security settings. A shortcut to this uninstaller in the ORDEM 3.0 program group is in the Windows Start Menu. You will need to delete manually any ORDEM 3.0 project directories that the user created.

Note for Windows 7 Users: Do not attempt to uninstall ORDEM 3.0 from the "Programs and Features" portion of the Windows Control Panel; it will not work. Instead, use the above removal procedure.

2.2 Software Description

ORDEM 3.0 includes two programs: a command-line executable, which performs the numerical computations; and a separate GUI. Upon installation, these executables are stored in the Application Directory (see Table 2-6). The default location of the Application Directory is the NASA\ORDEM 3.0 folder in the "Program Files (x86)" directory. This directory also includes the debris population files that form the database of the model (stored in the subdirectory "data").

The results of an ORDEM 3.0 computation are stored in the user-defined "Project Directory". This directory is located where the user creates it. It is a writable area for running the computational model and saving all GUI values. The user may create as many project directories as desired. The directory (shown in Table 2-7) contains the input parameter file and all output files.

Table 2-6: Files in Application Directory

File Name	Description
data/YYYY.POP data/*.SIG data/*.TIG data/*.DAT data/*.BIN data/*.out	Yearly input population data for ORDEM 3.0 calculations Spacecraft-mode igloo description files Telescope/Radar-mode igloo description files Data defining the bin boundaries of the debris populations Binary file containing 7-dimensional Sobol sequences Gridline coordinates for the spacecraft-mode plot of "2-D Directional Flux"
help/ORDEM_UserGuide.pdf	User's guide for ORDEM 3.0
model/ORDEM.exe	Computational model executable
uninstall/ORDEM_3.0-uninstall.exe	Uninstall model executable
LICENSE.txt	Software Usage Agreement (SUA)
ORDEM-GUI.exe	Graphical user interface executable
README.txt	

Table 2-7: Files in Project Directory

File Name	Description
ORDEM-Project.prj	The saved project values from the GUI
ORDEM-GUI_Log.txt	The project log file
runtime.log	An error log created by the command-line program
ORDEM.IN	The command file, which holds the parameters for running the computational model executable
*_SC.OUT	Spacecraft assessment output files
*_TEL.OUT	Telescope/Radar assessment output files

* See Appendix B (Table B-2) for output file names.

2.3 Program Execution

ORDEM 3.0 may be run using the GUI or the command-line ("DOS") interface. The GUI accepts inputs from the user, sets up and performs a single run, and displays the results as on-screen plots. The command-line interface requires the user to supply a separate text input file or a driver/batch code for serial batch processing. This interface also produces the standard output files listed in Table 2-7, but does not produce plots.

2.3.1 GUI-based Computation

The usual means of running ORDEM 3.0 is through the GUI. Figure 2-1 illustrates the user actions and subsequent program performance associated with the GUI. After mode selection, with required inputs, the ORDEM 3.0 code selects the appropriate population bin set and begins the mapping of bins to encounter igloos or segmented bore-sight vectors. Encountered fluxes are compiled and tabulated in output files that are, in turn, accessed by TeeChart plotting routines via the GUI.

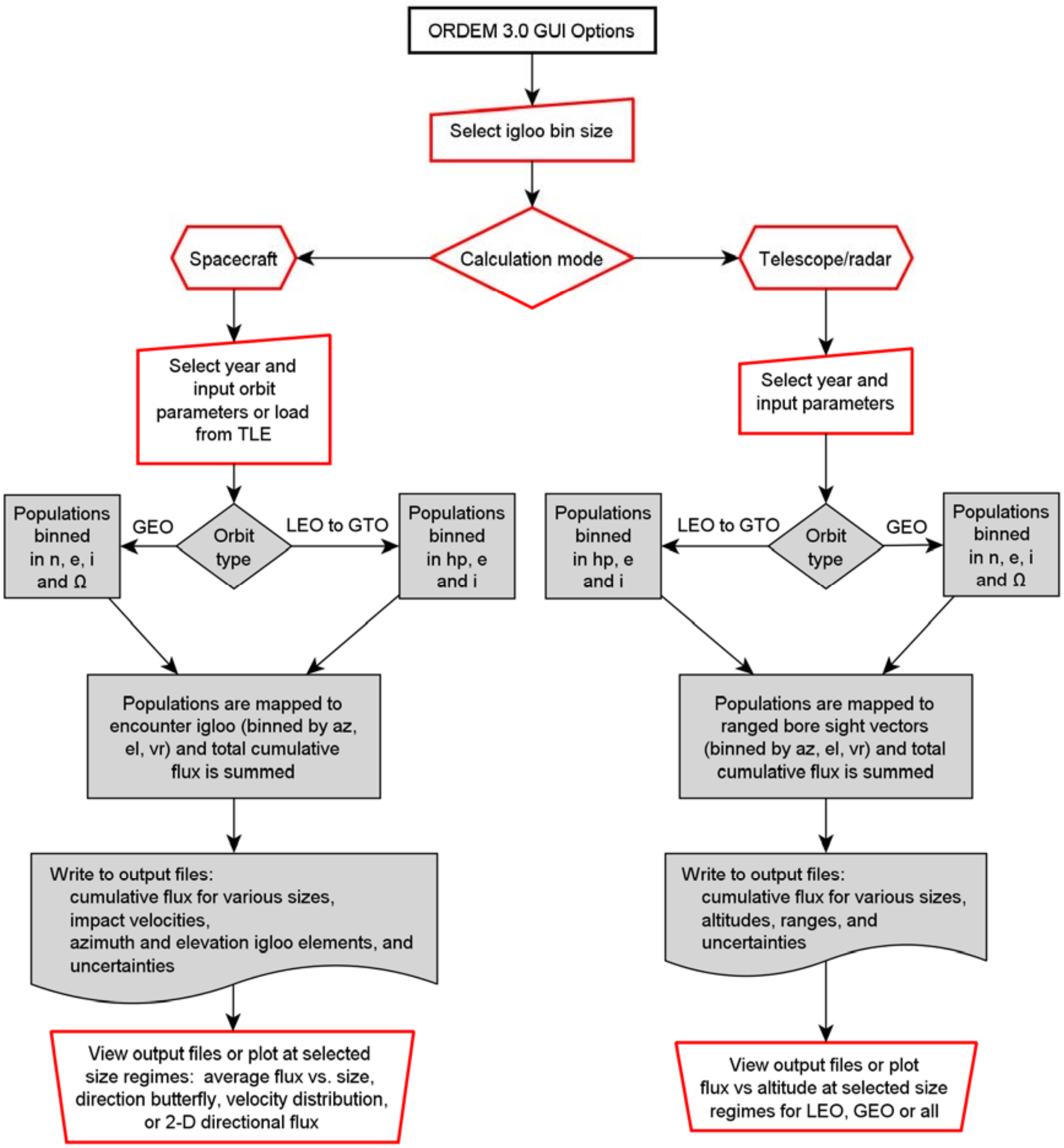

Figure 2-1: ORDEM GUI options and coding structure flowchart. Both LEO and GEO calculations are accessed for any orbits whose parameters overlap into LEO and GEO igloo bins. Red indicates GUI user selections; gray background indicates ORDEM processes.

Specifically, to run ORDEM 3.0 through the GUI the user chooses the "ORDEM-GUI.exe" in the Application Directory. The ORDEM 3.0 initial "project window" appears (see Figure 2-2). The user defines a project directory (the location the user chooses), to which all output files and

GUI settings will be saved. Project folders allow a user to save and load different projects without having to re-enter the inputs.

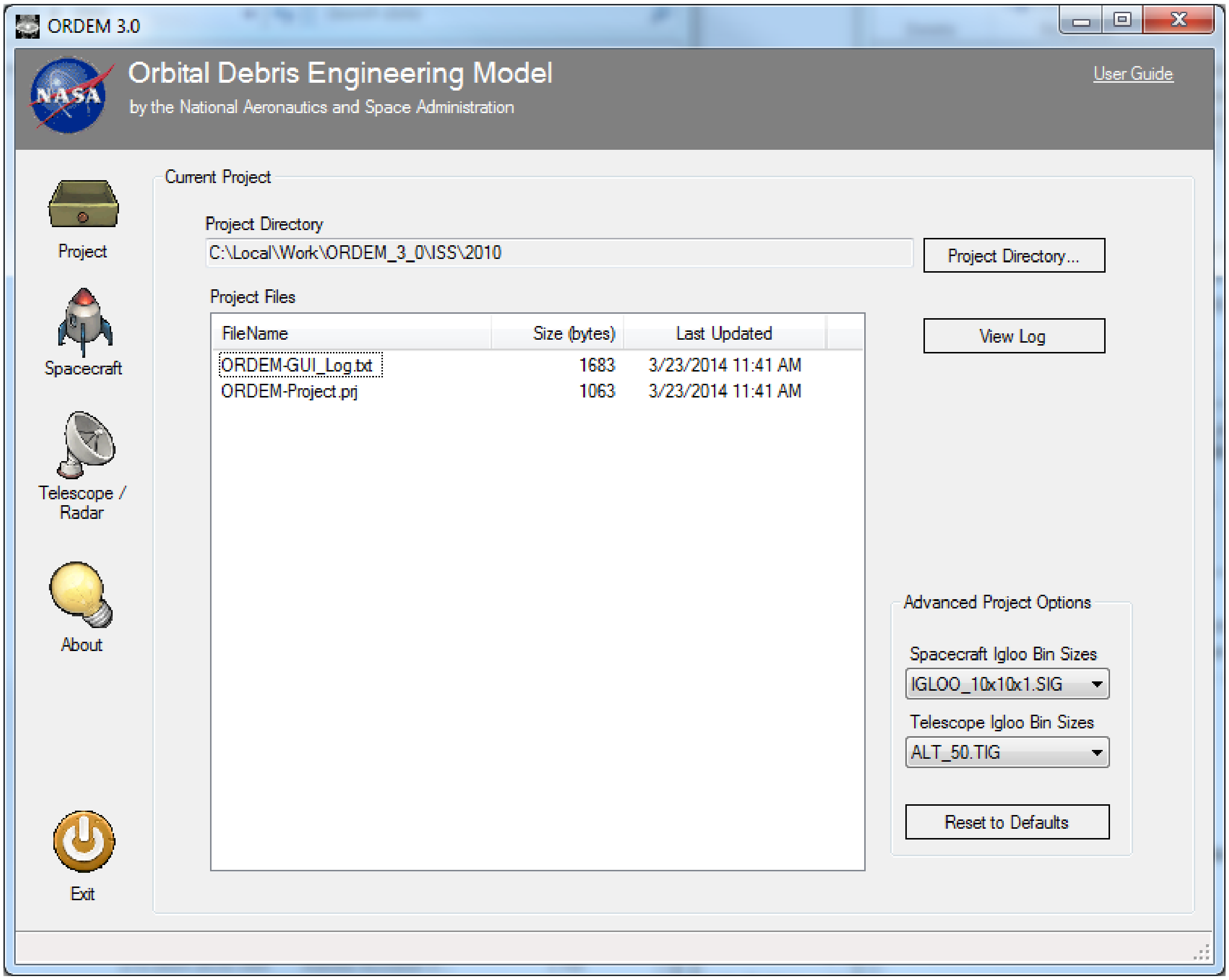

Figure 2-2: ORDEM 3.0 project window.

The top area of the project window displays the currently selected project directory. This directory is the location for all the computational output and GUI settings. The application allows the user to save as many projects as desired. *Note that creating a project directory by other means will NOT create the required ".prj" file, causing ORDEM 3.0 to reject that directory.* Click the ***Project Directory…*** button to open the Project Directory selection window. To open a previously created project, the user selects the desired directory. To create a new project, the user selects the ***Make New Folder*** button in the selected directory. When the desired projected directory is selected, the user clicks the ***OK*** button. On the main project window, the current values in the GUI are saved to the current .prj file. The ***Reset to Defaults*** button resets all the GUI values to the last saved values.

Toward the center of the window is a box with a list of project files in the current project directory. (If the directory is new, it is empty and the box is empty.) It provides a quick access and view to any of the files. If double clicked, a file will be opened in another window for viewing. ***View Log*** will bring up a window allowing the user to view the log of past activity. Last, the ***Reset to Defaults*** button will reset all the GUI values to default values. This includes the currently known project directory in the project window and the system registry (used for loading the last used project on startup).

Before moving to one of the assessment modes, Spacecraft or Telescope/Radar, the user may choose from a set encounter igloo or segmented bore-sight vector gradations in the Advanced Project Options box (see Table 2-8).

Table 2-8: Advanced Project Options

Selection Name	**Description**
Spacecraft Igloo Bin Sizes	
IGLOO_10x10x1.SIG*	Spacecraft encompassing igloo with dimensions 10° in azimuth, 10° elevation, 1 km/sec in velocity
IGLOO_30x30x2.SIG	Spacecraft encompassing igloo with dimensions 30° in azimuth, 30° elevation, 2 km/sec in velocity
Telescope/Radar Igloo Bin Sizes	
ALT_50.TIG* ALT_100.TIG	Segmented bore-sight vector defined by 50 km or 100 km altitude bins from LEO to GEO (200 km - 40,000 km)
ALT_5_GEO.TIG ALT_50_GEO.TIG ALT_100_GEO.TIG	Segmented bore-sight vector defined by 5 km, 50 km, or 100 km altitude bins in GEO-only (34,000 km - 40,000 km)
ALT_5_LEO.TIG ALT_50_LEO.TIG ALT_100_LEO.TIG	Segmented bore-sight vector defined by 5 km, 50 km, or 100 km altitude bins in LEO-only (200 km - 2,000 km)

*The finer gradations are the ORDEM 3.0 default values (see Figure 2-2).
These are recommended for any serious analysis.

2.3.1.1 Spacecraft Assessment

The Spacecraft Assessment window (see Figure 2-3) is used for evaluating the orbital debris environment for spacecraft and missions. This window contains the input fields (at the top) and the runtime output window (at the bottom).

