NASA/TP-2019-220448

NASA Orbital Debris Engineering Model ORDEM 3.1 – Software User Guide

Orbital Debris Program Office

Andrew Vavrin
Alyssa Manis
John Seago
Drake Gates
Phillip Anz-Meador
Yu-Lin Xu
Ronald Barahona
Avery Malachi
Ian Bigger
Jacobs
Houston, Texas

Mark Matney
J.-C. Liou
NASA Johnson Space Center
Houston, Texas

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

December 2019

NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TP-2019-220448

NASA Orbital Debris Engineering Model ORDEM 3.1 – Software User Guide

Orbital Debris Program Office

Andrew Vavrin
Alyssa Manis
John Seago
Drake Gates
Phillip Anz-Meador
Yu-Lin Xu
Ronald Barahona
Avery Malachi
Ian Bigger
Jacobs
Houston, Texas

Mark Matney
J.-C. Liou
NASA Johnson Space Center
Houston, Texas

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

December 2019

Available from:

NASA STI Program
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

This report is also available in electronic form at http://www.sti.nasa.gov/ and http://ntrs.nasa.

Report Approval

Prepared:	*Andrew Vavrin* Author	11/14/2019 Date:
Reviewed:	*Mark Matney, Ph.D.* NASA ORDEM Project Manager	11/14/2019 Date:
Approved:	*J.-C. Liou, Ph.D.* NASA Orbital Debris Program Manager	11/14/2019 Date:

REVISION HISTORY

Revision	Description	Author	Effective Date
Initial	Internal Release	A. Vavrin	June 2017
A	Reorganized sections	A. Vavrin	January 2018
Revised for ORDEM 3.1	Changed ORDEM 3.0 to ORDEM 3.1; updated runtime estimates, screenshots, and Windows 10 compatibility	A. Vavrin	September 2019

Table of Contents

Figures

Tables

Acronyms

CPU	Central Processing Unit
GB	Gigabyte
GEO	Geosynchronous Orbit
GTO	Geosynchronous Transfer Orbit
GUI	Graphical User Interface
HD	High Density Debris
IN	Intact/Launched Objects
ISS	International Space Station
LEGEND	LEO-to-GEO Environment Debris Model
LEO	low Earth orbit
LD	Low Density Debris
MASTER	Meteoroid and Space Debris Terrestrial Environment Reference
MD	Medium Density Debris
MEM	Meteoroid Environment Model
MODEST	Michigan Orbital Debris Survey Telescope
NK, NaK	Sodium potassium eutectic coolant for RORSAT reactors
NASA	National Aeronautics and Space Administration
ODPO	Orbital Debris Program Office
ORDEM	Orbital Debris Engineering Model
RAM	random-access memory
RORSAT	Radar Ocean Reconnaissance SATellite
SBRAM	Satellite Breakup Risk-Assessment Model
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
ecc, e	eccentricity
h_p	height at perigee
inc, i	inclination
n	mean motion
RAAN, Ω	right ascension of the ascending node
σ	standard deviation (i.e., sigma)

(This page intentionally left blank)

1 INTRODUCTION

This National Aeronautics and Space Administration (*NASA) Orbital Debris Engineering Model (ORDEM) 3.1 Software User Guide* accompanies delivery of the latest upgraded version of the model, ORDEM 3.1. The user guide also provides a top-level program description and a list of capabilities. It includes descriptions of runtime error and information codes, input/output file formats, runtimes for different orbit configurations, and how to use uncertainty files.

ORDEM 3.1 supersedes the previous NASA Orbital Debris Program Office (ODPO) models – ORDEM 3.0 (Stansbery, et al. 2014) and ORDEM2000 (Liou, *et al.* 2002). The availability of new sensor and *in situ* data, re-analysis of older data, and 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. For example, these range from the conventional flux vs. average debris size (or altitude bin) 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.

The current model, ORDEM 3.1, supports spacecraft as well as telescope/radar project assessments. ORDEM 3.1 contains updated debris populations covering low Earth orbit (LEO, up to 2000 km altitude) to geosynchronous orbit (GEO, up to 40,000 km altitude) and can assess debris calculations up to year 2050, extending coverage past the previous limit of 2035 in ORDEM 3.0. Although populations differ from its predecessor, ORDEM 3.1 is functionally the same as ORDEM 3.0 and can support ORDEM 3.0 projects through backward compatibility.

1.1 Requirements of an Orbital Debris Engineering Model

The primary requirement for any engineering model is to provide the user with accurate results to meet these requirements. The two main types of ORDEM users are spacecraft designers/operators and debris researchers. A third user group includes mission planners and analysts using the ODPO Debris Assessment Software (DAS) package (Liou, et al. 2019), which implements ORDEM populations in analysis of space missions’ compliance with NASA’s requirements for reduction of orbital debris.

The requirements of each user group differ somewhat, though they share many common necessities. To facilitate implementation of cost-effective shielding, the spacecraft designer needs detailed estimates of the particle flux as a function of local azimuth/elevation and relative velocity, all in the spacecraft frame. 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.