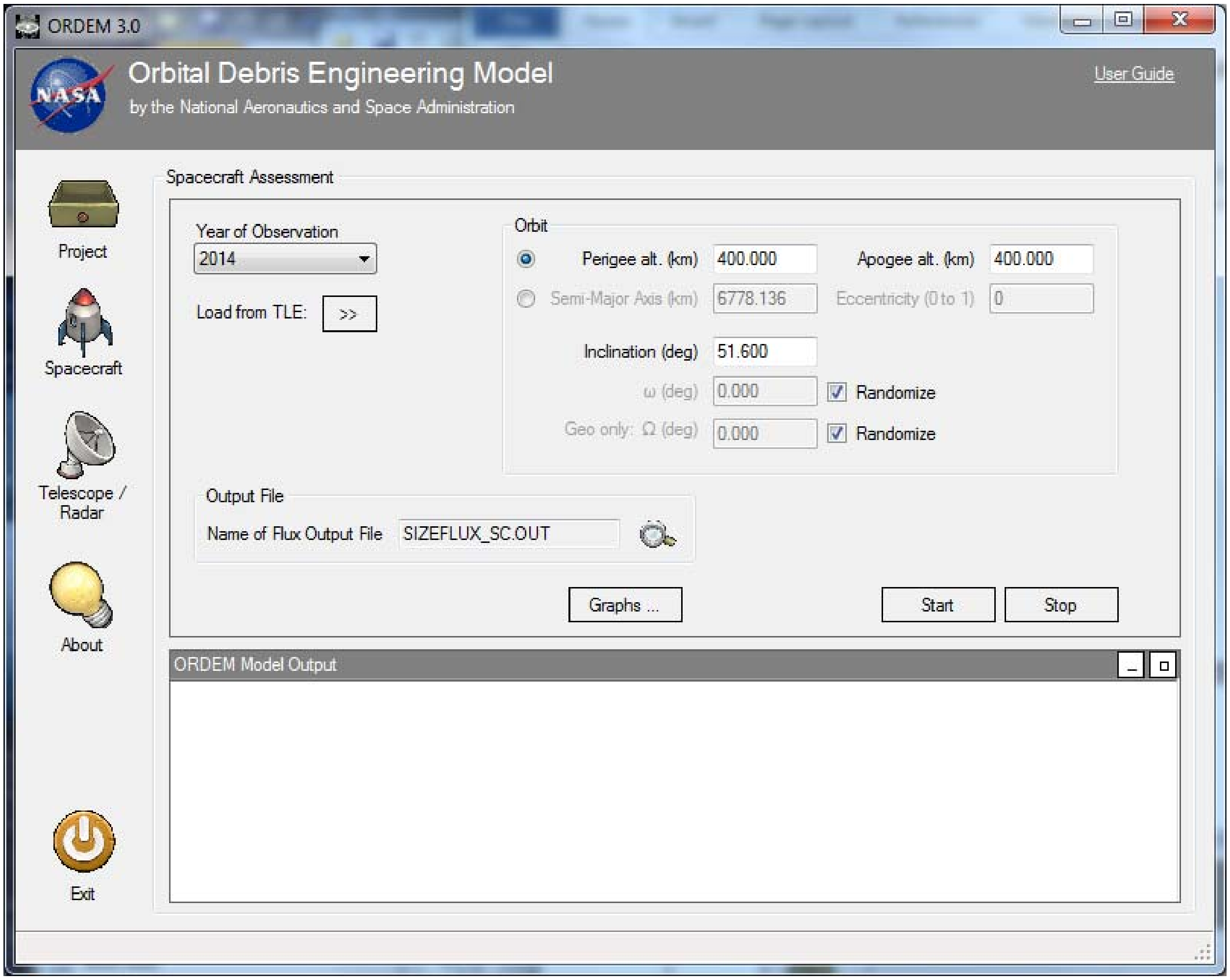

Figure 2-3: ORDEM 3.0 Spacecraft Assessment window.

The input orbit information can be entered as orbital parameters (h_p, h_a), Keplerian orbit elements (a, e), or as a standard two-line element (TLE) set. When entering input information by hand, the user can define the orbit by inclination and either the perigee and apogee altitudes or by the semi-major axis and eccentricity. The user may define the argument of perigee and right ascension of the ascending node (RAAN). It is also possible to choose a "randomized" value for argument of perigee and RAAN. The results will represent time-averaged fluxes over all possible values of the RAAN that are appropriate for long-term flux calculations in many cases. Note that a non-random choice of argument of perigee or RAAN affects only flux calculations in the Molniya-type orbits or the GEO regime, respectively. The LEO populations are assumed to consist of populations with randomized argument of perigee and RAAN, so a specific choice of these orbital elements will not affect LEO fluxes.

To input the orbit as a TLE set, click on the ***Load from TLE*** button. Figure 2-4 shows the pop-up window that is displayed for decomposing a TLE.

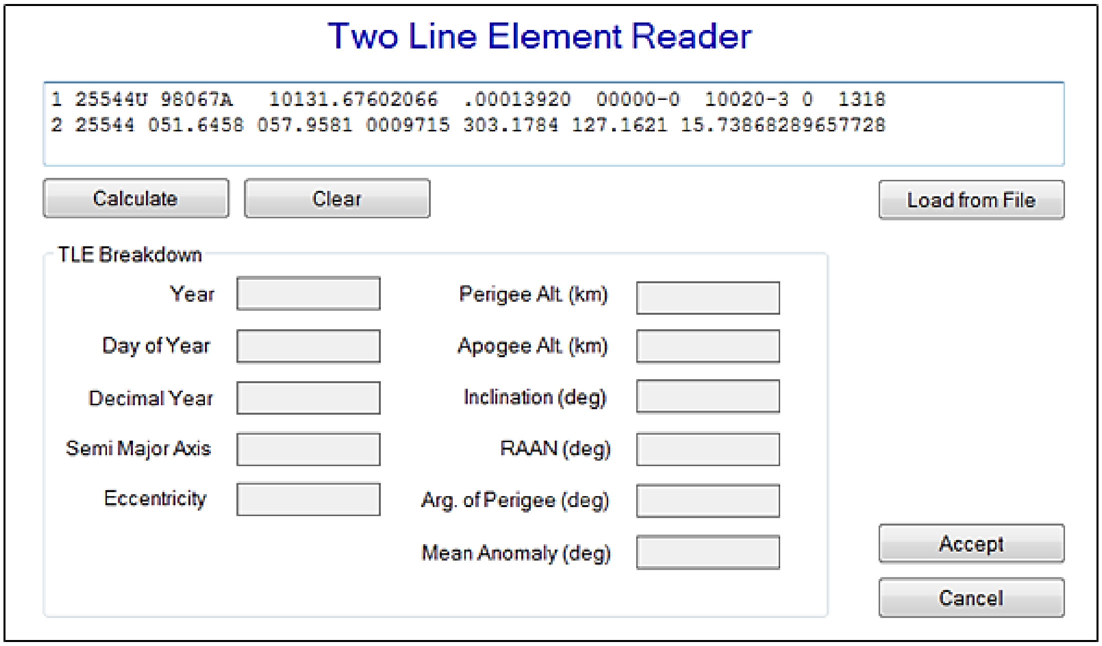

Figure 2-4: ORDEM 3.0 Spacecraft Assessment TLE window.

The TLE window allows the user to specify the TLE by loading from a text file, hand typing, or pasting into the TLE area. When loading from a text file (***Load from File*** button), the software reads only the first TLE set. The ***Calculate*** button will break down the TLE into the various orbital parameters. If these are the desired values, the user must click the ***Accept*** button. The TLE breakdown values will then appear in the Spacecraft assessment window. The ***Cancel*** button will close this window and the ***Clear*** button will clear the TLE area.

After all input parameters are set in the Spacecraft assessment window, the user must click the ***Start*** button to begin the computations. The ***Stop*** button is provided to abort a run. Immediately below the ***Start*** and ***Stop*** buttons is the ***ORDEM 3.0 Model Output*** area (See Figure 2-3). After clicking the ***Start*** button, the model process will begin and the output messages will be redirected into this output area. Normal output messages from the model will appear in black text and error messages will appear in red text. The GUI will write other informative messages in blue text. (Note that the different-colored messages may not appear to be synchronized, because they come from different sources.)

After running the computational model, the files listed in the "Output File" area may be viewed by clicking the icon to the right of the file name. The user can view four types of output graphs by clicking the ***Graphs*** button: average flux vs. size, directional flux "butterfly," 2-D directional flux , and flux velocity distribution (as shown in Figure 2-9). The full description of these graphs is in Section 2.4.

2.3.1.2 Telescope/Radar Assessment

The Telescope and Radar Assessment window is provided for modeling the orbital debris environment as viewed through the bore-sight of a ground-based telescope or radar. Figure 2-5 shows the Telescope/Radar Assessment window.

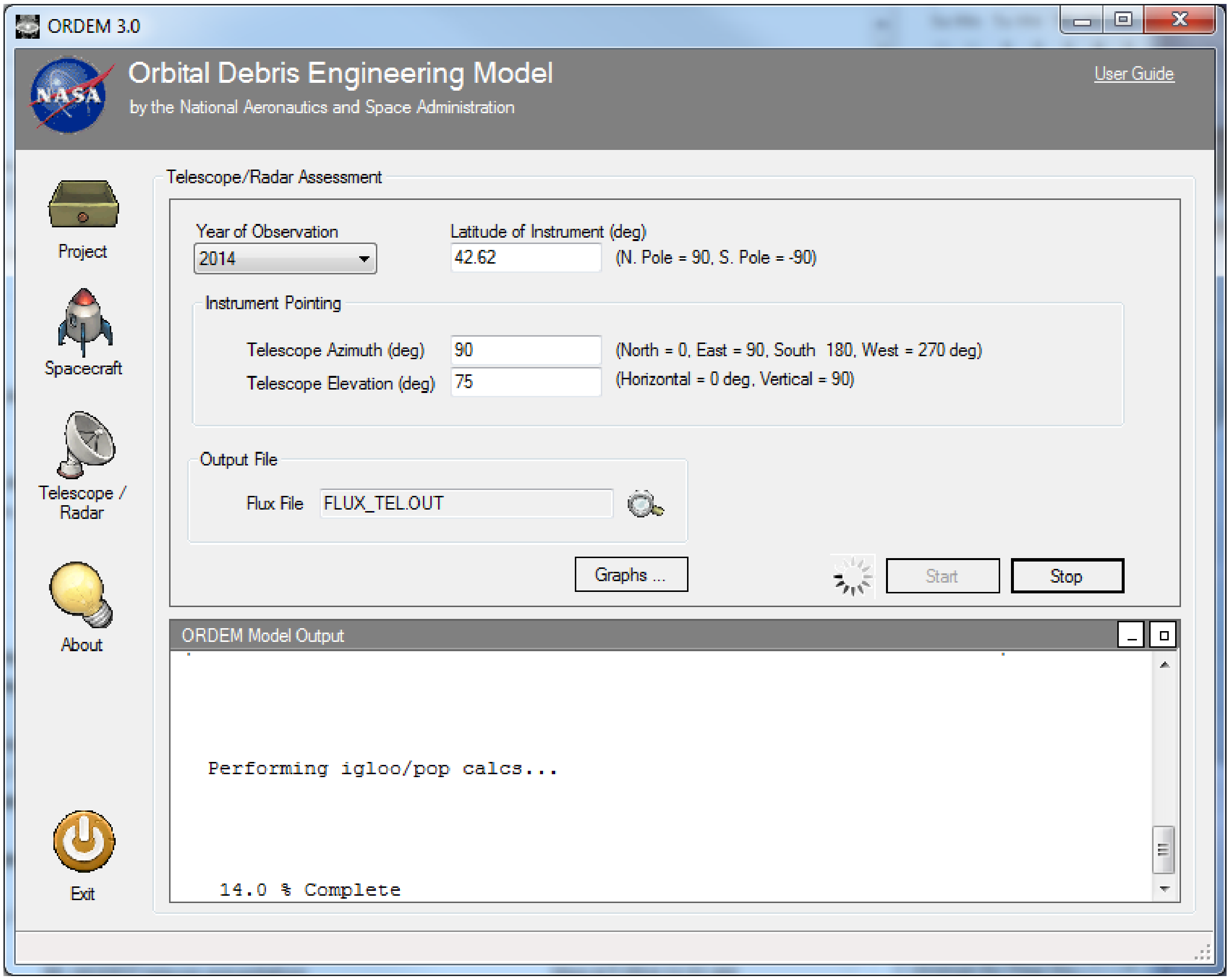

Figure 2-5: ORDEM 3.0 Telescope/Radar Assessment window.

This window is very similar in functionality to the Spacecraft Assessment window. There are fields for the inputs, start and stop buttons for running the model, and buttons for viewing the output. There is a single output file listing Flux vs. Altitude: LEO-only, LEO+GEO, and GEO-only. This file may be viewed by clicking the icon to the right of the file name – the ***Graphs…*** button. Section 2.4 includes the full description of these graphs.

2.3.2 Command-line-based Computation

The second method of running ORDEM 3.0 is via the command-line interface, with or without a batch file. This approach is possible because the computational model is a separate executable program. Running from the command line requires the user to manually edit the ORDEM.IN input file. A sample ORDEM.IN file is displayed in Table B-1. In GUI runs, this file is produced from the user set input parameters. It holds all values needed to run the simulation. The file is annotated to assist in editing if needed (the user may wish to create the file first using the GUI).

To run the application via command-line interface, the user enters:

```
ORDEM.exe "D:\ORDEMtestrun\"
```

(assuming a sample project directory, "D:\ORDEMtestrun\").

If the NASA\ORDEM 3.0\model directory is not in the PATH environment variable (as described in step 9 of section 2.1), then the user must use the full path of the ORDEM.exe file instead of just typing the ORDEM.exe file name in the batch file. This will run the model and the user will see the output messages as it is running. Output files will be written to the project directory. No plots are produced when ORDEM 3.0 is run from the command line. The GUI can be used to plot output files generated in command-line mode.

Using a batch file negates the need to enter input parameters in the GUI at the beginning of each ORDEM 3.0 run and is useful when a series of runs is needed. To run a series of input cases non-interactively, the user must first create a separate project directory for each case, then create and edit the ORDEM.IN input file within each project directory (using the GUI to create a template ORDEM.IN file). After the inputs are ready, the user will write and execute a batch file in a user-specified directory or simple driver program to run ORDEM 3.0 for each of the series of project directory paths. Below is a sample batch file. Each folder, here labeled D:\2011_folder\, etc., must contain a modified ORDEM.IN file.

```
filename batch_run.bat:
ORDEM.exe "D:\2011_folder\"
ORDEM.exe "D:\2012_folder\"
ORDEM.exe "D:\2013_folder\"
ORDEM.exe "D:\2014_folder\"
ORDEM.exe "D:\2015_folder\"
```

The example above uses a batch file to perform a series of ORDEM 3.0 runs on a spacecraft every year from 2011 to 2015. This batch file is run in the user-specified directory by typing:

```
batch_run.bat
```

at the command prompt.

2.4 Output Data and Graphs

The ORDEM 3.0 output files (described in Appendix B) are plain text and column-separated for easy transfer into spreadsheets or other visualization programs. The ORDEM 3.0 GUI uses TeeChart by Steema Software (http://www.steema.com/), to display and manipulate graphs of the output data. The GUI graphing windows have a number of useful features. The user may manipulate the graphs to zoom, pan, and copy to the clipboard and export to various file types. Each of the graph windows works identically and each provides similar features. A series of buttons in the upper left menu bar area of each graph window (see Figure 2-6) provides the following functions:

1. ***Reset*** – selecting this button resets the graph window. If zooming and reformatting of the graph occurs, the **Reset** button will return the graph to the original setup.

2. ***Copy*** – selecting this button copies the graph to the clipboard so the graph can be pasted directly into another document such as a document editor.

3. ***Export*** – selecting this button presents the user with a dialog (see Figure 2-7) containing a number of image format choices for exporting, such as JPEG, etc.

4. ***Configure*** – selecting this option presents a graph editor window (Figure 2-8) from which almost any aspect of the graph can be customized. An in-depth description of these controls is beyond the scope of this guide, but the major tabs include:

   - ***Chart*** provides options for altering the chart's appearance. Options from legend titles, background color, axis labels, and line styles may be found here.

   - ***Series*** provides options with respect to the plotted data. Here may be found opportunities to alter the appearance of line and plotted points.

   - ***Data*** is not pertinent to this application, and remains only because of the off-the-shelf TeeChart program. The user is encouraged to ignore this feature.

   - ***Print*** provides additional functionality in printing the chart to the user's available printers.

   - ***Export*** provides the ability to export the selected chart to a variety of file formats, as well as some other limited features such as resizing the image.

   - ***Tools*** provides miscellaneous tools for manipulating the chart.

   - ***Themes*** provides a set of pre-set themes that the user may select.

5. ***Print*** – choosing this button causes a print preview window to be displayed. The user can then select the print button from the menu bar to send the graph to the printer.

Figure 2-6: ORDEM 3.0 graph options menu.

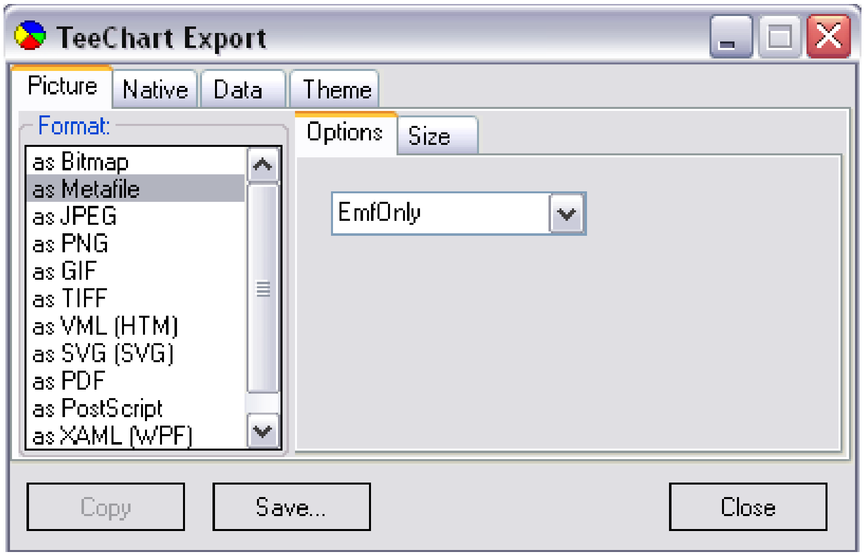

Figure 2-7: ORDEM 3.0 graph export dialog window.

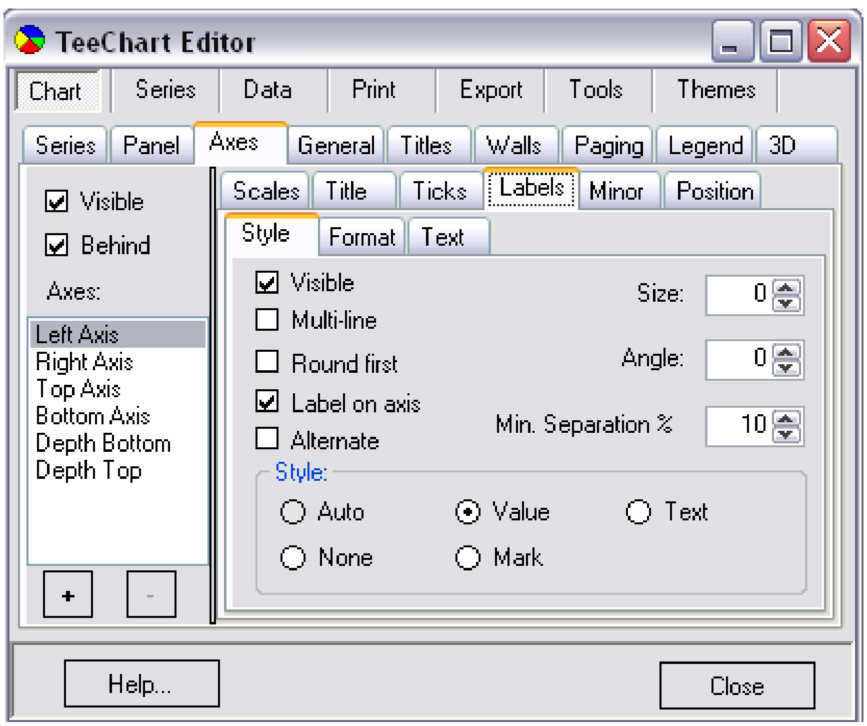

Figure 2-8: ORDEM 3.0 graph configuration dialog window.

The user also has the availability of some standard capabilities within the graph window. For example, assuming the standard, right-hand mouse set-up, zooming is supported through the left mouse button. Simply select the zoom region by pressing and holding the left mouse button over the upper left corner of the area to be magnified, and drag the cursor down and to the right until the entire zoom region is selected, then release the mouse button. Panning is supported by pressing and holding the right mouse button while dragging the graph as needed. Note that a pan movement for a plot that has a logarithmic axis may give unexpected results.

To undo any zoom magnification and return to the original full graph, reverse the zoom movement of the mouse by pressing and holding the left mouse button and dragging the cursor to the left and up. When the mouse button is released, the graph will return to its original magnification state.

ORDEM output files are generated for the two analysis modes: Spacecraft and Telescope/Radar. The files represent the debris fluxes encountered by the chosen Spacecraft or Telescope/Radar beam. The fluxes are categorized mainly by size. Table 2-9 lists output files and descriptions.

Table 2-9: Files Output by each ORDEM 3.0 Mode

File Name	Description
Spacecraft assessment output files	
SIZEFLUX_SC.OUT	Average impact flux vs. size on the spacecraft per orbit. Graph input.
VELFLUX_SC.OUT	Impact velocity distribution on the spacecraft per orbit. Graph input.
BFLY_SC.OUT	Fluxes vs. yaw (collapsed in pitch) in the spacecraft frame. Graph input.
DIRFLUX_SC.OUT	Fluxes in 2-D map projection in the spacecraft frame. Graph input.
IGLOOFLUX_SC.OUT	Igloo element fluxes and velocities. Intermediate file.
IGLOO_FLUX_SIGMAPOP_SC.OUT	Correlated population uncertainty estimates.
IGLOOFLUX_SIGMARAN_SC.OUT	Random uncertainty estimates.
Telescope/Radar assessment output files	
FLUX_TEL.OUT	Surface area flux vs. altitude of debris of a given size. Graph input.
IGLOOFLUX_TEL.OUT	Segmented bore-sight vector element fluxes. Intermediate file.
IGLOOFLUX_SIGMAPOP_TEL.OUT	Correlated population uncertainty estimates.
IGLOOFLUX_SIGMARAN_TEL.OUT	Random uncertainty estimates.

2.4.1 Spacecraft Mode Graphs

After completing a computation, clicking the ***Graphs…*** button in the Spacecraft Assessment window initiates a new window (shown in Figure 2-9) from which a different graphical output is generated.

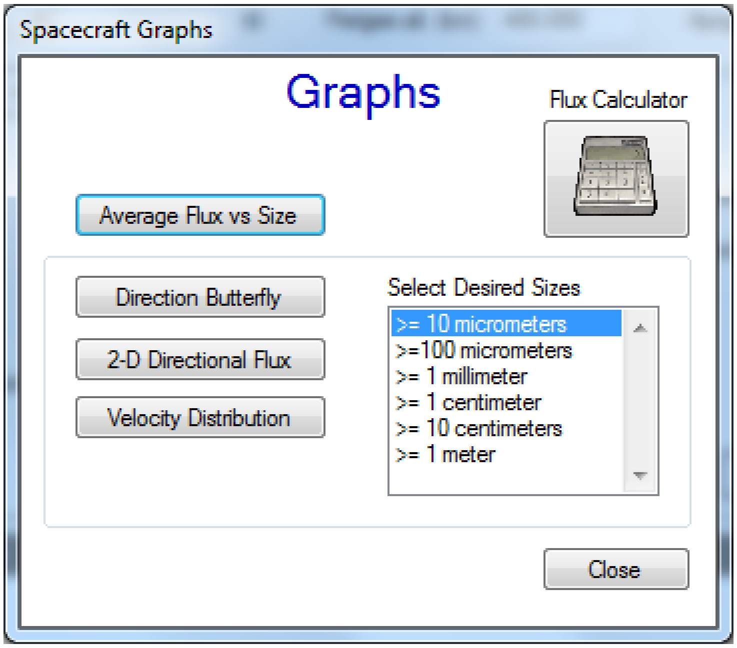

Figure 2-9: ORDEM 3.0 Spacecraft Assessment Graphs selection window.

An example of the ***Average Flux vs. Size*** along the chosen spacecraft orbit is shown in Figure 2-10. It represents the particle flux at specific sizes and larger (i.e., cumulative flux) on a satellite over an orbit and has become a common metric of the debris environment for the ORDEM series, as well as for the ESA MASTER series. Given the proved utility of this type of chart and underlying data, a ***flux calculator*** is also included as an option associated with the Spacecraft assessment graphs. This function calculates flux given a particle size value and a chosen uncertainty of zero to three sigmas (Figure 2-11).

Figure 2-10: Spacecraft Assessment Average Flux vs. Size graph.

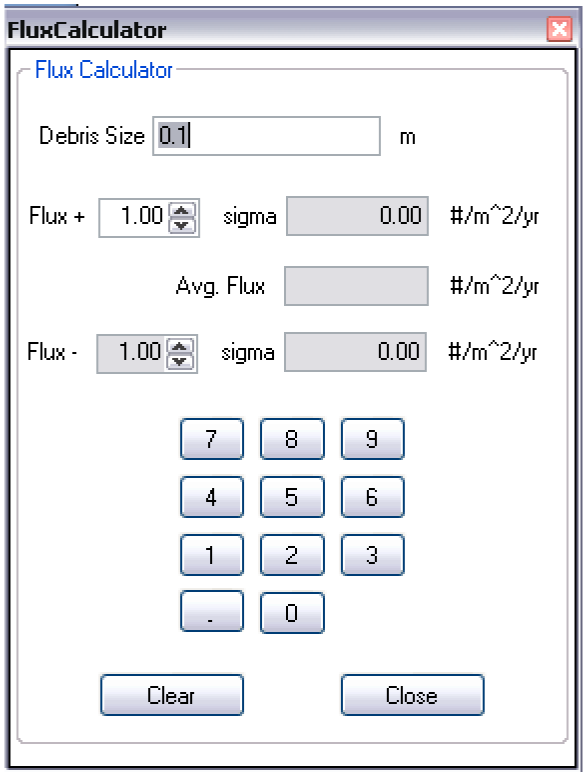

Figure 2-11: Spacecraft Assessment Flux Calculator.

Examples of the two ***Direction Butterfly*** graphs are presented in Figures 2-12 and 2-13. These figures represent average directional fluxes on the spacecraft from all directions, in three dimensions. These fluxes are summed and then collapsed to the 2-D spacecraft plane defined by the velocity and angular momentum vectors. The assessment velocity flux distribution on the spacecraft is displayed in Figure 2-14. The three-dimensional average flux on the spacecraft is fully realized in the mapped 2-D directional flux projection in Figure 2-15.

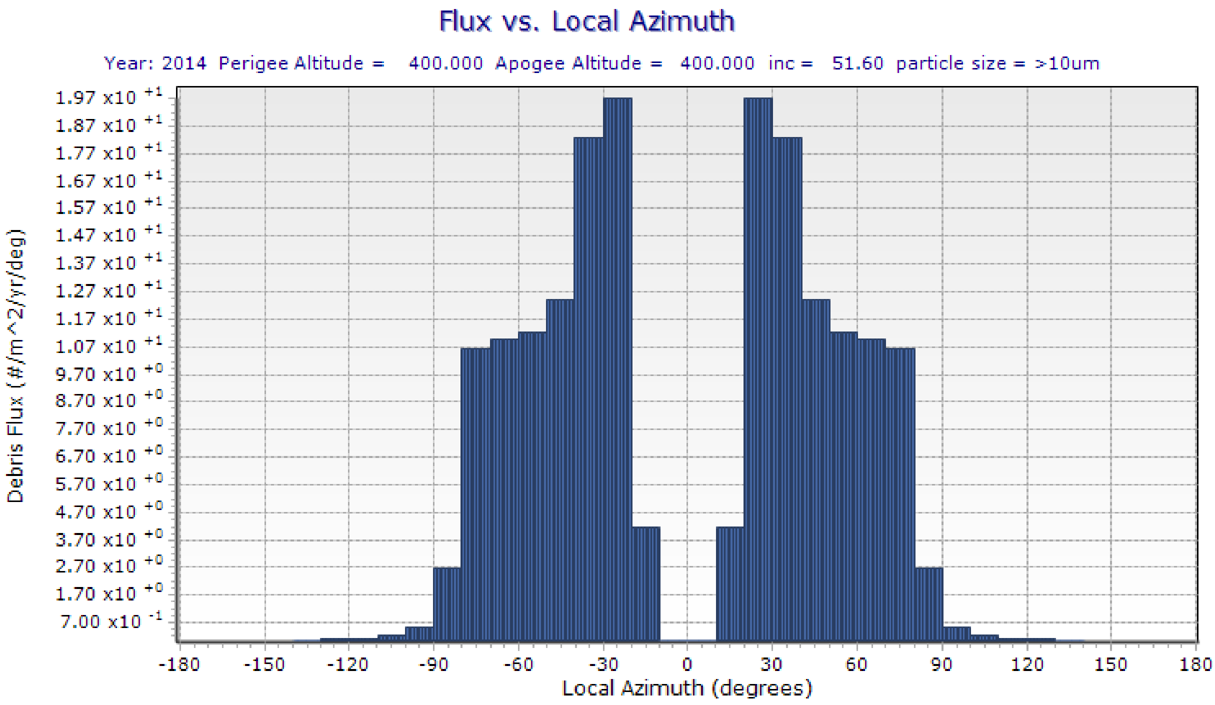

Figure 2-12: Spacecraft Assessment skyline butterfly graph.