Thus, any such orbital debris model must include, at a minimum, an accurate assessment of the orbital debris environment as a function of altitude, latitude, and debris size. ORDEM is an engineering model that is consistent with this requirement. It is based upon debris populations with various altitude, inclination, and size distributions, to provide a detailed measure of the 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 of models. ORDEM is designed to provide yearly estimates of the debris environment. For example, the model 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. Studies of the long-term effect of various mitigation measures on the debris environment must rely on a debris evolutionary model. The NASA ODPO LEO-to-GEO Environment Debris (LEGEND) model (Liou, et al. 2005) is applicable for examining the consequences of such phenomena. Additionally, the application of telescope/radar debris assessments is limited to ground-based (specifically, pencil-beam type) sensors.

1.3 ORDEM 3.1 Program Philosophy

The core capability of the ORDEM program is to compute fluxes. In this context, flux is the rate (per year) from a given direction that debris from a given population and of a given size and larger would strike an equivalent spherical spacecraft with unit cross-sectional area ($\pi r^2 = 1\ m^2$). For spacecraft, the direction is important in computing the projected area of a spacecraft element. The ORDEM model also breaks down the flux by relative velocity (in the frame of the spacecraft) and material density, which is important for damage assessments. Therefore, the flux is a function of year, size, material type, and, for spacecraft mode, elevation/azimuth and relative velocity in the local spacecraft frame.

For ground-based telescope/radar sensors, the telescope flux is the yearly rate debris from a given population and of a given size and larger would cross a thin conical beam of surface area 1 km^2, with the area corrected by multiplying by the cosine of the local angle with respect to vertical. These surface area fluxes are a function of altitude and latitude. ORDEM computes the telescope flux by mapping a series of range bins from a given telescope pointing direction to a distribution of debris orbits with randomized ascending/descending nodes and then integrating over this orbit distribution.

In ORDEM, the spacecraft flux is integrated over the entire orbit, calculating the fraction of time the spacecraft spends at different points in its orbit. This requires that the spatial density and velocity vector of each population sub-component be computed. Such a task is computationally-intensive, resulting in potentially long computation times in ORDEM 3.0 and 3.1 (see Section 5 for ORDEM 3.1 runtime estimates).

1.4 Point of Contact

The official point of contact for ORDEM 3.1 at the NASA ODPO is:

Dr. Jer-Chyi Liou, ODPO Program Manager
Mail Code: XI5-B9E
NASA Johnson Space Center
Houston, TX 77058
USA
Phone: (281)-483-5313
Email: jer-chyi.liou-1@nasa.gov

1.5 Project Team

The development team thankfully acknowledges the careful review and detailed comments and suggestions provided by the software review panel. The individuals listed below were involved in the research and collaboration efforts of the ORDEM 3.1 project (affiliations are at the time of the collaboration).

ORDEM Project Members

NASA
Jer-Chyi Liou, Program Manager
Mark Matney
Timothy Kennedy
Heather Cowardin

Jacobs JETS
Alyssa Manis, Project Manager
Phillip Anz-Meador
Andrew Vavrin
John Seago
Yu-Lin Xu
Drake Gates
James Murray
Rossina Miller
Melissa Ward
Brent Buckalew
James Frith
Christopher Blackwell
Ronald Barahona
Avery Malachi
Ian Bigger

2 ORDEM 3.1 SOFTWARE MODEL

Since ORDEM 3.0 was released (Stansbery 2014), new debris data have become available and analysis techniques have matured to currently reflect the debris environment. The current version, ORDEM 3.1, includes the same capabilities as ORDEM 3.0, but updates the model populations using the most recent and highest-fidelity datasets from radar, *in situ*, and optical sources. Table 2-1 compares the top-level output features of ORDEM 3.1 with ORDEM 3.0.

Table 2-1 Feature Comparison of ORDEM 3.0 and ORDEM 3.1

Parameter	ORDEM 3.0	ORDEM 3.1
Spacecraft & Telescope/Radar analysis modes	Yes	Yes
Time range	2010 to 2035	2016 to 2050
Altitude range with minimum debris size	100 to 40,000 km (>10 µm) (non-GEO) 34,000 to 40,000 km (>10 cm) (GEO)	100 to 40,000 km (>10 µm) (non-GEO) 34,000 to 40,000 km (>10 cm) (GEO)
Orbit types	Circular to highly elliptical	Circular to highly elliptical
Model population breakdown by type & material density	(IN) Intacts (LD) Low-density (1.4 g/cc) fragments (MD) Medium-density (2.8 g/cc) fragments & microdebris (HD) High-density (7.9 g/cc) fragments & microdebris (NK) RORSAT NaK coolant droplets (0.9 g/cc)	(IN) Intacts (LD) Low-density (1.4 g/cc) fragments (MD) Medium-density (2.8 g/cc) fragments & microdebris (HD) High-density (7.9 g/cc) fragments & microdebris (NK) RORSAT NaK coolant droplets (0.9 g/cc)
Model cumulative size thresholds (*fiducial points*)	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	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	Yes	Yes
Total *.POP File Size	1.25 GB	4 GB

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 up to 1 mm) and remote sensors (for debris ranging larger than 1 mm). For the non-GEO populations, these data are applied to ORDEM 3.1 in a maximum likelihood estimation and a Bayesian statistical process, respectively, in which the NASA ODPO models listed in Table 2-2 form the *a priori* conditions. The modeled debris populations, initially based largely on objects found in the Space Surveillance Network (SSN) catalog, are reweighted in number to be compatible with other data in orbital regions where the data are collected. By extension, this reweighting also adjusts the model debris populations 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]). For GEO populations, the model populations are extended to small sizes difficult to detect and track in GEO.