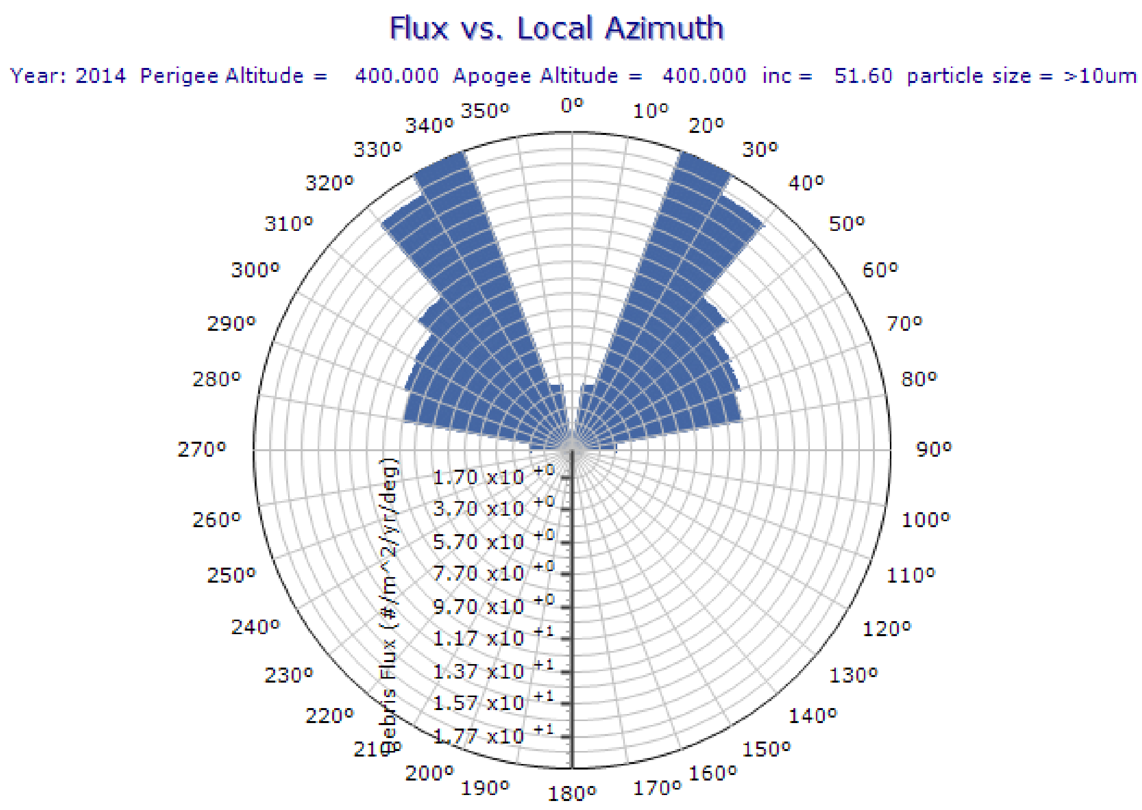

Figure 2-13: Spacecraft Assessment radial butterfly graph.

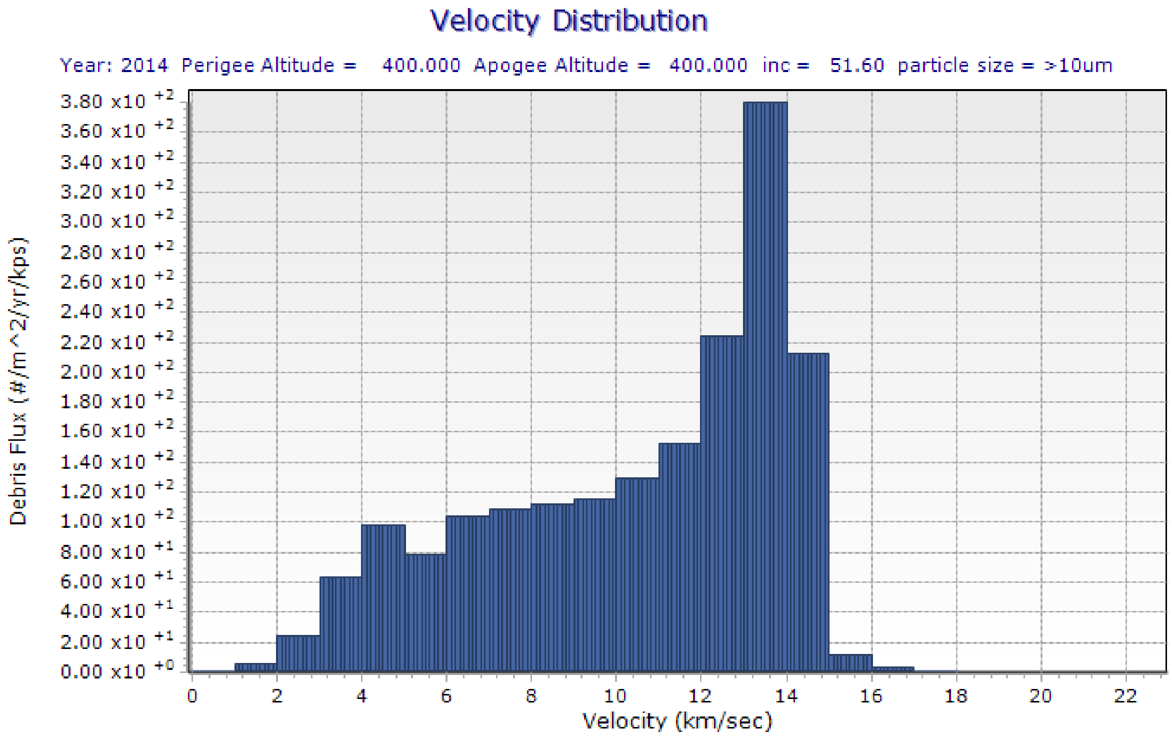

Figure 2-14: Spacecraft Assessment Velocity flux distribution.

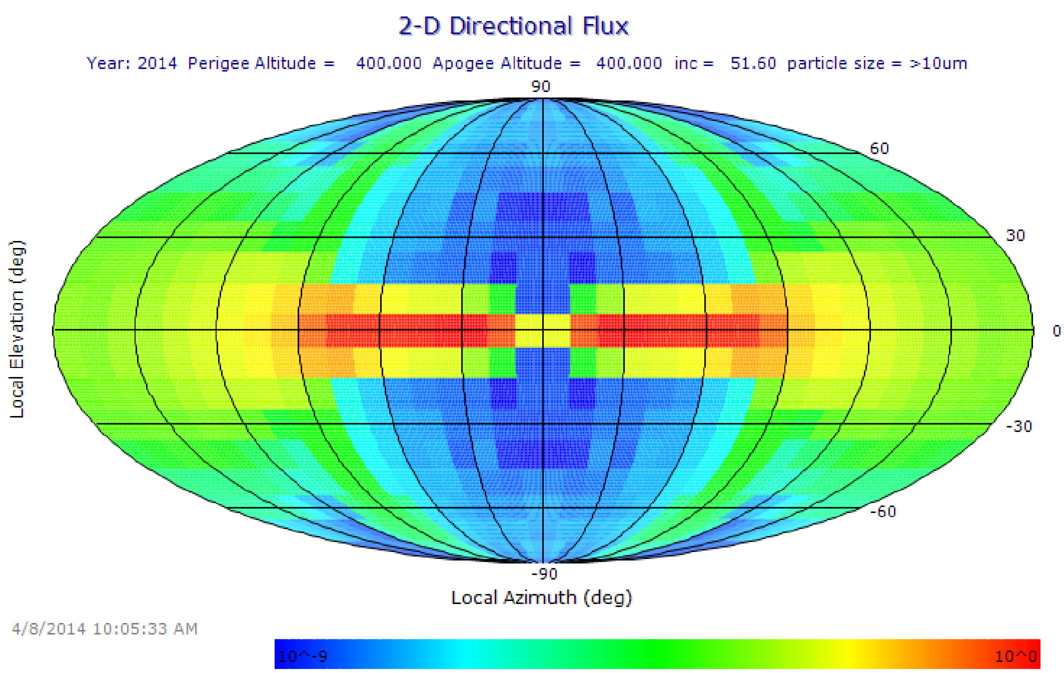

Figure 2-15: Spacecraft Assessment 2-D Directional Flux projection. Direction relative to the spacecraft is noted in coordinates (local azimuth and local elevation): where azimuth runs along the horizontal from left to right and ranges from -180º to 180º and elevation runs vertically from bottom to top and ranges from -90º to 90º.

2.4.2 Telescope/Radar Mode Graphs

After completing a computation, clicking the ***Graphs…*** button in the Telescope/Radar Assessment window initiates a new window, shown in Figure 2-16, from which a different graphical output is generated.

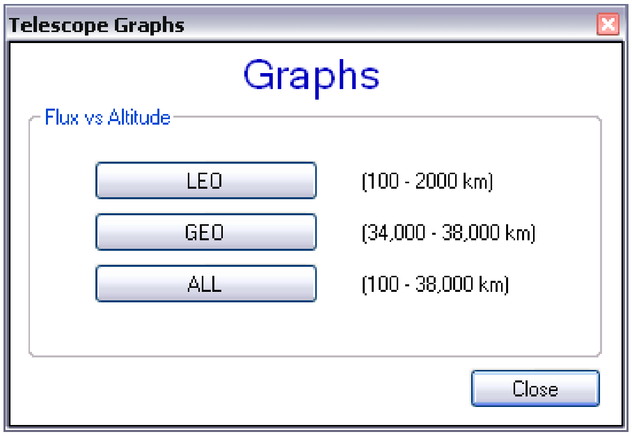

Figure 2-16: ORDEM 3.0 Telescope/Radar Assessment Graph selection window.

Two examples of ***Flux vs. Altitude*** graphs are displayed in Figures 2-17 and 2-18 for the LEO and the GEO cases, respectively. These figures represent the surface area flux at specific sizes over altitude ranges in the Telescope/Radar mode.

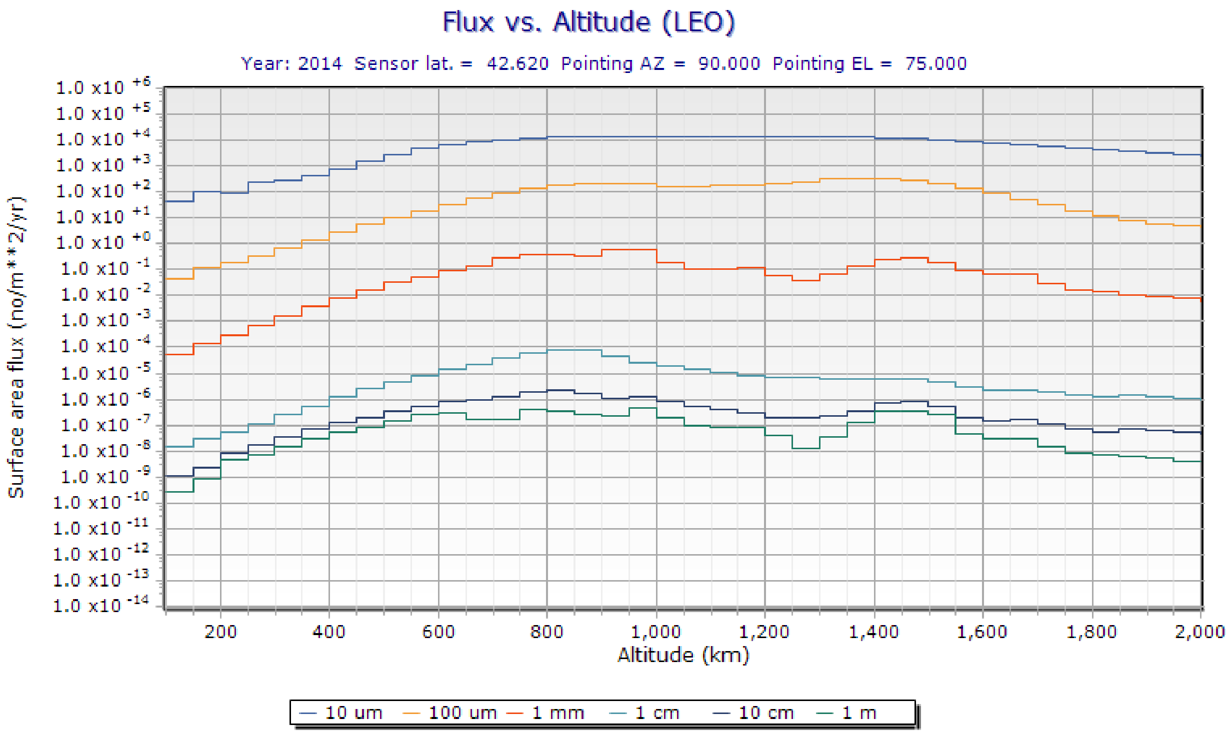

Figure 2-17: Telescope/Radar Assessment Flux vs. Altitude graph, LEO region-only.

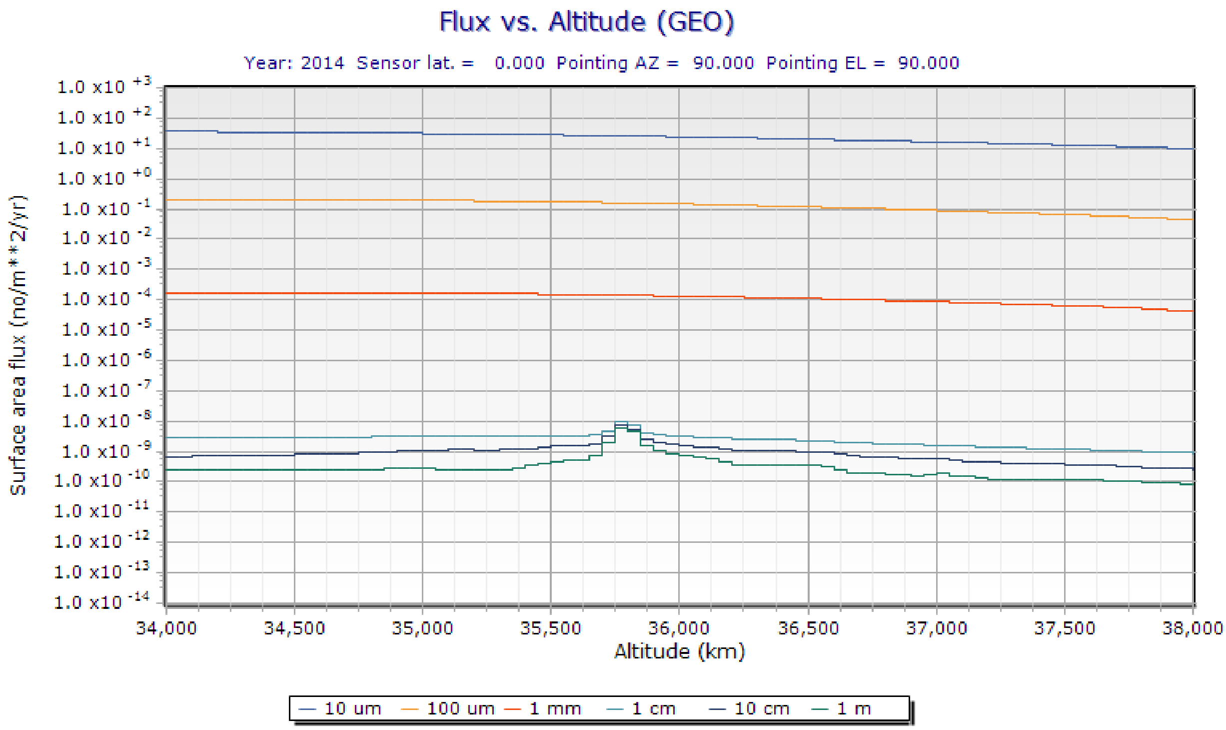

Figure 2-18: Telescope/Radar Assessment Flux vs. Altitude graph, GEO region-only.

The flux curves below 10 cm in Figure 2-18 represent GTO objects at GEO altitudes (see Table 2-1). In an ORDEM 3.0 run (for both Spacecraft and Telescope/Radar modes), which calculates debris fluxes at altitudes higher than 2000 km, a status window warning message is displayed at the beginning and end of the run as in Figure 2-19.

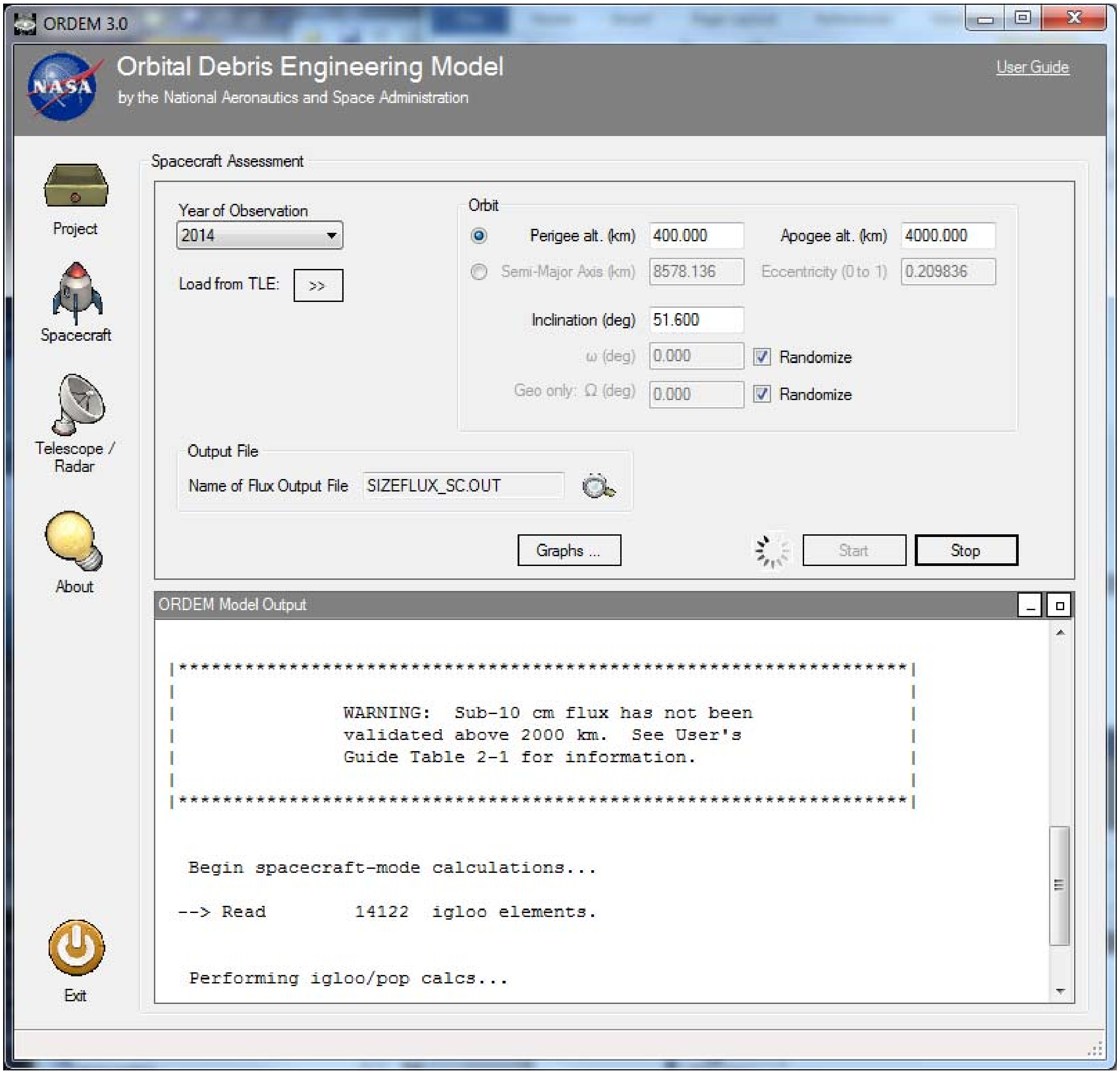

Figure 2-19: Warning message in status window in both Spacecraft and Telescope/Radar modes for analysis apogees above 2000 km.

3.0 References

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Appendix A: ORDEM 3.0 Processor Messages and GUI Dialog Boxes

Table A.1 lists the message codes that may appear in the ORDEM 3.0 output text area. These codes are useful when diagnosing or reporting errors.

Table A.1. Processor Messages

Code	Message ID	Description
1	main_badasmtype	Invalid assessment type in 'ORDEM.IN' file
2	main_badobsyr	Observation year out of range in 'ORDEM.IN'
3	main_badorbdeftype	Orbit definition type out of range in 'ORDEM.IN'
4	main_noini	No input file 'ORDEM.IN'
5	main_badini	Error reading 'ORDEM.IN' file
6	main_igorberr	Fatal error in orbit mapping [igloo_orbit]
7	main_igpoperr	Fatal error in population mapping [igloo_pop]
8	main_gensccalcserr	Fatal error somewhere in sc_calcs
9	main_genscploterr	Fatal error somewhere in generating the Spacecraft mode plot tables
10	main_badorbit	Fatal error if the input orbit is nonsensical (i.e., perigee>apogee)
11	main_gentelecalcserr	Fatal error somewhere in tele_calcs
12	main_gentelploterr	Fatal error somewhere in generating the Telescope/Radar mode plot tables
13	main_numpopsmismatch	Fatal error if population file read has a problem
14	main_noopsfile	Fatal error if the operational errors file cannot be opened
15	main_datvermismatch	Fatal error if the data versions mismatch (found in header of .POP files)
16	main_leohdryear	Population file in the LEO data has incorrect year value
17	main_badleoigloobins	Fatal error if the LEO igloo bins are nonsensical
18	main_badgeoigloobins	Fatal error if the GEO igloo bins are nonsensical
19	main_leogeocntr	Fatal error if the LEO/GEO counters are nonsensical
20	main_idbleo	Fatal error if the idb totals of LEO data are not working
21	main_datamaprange	Fatal error if the datamap range is out of range
22	main_popfileopen	Cannot open the debris population data file
23	main_sobol	Sobol General Error
24	main_sobol_read	Cannot read Sobol coefficients data file
25	main_sobol_ unhandled	Unhandled Sobol error
26	main_sobol_open	Cannot open Sobol coefficients data file
27	main_geo_mm_open	Cannot open GEO mean motion bin definitions file
28	main_geo_ecc_open	Cannot open GEO eccentricity bin definitions file
29	main_geo_inc_open	Cannot open GEO inclination bin definitions file

Code	Message ID	Description
30	main_geo_raan_open	Cannot open GEO RAAN bin definitions file
31	main_leo_hperi_open	Cannot open LEO perigee alt. bin definitions file
32	main_leo_inc_open	Cannot open LEO inclination bin definitions file
33	main_leo_ecc_open	Cannot open LEO eccentricity bin definitions file
34	main_Runtimelog_open	Cannot open the runtime log
35	main_geo_mm_read	Error reading GEO mean motion bin definitions file
36	main_geo_ecc_read	Error reading GEO eccentricity bin definitions file
37	main_geo_inc_read	Error reading GEO inclination bin definitions file
38	main_geo_raan_read	Error reading GEO RAAN bin definitions file
39	main_leo_hperi_read	Error reading LEO perigee altitude bin definitions file
40	main_leo_inc_read	Error reading LEO inclination bin definitions file
41	main_leo_ecc_read	Error reading LEO eccentricity bin definitions file
42	main_populations_read	Cannot read debris population data file
43	main_igloo_sc_open	Cannot open Spacecraft igloo definition data file
44	main_igloo_sc_read	Cannot read Spacecraft igloo definition data file
45	main_igloo_tel_open	Cannot open Telescope/Radar igloo definition data file
46	main_igloo_tel_read	Cannot read Telescope/Radar igloo definition data file
47	main_Runtimelog_read	Error in test read of Runtimelog file
48	igorb_flux_sc_open	Cannot open igloo flux file for output
49	igorb_sigran_sc_open	Cannot open igloo flux random uncertainties file for output
50	igorb_sigpop_sc_open	Cannot open igloo flux population uncertainties file for output
51	igorb_pop_sc_read	Error reading debris population data file
52	igorb_sc_index	Orbit index scheme violated
53	igorb_orbit_sc	Incompatible selections in LEO (bad input configuration)
54	igorb_orbit_index	Hperi, ecc, or inc bin index is out of range
55	igorb_numpops	Number of populations input exceeded the number defined
56	igorb_lgcount	Total population cells in GEO does not match computed
57	plotdata_sc_noflux	Cannot open igloo flux (results) file
58	plotdata_sc_nosigpop	Cannot open igloo flux population uncertainties file
59	plotdata_sc_nosigran	Cannot open igloo flux random uncertainties file
60	plotdata_sc_sigran_read	Cannot read igloo flux random uncertainties file
61	plotdata_sc_sigpop_read	Cannot read igloo flux population uncertainties file
62	plotdata_sc_flux_read	Cannot read igloo flux (results) file
63	sc_calcs_GEO_MM_read	Cannot read GEO mean motion bin definition file
64	sc_calcs_sobol	General Sobol failure

Code	Message ID	Description
65	sc_calcs_sobol_read	Cannot read Sobol coefficients data file
66	sc_calcs_GEO_ECC_read	Cannot read GEO eccentricity bin definition file
67	sc_calcs_GEO_INC_read	Cannot read GEO inclination bin definition file
68	sc_calcs_GEO_RAAN_read	Cannot read GEO RAAN bin definition file
69	sc_calcs_IGLOO_SC_read	Cannot read Spacecraft igloo bin definition file
70	sc_calcs_LEO_HPERI_read	Cannot read LEO perigee altitude bin definition file
71	sc_calcs_LEO_ECC_read	Cannot read LEO eccentricity bin definition file
72	sc_calcs_LEO_INC_read	Cannot read LEO inclination bin definition file
73	sc_calcs_delta_az_small	Igloo azimuth bin size is too small
74	sc_calcs_delta_az_big	Igloo azimuth bin size is too large
75	sc_calcs_vel_min_small	Igloo minimum velocity bin is too low
76	sc_calcs_vel_max_big	Igloo maximum velocity bin is too high
77	sc_calcs_velmaxmin	Igloo minimum velocity is higher than max. vel.
78	sc_calcs_delta_vel_small	Igloo velocity bin size is too small
79	sc_calcs_delta_vel_big	Igloo velocity bin size is too large
80	sc_calcs_delta_el_small	Igloo elevation bin size is too small
81	sc_calcs_delta_el_big	Igloo elevation bin size is too large
82	sc_calcs_IGLOO_NMAX	Stated igloo dimensions do not match calculated dimensions
83	sc_calcs_IGLOO_CHECKICELL	Failed igloocell check in Spacecraft mode
84	icell_open	Failed match of igloocell
85	icell_mismatch	Mismatch in population cell mapping
86	getinterp_cum	Interpolation error
87	check_cum	Cumulative Flux Check
88	sc_calcs_IGLOO_RANGELOCAL_AZ	Azimuth bin is not bound
89	sc_calcs_IGLOO_AZ_RANGE	Azimuth bin is out of bounds
90	sc_calcs_IGLOO_RANGELOCAL_EL	Elevation bin is not bound
91	sc_calcs_IGLOO_EL_RANGE	Elevation bin is out of bounds
92	sc_calcs_IGLOO_RANGELOCAL_VEL	Velocity bin is not bound
93	sc_calcs_IGLOO_VEL_RANGE	Velocity bin is out of bounds
94	sc_calcs_IGLOO_RANGE_WIDTH_AZ	Azimuth bin has a bin size issue
95	sc_calcs_IGLOO_RANGE_WIDTH_EL	Elevation bin has a bin size issue
96	sc_calcs_IGLOO_RANGE_WIDTH_VEL	Velocity bin has a bin size issue
97	tele_calcs_sobol_read	Sobol dimensioning is not correct

Code	Message ID	Description
98	tele_calcs_GEO_MM_read	Mean motion bin file is not able to be read
99	tele_calcs_GEO_ECC_read	Eccentricity bin file is not able to be read
100	tele_calcs_GEO_INC_read	Inclination bin file is not able to be read
101	tele_calcs_GEO_RAAN_read	RAAN bin file is not able to be read
102	tele_calcs_LEO_HPERI_read	Height perigee bin file is not able to be read
103	tele_calcs_LEO_ECC_read	LEO Eccentricity file is not able to be read
104	tele_calcs_LEO_INC_read	LEO Inclination file is not able to be read
105	tele_calcs_general	Unknown error in the Telescope/Radar mode
106	main_path_proj	Provided project path to ORDEM.exe is not valid
107	tele_leo_rng_minmax_calc	Telescope/Radar min/max range problem
108	tele_leo_xe_lo	Low radius debris orbit error
109	tele_leo_xe_hi	High radius debris orbit error
110	plotdata_sc_sizeflux_open	Cannot open SIZEFLUX_SC.OUT
111	plotdata_sc_velflux_open	Cannot open VELFLUX_SC.OUT
112	plotdata_sc_dirflux_open	Cannot open DIRFLUX_SC.OUT
113	plotdata_sc_butterfly_open	Cannot open BFLY_SC.OUT
114	get_interp_cum_non_cumulative	Cumulative interpolation error
115	match_cumu_3pt_bracketing	3-point bracketing mismatch in cumulative interpolation
116	seek_igloocell_null_az	Azimuth mismatch in igloo mapping function
117	seek_igloocell_null_el	Elevation mismatch in igloo mapping function
118	seek_igloocell_null_vel	Velocity mismatch in igloo mapping function
119	seek_igloocell_null_pole	Pole mismatch in igloo mapping function
120	seek_igloocell_index_range	Mapping function trying to go outside igloo range
121	seek_igloocell_az_limit	Mapping function azimuth limit nonsensical
122	seek_igloocell_el_limit	Mapping function elevation limit nonsensical
123	seek_igloocell_vel_limit	Mapping function velocity limit nonsensical
124	bin_sequence_check_misalignment	Bin sequence verification failed due to misalignment
125	bin_sequence_check_coherency	Bin sequence verification failed due to incoherence
126	check_igflux_density	Density bin is out of range
127	check_igflux_geo_density	Density bin for GEO population is out of range
128	check_igflux_geo_cum	GEO population is not loading in cumulative size
129	plotdata_sc_interpolation	Interpolation error in Spacecraft mode sizeflux curve

Figures A-1 through A-14 represent the possible GUI Dialog Boxes, which result when user inputs are invalid.

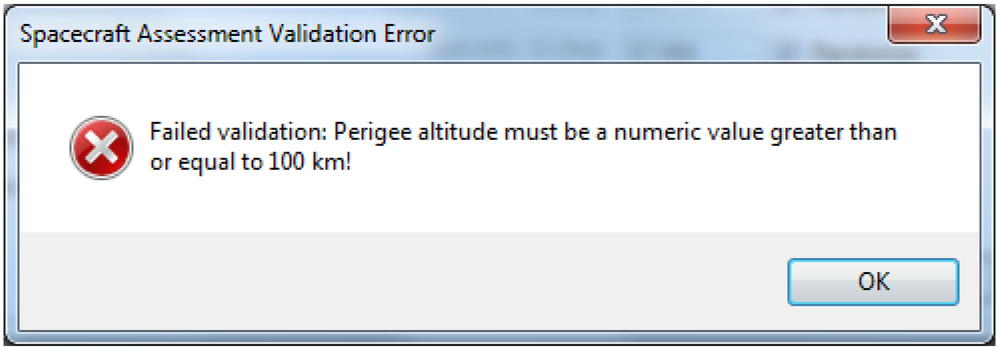

Figure A-1: Low perigee error.

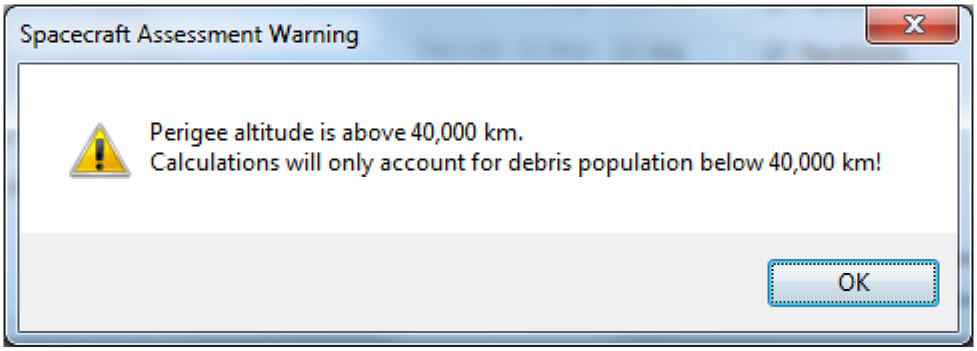

Figure A-2: High perigee warning.

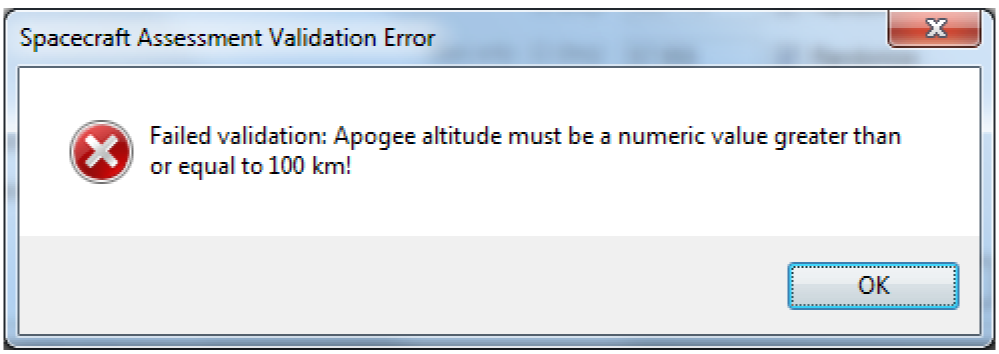

Figure A-3: Low apogee error.

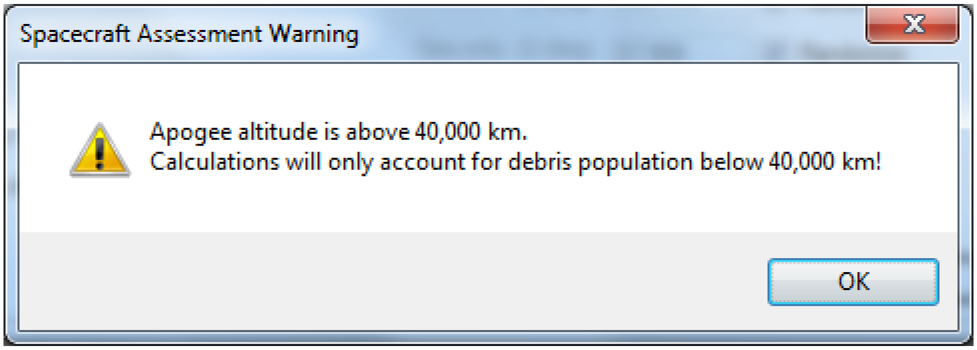

Figure A-4: High apogee warning.

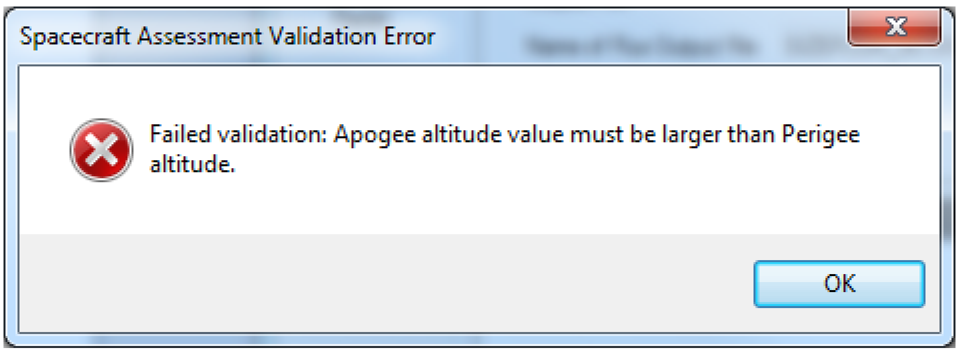

Figure A-5: Switched apogee and perigee error.

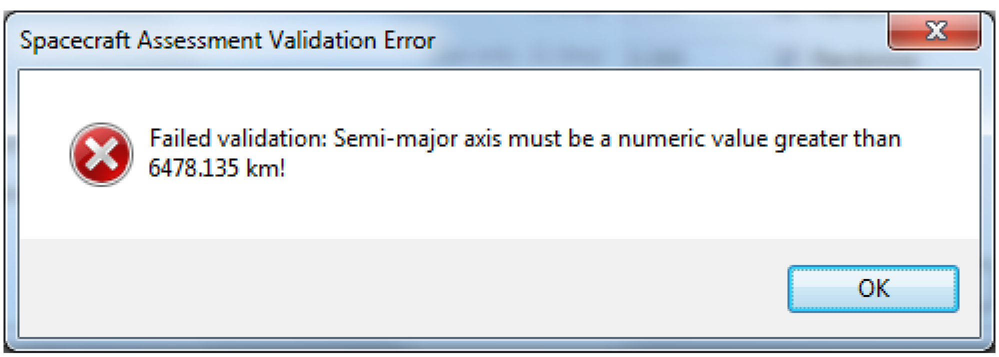

Figure A-6: Low semi-major axis error.

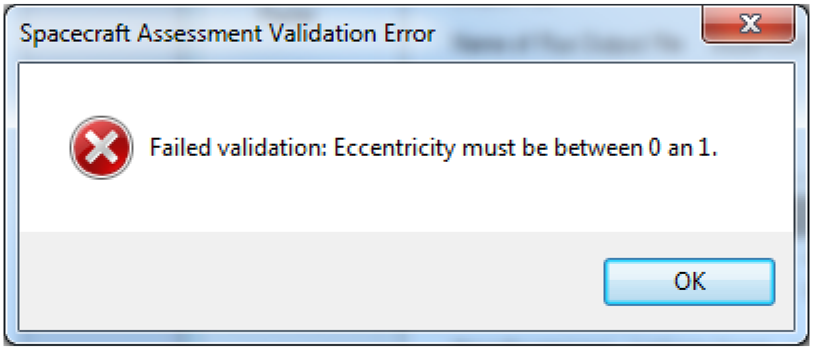

Figure A-7: Out-of-range ECC error.

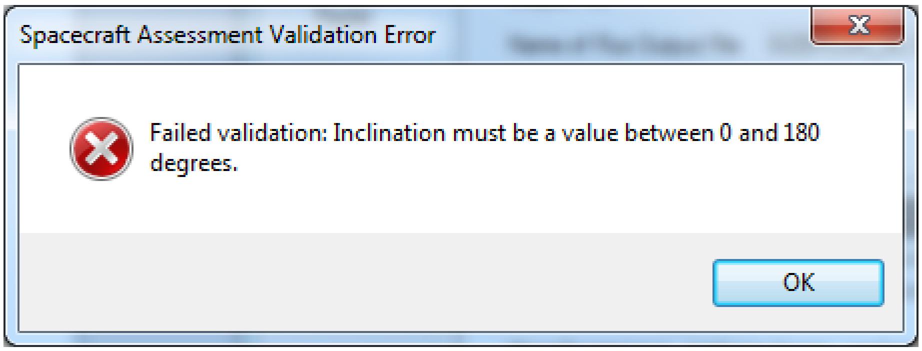

Figure A-8: Out-of-range INC error.

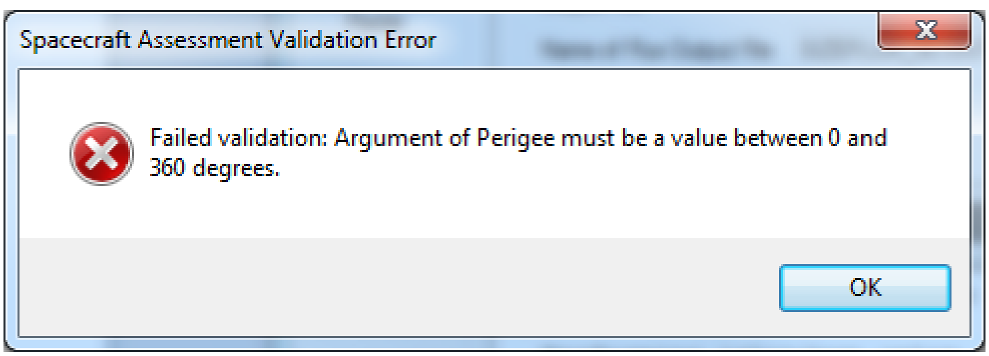

Figure A-9: Out-of-range AP error.

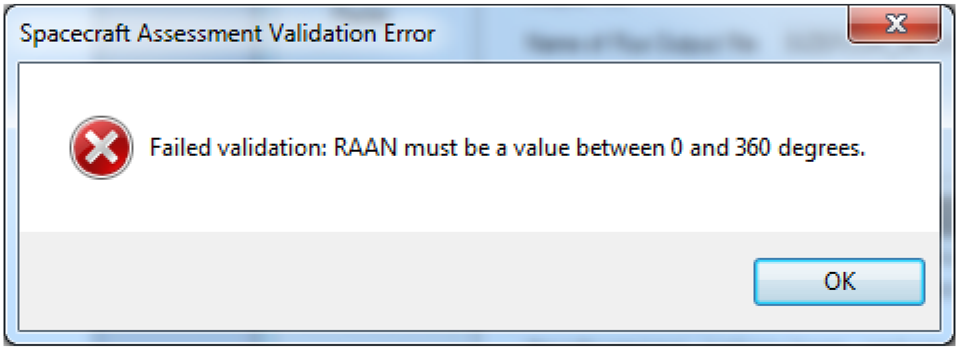

Figure A-10: Out-of-range RAAN error.

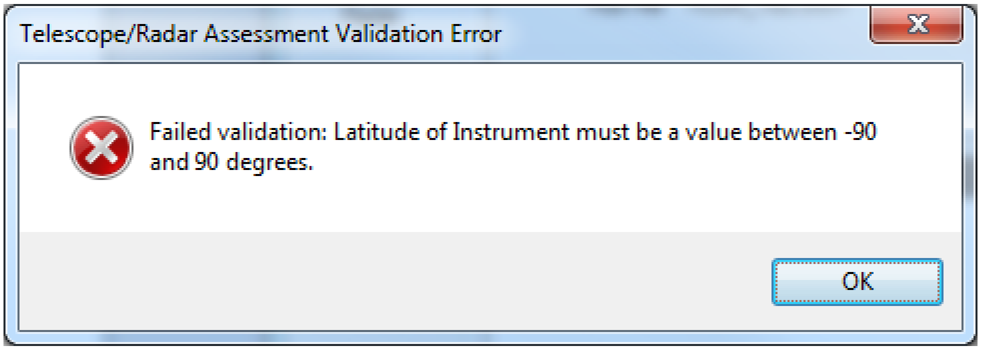

Figure A-11: Out-of-range latitude error.

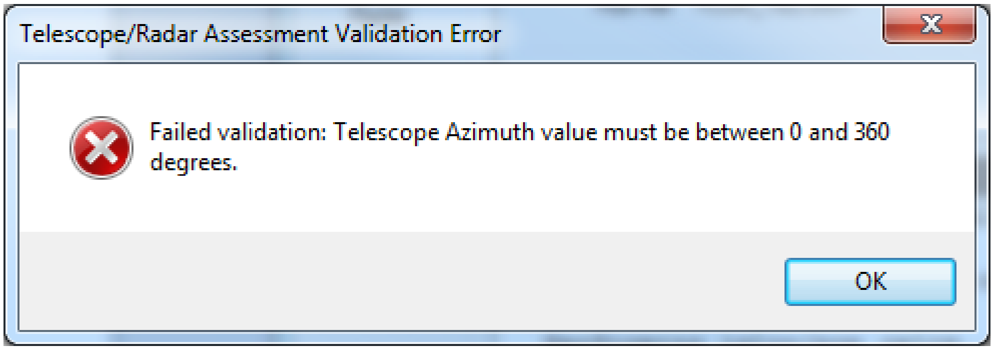

Figure A-12: Out-of-range azimuth error.

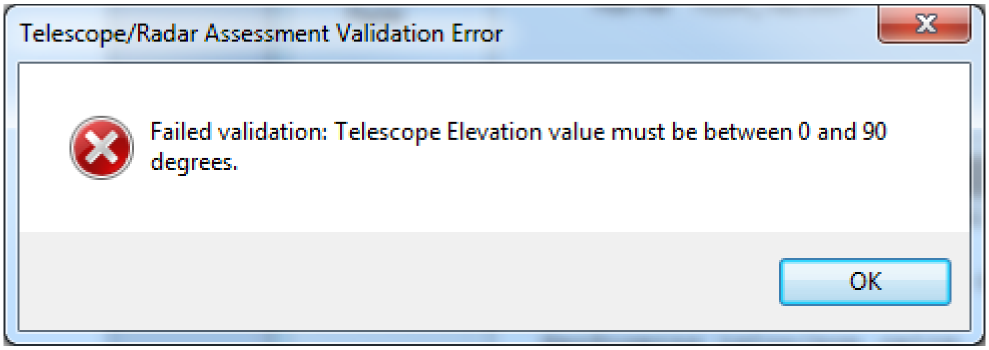

Figure A-13: Out-of-range elevation.

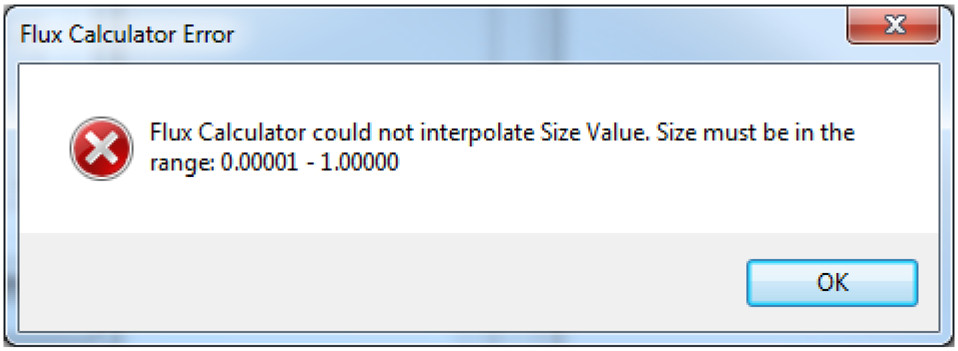

Figure A-14: Out-of-range flux calculator size.

Appendix B: ORDEM 3.0 Input/Output File Formats

This appendix contains sample file formats and descriptions of ORDEM 3.0 input and output files.

B.1 Input File Format

The ORDEM 3.0 input file containing all user-specified parameters is "ORDEM.IN". This file is located in the project directory. The ORDEM 3.0 GUI creates this file as input for the computational run. When running ORDEM 3.0 using the command line interface, the user may create or edit the file using a simple text editor. (The user may wish to run the GUI once to create a template file.)

The file contains both data and comments, the latter marked by the "!" character. ORDEM 3.0 reads specific values from specific lines of the file, so the format (as produced by the GUI) must be strictly followed. See Table B.1 for the file format and line-by-line descriptions. The first group of values (lines 2 through 3) specifies the type and year of assessment. The second group of values (lines 5 through 13) specifies the orbit and "Spacecraft encounter igloo" for Spacecraft assessment mode. The value on line 5 determines which two of the next four lines are used to define the input orbit, but the unused data lines must still be present to maintain the file format. The third group of values (lines 15 through 18) specifies the observer's latitude and viewing angle, and "segmented bore-sight vector" to Telescope/Radar assessment mode.

Table B-1: The ORDEM 3.0 Input File, "ORDEM.IN"

Line no.	
1	!file=ORDEM.IN file generated by ORDEM 3.0-GUI.exe created 6/7/2010 8:22 AM
2	2 ! type of assessment (1=spacecraft 2=telescope/radar)
3	2010 ! year of observation (2010-2035)
4	!---------- S/C assessment --
5	1 ! way to determine orbit (1=apogee & perigee, 2=semi major axis & eccentricity)
6	400.000 ! perigee (km)
7	400.000 ! apogee (km)
8	6778.136 ! semi-major axis (km)
9	0 ! eccentricity (0-1)
10	51.600 ! inclination (0 to 180deg)
11	-1 ! argument of perigee (0 to 360deg, -1=random)
12	-1 ! right ascension of the ascending node, RAAN (0 to 360deg, -1=randomize)
13	IGLOO_10x10x1.SIG ! file defining all 'igloo' element boundaries (az, el, vel)
14	!---------- telescope/radar assessment --
15	42.620 ! sensor latitude (SP=-90 to NP=90)
16	90.000 ! azimuth (0 deg=North, 90 deg=East, to 360 deg)
17	75.000 ! elevation (0 deg=horz to 90 deg=zenith)
18	ALT_50.TIG ! file defining all 'igloo' element boundaries (az, el, vel)

B.2 Output File Formats

This section has sample file formats of ORDEM 3.0 output. Table 2-9 is reprinted here as Table B-2 for reference. These text files may be used for external analysis but their main purpose is as interfaces between the program executable and the GUI.

Table B-2: Files Output by ORDEM 3.0 Modes

File Name	Description
Spacecraft assessment output files	
SIZEFLUX_SC.OUT	Average impact cross-sectional area flux vs. size on the spacecraft along its orbit. Graph input.
VELFLUX_SC.OUT	Impact velocity distribution on the spacecraft along its orbit. Graph input.
BFLY_SC.OUT	Cross-sectional area flux vs. yaw (collapsed in pitch) in the spacecraft frame. Graph input.
DIRFLUX_SC.OUT	Cross-sectional area flux in 2-D map projection in the spacecraft frame. Graph input.
IGLOOFLUX_SC.OUT	Igloo element cross-sectional area fluxes and velocities. Intermediate file.
IGLOOFLUX_SIGMAPOP_SC.OUT	Correlated population uncertainty estimates.
IGLOOFLUX_SIGMARAN_SC.OUT	Random uncertainty estimates.
Telescope/Radar assessment output files	
FLUX_TEL.OUT	Surface area flux vs. altitude of debris of a given size. Graph input.
IGLOOFLUX_TEL.OUT	Segmented bore-sight vector element fluxes. Intermediate file.
IGLOOFLUX_SIGMAPOP_TEL.OUT	Correlated population uncertainty estimates.
IGLOOFLUX_SIGMARAN_TEL.OUT	Random uncertainty estimates.

B.2.1 SIZEFLUX_SC.OUT

This is the output data for generating the plot of average, cumulative flux by particle size. It is the Spacecraft-mode graph “Average Flux vs. Size”. The file has five header lines (see Table B-3).

The first column is the debris particle size threshold and the second column is the debris flux for debris of the stated size and larger. The third and fourth columns are the lower and upper one-sigma uncertainties, respectively.

Table B-3: Illustration of Output for SIZEFLUX_SC.OUT

```
ORDEM Spacecraft Mode
 Debris Flux (#/m^2/yr)
  Year: 2010  a =   6778.136  e = 0.000000  inc =   51.60
Size (m)              Flux                  -Sigma                +Sigma
--------              --------              --------              --------
1.00E-05              4.59E+02              3.35E+01              7.35E+01
1.02E-05              4.45E+02              7.17E+01              7.17E+01
1.05E-05              4.32E+02              7.00E+01              7.00E+01
.
.
.
9.55E-01              1.62E-07              1.43E-08              1.43E-08
9.77E-01              1.61E-07              1.42E-08              1.42E-08
1.00E+00              1.60E-07              1.42E-08              1.42E-08
```

B.2.2 VELFLUX_SC.OUT

This is the output file for generating the plot of debris flux as an impact relative velocity. It is the Spacecraft-mode graph "Velocity Distribution". The file has eight header lines (as shown in Table B-4), including minimum and maximum values for each flux data column (useful for axis scaling).

The first two columns define the lower and upper velocity bin bounds in km/s. Subsequent columns list the debris flux for each of several-size thresholds, as shown in the column headers.

Table B-4: Illustration of Output for VELFLUX_SC.OUT

```
ORDEM Spacecraft Mode
Debris Flux (#/m^2/yr/kps)
Year: 2010  a =   6778.136  e = 0.000000  inc =   51.63
Vel 1   Vel 2   >10um       >100um     >1mm       >1cm       >10cm      >1m
-----   -----   -----       -----      -----      -----      -----      -----
Min.:           2.65E-01    3.13E-06   1.39E-06   3.29E-13   1.12E-11   8.56E-12
Max.:           7.23E+01    3.23E+00   6.27E-03   4.61E-07   5.14E-08   2.41E-08
-----   -----   -----       -----      -----      -----      -----      -----
   0.0     0.1  9.17E-01    2.23E-02   1.92E-05   4.42E-09   2.51E-09   2.18E-09
   0.1     0.2  9.17E-01    2.23E-02   1.92E-05   4.42E-09   2.51E-09   2.18E-09
   0.2     0.3  9.17E-01    2.23E-02   1.92E-05   4.42E-09   2.51E-09   2.18E-09
.
.
.
  22.7    22.8  1.00E-99    1.00E-99   1.00E-99   1.00E-99   1.00E-99   1.00E-99
  22.8    22.9  1.00E-99    1.00E-99   1.00E-99   1.00E-99   1.00E-99   1.00E-99
  22.9    23.0  1.00E-99    1.00E-99   1.00E-99   1.00E-99   1.00E-99   1.00E-99
```

B.2.3 BFLY_SC.OUT

This is the output file for generating the plot of debris flux as a local impact azimuth. It is the Spacecraft-mode graph "Direction Butterfly". As defined in the Figure 2-12 caption, "local azimuth" is the angle, measured in the local horizontal plane, running from left to right. The file has eight header lines (as shown in Table B-5), including minimum and maximum values for each flux data column (useful for axis scaling).

The first two columns define the lower and upper azimuth bin bounds in degrees (positive to right of the velocity vector). Subsequent columns list the debris flux for each of several-size thresholds, as shown in the column headers.

Table B-5: Illustration of Output for BFLY_SC.OUT

```
ORDEM Spacecraft Mode
Debris Flux (#/m^2/yr/deg)
Year: 2010  a =   6778.136  e = 0.000000  inc =   51.63
Az 1     Az 2     >10um     >100um    >1mm      >1cm      >10cm     >1m
-----    -----    -----     -----     -----     -----     -----     -----
Min.:             2.13E-02  3.77E-04  1.15E-06  7.08E-11  1.09E-11  1.85E-12
Max.:             4.07E+00  1.82E-01  3.24E-04  2.32E-08  2.94E-09  1.49E-09
-----    -----    -----     -----     -----     -----     -----     -----
-180     -179     2.78E-02  1.33E-03  1.47E-05  8.07E-10  4.08E-11  2.03E-12
-179     -178     2.78E-02  1.33E-03  1.47E-05  8.07E-10  4.08E-11  2.03E-12
-178     -177     2.78E-02  1.33E-03  1.47E-05  8.07E-10  4.08E-11  2.03E-12
.
.
.
177      178      2.78E-02  1.33E-03  1.47E-05  8.07E-10  4.08E-11  2.03E-12
178      179      2.78E-02  1.33E-03  1.47E-05  8.07E-10  4.08E-11  2.03E-12
179      180      2.78E-02  1.33E-03  1.47E-05  8.07E-10  4.08E-11  2.03E-12
```

B.2.4 DIRFLUX_SC.OUT

This is the output file for generating the plot of debris flux as a local impact azimuth and elevation. It is the Spacecraft-mode graph "2-D Directional Flux", also known as a Mollweide projection. As defined in the Figure 2-15 caption, "local azimuth" is the angle, measured in the local horizontal plane, running from left to right and "local elevation" is measured in a plane perpendicular to the local horizontal, running from bottom to top.

The file has eight header lines (as shown in Table B-6), including minimum and maximum values for each flux data column (useful for axis scaling). The format of the output data was chosen for ease of use with the on-screen Mollweide plotting routine. The first eight columns define the corners of a box outline in X and Y coordinates. Consequently, "X_NE" and "Y_NE" are defined as the X and Y coordinates of the "northeast" corner of the box, as would be viewed on a flat map. With X and Y coordinates as Local Azimuth and Local Elevation, the pattern in the output file becomes clear. For example, minimum "X_NW" and "X_SW" is -180. Minimum "Y_SW" and "Y_SE" is -90. The box boundaries are easily identified in Figure 2-15 by color.

The ninth and tenth columns list the central coordinate of the box outline, while subsequent columns list the debris flux for each of several-size thresholds, as shown in the column headers.

Table B-6: Illustration of Output for DIRFLUX_SC.OUT

```
ORDEM Spacecraft Mode
 Debris Flux (#/m^2/yr/kps)
  Year: 2010  a =   6778.136  e =  0.000000  inc =   51.60
 X_NE     Y_NE     X_SE     Y_SE     X_SW     Y_SW     X_NW     Y_NW     X-mid    Y-mid    >10um      >100um     >1mm      >1cm      >10cm     >1m
 -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  --------    --------  -------  --------   --------  --------
   Min.:                                                                                    7.68E-10  2.06E-11   8.06E-14  2.95E-17  8.80E-18  7.04E-18
   Max.:                                                                                    4.05E-01  1.77E-02   1.07E-05  5.35E-09  3.16E-10  1.48E-10
 -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  --------  --------    -------- --------   --------  --------
  -12.71   -89.77     0.00   -90.00     0.00   -90.00   -12.78   -89.77   -10.12   -89.86  7.68E-10  1.22E-10   4.03E-13  2.95E-17  8.80E-18  7.04E-18
  -20.17   -89.43   -12.71   -89.77   -12.78   -89.77   -20.28   -89.43   -17.30   -89.58  2.31E-09  3.66E-10   1.21E-12  8.84E-17  2.64E-17  2.11E-17
  -26.40   -89.02   -20.17   -89.43   -20.28   -89.43   -26.55   -89.02   -23.76   -89.21  3.84E-09  6.10E-10   2.02E-12  1.47E-16  4.40E-17  3.52E-17
.
.
.
   20.28    89.43    26.55    89.02    26.40    89.02    20.17    89.43    23.76    89.21  3.84E-09  6.10E-10   2.02E-12  1.47E-16  4.40E-17  3.52E-17
   12.78    89.77    20.28    89.43    20.17    89.43    12.71    89.77    17.30    89.58  2.31E-09  3.66E-10   1.21E-12  8.84E-17  2.64E-17  2.11E-17
    0.00    90.00    12.78    89.77    12.71    89.77     0.00    90.00    10.12    89.86  7.68E-10  1.22E-10   4.03E-13  2.95E-17  8.80E-18  7.04E-18
```

B.2.5 IGLOOFLUX_SC.OUT

The plottable files are derived from this output file. The file has five header lines (see Table B-7).

The first column lists the encounter igloo element number. The second through seventh columns list the lower and upper azimuth bin bounds, lower and upper elevation bin bounds, and lower -and upper-relative-impact velocity bin bounds, respectively. Subsequent columns list the individual sub-population fluxes for the defined igloo element. The sub-population names are abbreviated using two letters for the population type and two numbers for the size (in powers of 10 µm).

Debris type codes:

- NK - sodium-potassium (NaK) reactor coolant
- LD - general low-density debris (<2 g/cc)
- MD - general medium-density debris (2-6 g/cc)
- HD - general high-density debris (>6 g/cc)
- IN - intact/launched objects

Debris size bin codes, in powers of 10 µm:

- "10" = $10^{1.0}$ µm = 1.00e^{-5} m = 10 µm
- "15" = $10^{1.5}$ µm = 3.16e^{-5} m = 31.6 µm
- "20" = $10^{2.0}$ µm = 1.00e^{-4} m = 100 µm
- "25" = $10^{2.5}$ µm = 3.16e^{-4} m = 316 µm
- "30" = $10^{3.0}$ µm = 1.00e^{-3} m = 1 mm
- "35" = $10^{3.5}$ µm = 3.16e^{-3} m = 3.16 mm
- "40" = $10^{4.0}$ µm = 1.00e^{-2} m = 1 cm
- "45" = $10^{4.5}$ µm = 3.16e^{-2} m = 3.16 cm
- "50" = $10^{5.0}$ µm = 1.00e^{-1} m = 10 cm
- "55" = $10^{5.5}$ µm = 3.16e^{-1} m = 31.6 cm
- "60" = $10^{6.0}$ µm = 1.00e^{+0} m = 1 m

Table B-7: Illustration of Output for IGLOOFLUX_SC.OUT

```
ORDEM Debris flux through spacecraft 'igloo'.
Igloo Debris Populations Flux in Bin (no./km^2/yr)
Year: 2010  Elements:    14122  Populations:  55  a =   6778.136  e =  0.000000  inc =   51.60
Element     az_low      az_high     el_low      el_high     vel_low     vel_high    Flux NK10        ...
-------     --------    --------    --------    --------    --------    --------    -------------
1           -180.00     180.00      -90.00      -85.00      0.00        1.00        0.0000000E+00    ...
2           -180.00     180.00      -90.00      -85.00      1.00        2.00        0.0000000E+00    ...
3           -180.00     180.00      -90.00      -85.00      2.00        3.00        0.0000000E+00    ...
.
.
.
14120       170.00      180.00      75.00       85.00       20.00       21.00       0.0000000E+00    ...
14121       170.00      180.00      75.00       85.00       21.00       22.00       0.0000000E+00    ...
14122       170.00      180.00      75.00       85.00       22.00       23.00       0.0000000E+00    ...
```

B.2.6 IGLOOFLUX_SIGMAPOP_SC.OUT

The format of this file is the same as that of IGLOOFLUX_SC.OUT, except the flux values are replaced by estimated population uncertainty values.

B.2.7 IGLOOFLUX_SIGMARAN_SC.OUT

The format of this file is the same as that of IGLOOFLUX_SC.OUT, except the flux values are replaced by estimated random uncertainty values.

B.2.8 FLUX_TEL.OUT

This is the output file for generating the plot of debris flux as an altitude or range within the beam. It is the Telescope/Radar-mode graph "Flux vs. Altitude". The file has five header lines (see Table B-8).

The first column lists the altitude bin boundaries for the data row. The second column lists the range, from the observer, corresponding to the altitude in the first column. Subsequent columns list the debris flux for each of several-size thresholds, as shown in the column headers.

Table B-8: Illustration of Output for FLUX_TEL.OUT

```
ORDEM Telescope/Radar Mode
 Surface Area Debris Flux (#/m^2/yr)
  Year: 2010  Sensor lat. =  42.620  Pointing AZ = 90.000 Pointing EL =  75.000
Alt        Rng      >10um     >100um    >1mm      >1cm      >10cm      >1m
-----      -----    -----     -----     -----     -----     -----      -----
100.0      113.6    6.56E-01  1.25E-02  7.40E-04  2.89E-08  2.14E-09   9.53E-10
150.0      165.2    6.56E-01  1.25E-02  7.40E-04  2.89E-08  2.14E-09   9.53E-10
150.0      165.2    3.48E+00  4.00E-02  9.72E-04  4.09E-08  6.46E-09   4.07E-09
.
.
.
39950.0    40147.5  9.50E-01  4.34E-02  8.72E-07  2.40E-11  6.71E-12   5.32E-12
39950.0    40147.5  9.20E-01  4.21E-02  8.58E-07  2.35E-11  6.56E-12   5.20E-12
40000.0    40197.5  9.20E-01  4.21E-02  8.58E-07  2.35E-11  6.56E-12   5.20E-12
```

B.2.9 IGLOOFLUX_TEL.OUT

The files with output that can be plotted are derived from this output file. The file has six header lines (see Table B-9).

The first column lists the segmented bore-site vector element number. The second through fifth columns list the lower and upper altitude bin bounds, and lower and upper range bin bounds, respectively. Subsequent columns list the individual sub-population fluxes for the defined element. The sub-population names are identical to those defined in Section B.2.5.

B.2.10 IGLOOFLUX_SIGMAPOP_TEL.OUT

The format of this file is the same as that of IGLOOFLUX_TEL.OUT, except the flux values are replaced by estimated population uncertainty values.

B.2.11 IGLOOFLUX_SIGMARAN_TEL.OUT

The format of this file is the same as that of IGLOOFLUX_TEL.OUT, except the flux values are replaced by estimated random uncertainty values.

Table B-9: Illustration of Output for IGLOOFLUX_TEL.OUT

```
ORDEM Debris flux through telescope/radar 'igloo'.
 Igloo Debris Populations Flux in Bin (no./m^2/yr)
 Year: 2010  Elements:      798  Populations:  55
Sensor lat. =  46.620  Pointing AZ = 90.000  Pointing EL =  75.000
Element       alt_low       alt high      rng_low       rng high      Flux NK10        ...
-------       ---------     ---------     ---------     ---------     -------------
      1       100.00        150.00        113.562       165.250       9.9130421E-08    ...
      2       150.00        200.00        165.250       216.911       4.0289432E-08    ...
      3       200.00        250.00        216.911       268.546       7.6370956E-08    ...
.
.
.
    796       39850.00      39900.00      40047.392     40097.424     0.0000000E+00    ...
    797       39900.00      39950.00      40097.424     40147.455     0.0000000E+00    ...
    798       39950.00      40000.00      40147.455     40197.487     0.0000000E+00    ...
```

Appendix C: How to Use Uncertainty Files

The ORDEM 3.0 output produces three files that capture the computations of the flux for each igloo or bore-sight vector bin. One (termed "IGLOOFLUX") is a table of the actual flux broken out by size, material density, and igloo or bore-sight vector element. The other two represent estimates of the errors of these fluxes and are in the same format as IGLOOFLUX. These files are termed "IGLOOFLUX_SIGMARAN" (σ^{ran}) and "IGLOOFLUX_SIGMAPOP" (σ^{pop}). These represent simplified error terms based on several assumptions. The first assumption is that the errors are linear and normal, and these files give the "one-sigma" estimates. The next assumption is that the uncertainties can be divided into two types: an uncorrelated, random uncertainty for each bin, and a correlated uncertainty that applies to each population/size.

Interpolation of fluxes is done for each bin individually. The logarithm of the flux is interpolated versus the logarithm of the size. To obtain interpolated sigma values, the ratio of the sigma value to the flux at each size node (not the logarithm) is interpolated versus the logarithm of the size.

The usual goal will be to create some sort of composite flux, which will usually be a linear combination of flux terms

$$F = \sum_d \sum_i c_i F_{di.}$$

Here, F is the total flux to be computed, c_i is the linear mapping term for each bin "i" (for a simple sum, $c_i = 1$ for all terms), and F_{di} is the flux from material density population "d" and igloo "i". If, for instance, the flux was computed for an oriented surface, each value of c_i would be different based on the igloo direction relative to the surface of interest for each case "i".

Because the correlated "population" sigmas apply across a single material density class, the computation of the sigma value for

$$F_d = \sum_i c_i F_{di}$$

is completed first. Note that the correlated "population" sigmas are handled differently from the uncorrelated "random" sigmas

$$\sigma_{F_d}^2 \approx \left(\sum_i c_i \, \sigma_{F_{di}}^{pop}\right)^2 + \sum_i c_i^2 \left(\sigma_{F_{di}}^{ran}\right)^2.$$

The final total flux uncertainty is then assembled by

$$\sigma_F^2 \approx \sigma_{F_d}^2.$$

Note this assumes that the uncertainties of each material density type are uncorrelated to those of other types.

Note that to compute the expected value of impacts over some observation time on some oriented surface, the time and projected area values could be folded into the "c_i" values for each flux case "i". In this case the expected number of impacts N would be

$$N = \sum_d \sum_i c_i \, F_{di.}$$

where c_i is now the projected area-time product of flux case "i" on the oriented surface of interest.

The corresponding uncertainty propagation equations would be

$$N_d = \sum_i c_i \, F_{di}$$

$$\sigma_{N_d}^2 \approx \left(\sum_i c_i \, \sigma_{F_{di}}^{pop} \right)^2 + \sum_i c_i^2 \left(\sigma_{F_{di}}^{ran} \right)^2$$

$$\sigma_N^2 \approx \sum_d \sigma_{N_d}^2$$

Appendix D: ORDEM 3.0 Current Runtime Estimates

D.1 Runtime Estimates for Spacecraft Assessment Mode

The following estimates are based upon a large set of testing runs performed on a DELL Optiplex 760, with 2 GB of RAM and a limited amount of background tasks run concurrently with ORDEM 3.0. Actual runtimes may vary greatly depending on the object examined and computer capabilities.

ORDEM 3.0 runtime estimates depend heavily on the user-chosen encounter igloo dimensions and the orbit being assessed. The binned population files are sparsely populated, but if an orbit located in a populated portion of that binned orbit space is chosen, there may be an exponential increase in calculations required to provide the user with flux and error bar estimates for the given orbit. In other cases, if the target satellite travels through spaces devoid of most debris, the runtime performance will increase markedly.

For general runtime performance, it is useful to examine through what areas the target object travels. For LEO objects with nearly circular orbits (i.e., eccentricity 0.01) and an igloo of 10° x 10° x 1 km/s, runtime performance of the ORDEM 3.0 model should generally be between 10 and 30 minutes. As orbital eccentricity increases, the object travels through more of the orbital population space of the model, and runtime performance can exceed several hours. For some geosynchronous transfer orbit objects, it is possible for the model to take over 2 hours on a modestly equipped PC. These runtimes would generally decrease when the 30° x 30° x 2 km/s igloo is used.

D.2 Runtime Estimates for Telescope/Radar Assessment Mode

The runtime performance of the Telescope/Radar mode is just as dependent on the binned population space examined; however, in general, the runtimes are easier to predict. For a given latitude of the sensor, the runtime is dependent on the pointing direction (i.e., bore-sight vector). Runtime may change markedly because, for a random pointing direction at a random latitude, the sensor may be viewing portions of the population space that are highly or sparsely populated. For instance, if a Telescope/Radar is located at a latitude of 42.6 degrees and pointed due north, this sensor will view heavy debris populations in LEO-only. Populations above LEO will be very sparse. In a case where the sensor is pointing due south, debris with inclinations lower than 42.6° will be detected as well.

That being considered, the runtimes observed during testing, with a user-chosen, segmented bore-sight vector graduated in 50 km increments in altitude from LEO to GEO, were between 10 minutes and 2 hours. If the user desires a shorter runtime and if the application allows for it, the 50 km altitude gradation could be applied to LEO-only or GEO-only.

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13. ABSTRACT *(Maximum 200 words)*

The ORDEM 3.0 model is appropriate for engineering solutions requiring knowledge and estimates of the orbital debris environment. It can also be used as a benchmark for ground-based debris measurements and observations. With significant improvements over its predecessor, ORDEM 3.0 includes uncertainties in the flux estimates and material density classes. It has also been extended to describe the orbital debris environment from low Earth orbit past geosynchronous orbit. A large set of observational data (both in-situ and ground-based) reflect the current debris environment. Analytical techniques are employed to determine the orbit populations used to calculate population fluxes and their uncertainties. The model output lists fluxes of debris in half-decade size bins by distinct material characteristics (i.e., intact objects, high-, medium-, or low-material density objects, and NaK droplets) either by direction and velocity for an encompassing 'igloo' (for spacecraft) or by range bins (for a sensor beam on the Earth's surface), depending on the user's chosen operational mode. The program graphical user interface, executable data files, and an ORDEM 3.0 User's Guide are included. ORDEM 3.0 has been subjected to extensive verification and validation. Currently, ORDEM 3.0 runs on Windows XP or more recent PC operating systems.

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