There are two ORDEM features that require further explanation. The first feature entails the altitude range with a minimum debris size. While geosynchronous transfer orbit (GTO) objects are not as well-observed as objects in LEO, the orbital dynamic forces and mechanisms for fragmentation in the two orbital regimes are considered similar. ORDEM therefore models > 10 µm fluxes with non-GEO (LEO and GTO) orbits. 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 regions physically overlap. ORDEM provides GEO debris fluxes for 10 cm and larger only. This is based on the SSN (1 m and larger), the Michigan Orbital Debris Survey Telescope (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 primarily due to GTO objects, so these smaller populations are incomplete at GEO altitudes.

The second feature is the exclusion of meteoroids in ORDEM. The Meteoroid Environment Model (MEM), produced by NASA's Meteoroid Environment Office at the Marshall Space Flight Center, is available independently from ORDEM (Moorhead, et al. 2015). Users should include this separate meteoroid model to calculate the total space particle impact environment for their spacecraft.

Table 2-2 ORDEM 3.1 Contributing Data Sets and Models

Contributing Data Sets		
Observational Data	**Role**	**Region/Approximate Size**
SSN catalog (radars, telescopes)	Intacts & large fragments	LEO > 10 cm, GEO > 1 m
Haystack (radar)	Statistical populations	LEO > 5.5 mm
STS windows & radiators (returned surfaces)	Statistical populations	10 µm < LEO $\leq$ 3.16 mm
MODEST (telescope)	GEO statistical populations	GEO > 30 cm
Contributing Models (with Corroborative Data)		
Model	**Usage**	**Corroborative Data**
LEGEND	LEO Fragments > 1 mm GEO Fragments > 10 cm	SSN, Haystack, MODEST, SSN
Degradation/Ejecta	10 µm < LEO $\leq$ 1 mm	STS windows & radiators

The ORDEM 3.1 input debris populations are binned in perigee altitude, eccentricity, and inclination for non-GEO objects (Table 2-3) and in mean motion, eccentricity, inclination, and right ascension of the ascending node (RAAN) for GEO objects (Table 2-4). Bin sizes are chosen to complement actual population distributions. The final files are from the direct yearly input database of ORDEM 3.1.

Table 2-3 Input File Population Bins for LEO to GTO

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

Table 2-4 Input File Population Bins for GEO

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

The binned input populations are accessed via the Spacecraft and Telescope/Radar modes, where the former uses the encounter igloo method, and the latter uses a segmented bore-sight vector for computation of flux.

2.1 Software Requirements

The system requirements to install ORDEM 3.1 are listed below:

- Windows 7 or later (Windows 10 recommended)
- Microsoft .Net framework 4.5 or later
- 4 GB RAM (8 GB recommended)
- 4 GB of available disk space

2.2 Software Installation and Uninstallation

It is important that the user does not modify (e.g., rename, remove) any files in the installed directories from the ORDEM 3.1 software. Files and directories may be copied to another location if necessary, but ORDEM 3.1 requires the originally-installed files to remain unaltered.

2.2.1 Installation

ORDEM 3.1 is distributed using an executable setup file. The installer will set up the ORDEM 3.1 software, libraries, and data files for the current user. The installer will also create Windows-based shortcuts to the ORDEM 3.1 GUI, ORDEM 3.1 User Guide, and software uninstaller (Figure 2-1). By default, the shortcuts reside in the Windows-based Start menu under **Programs → ORDEM 3.1**.

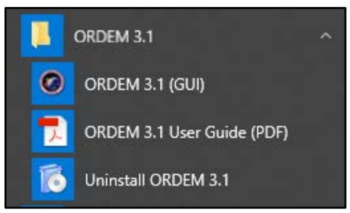

Figure 2-1 ORDEM 3.1 Start Menu Shortcuts

To install the ORDEM 3.1 software, follow the procedure below:

1. If not already installed, obtain and install Microsoft .NET framework 4.5 or greater (http://www.microsoft.com/net/Download.aspx).
2. Obtain the installation file for ORDEM 3.1 from the NASA ODPO Point of Contact or through the NASA software catalog (https://software.nasa.gov/).
3. Confirm the installer is copied to the user's local drive.
4. Run the ORDEM 3.1 installer.
   - If the installer detects that ORDEM 3.1 is already installed, it prompts the user to remove the installed version (Figure 2-2).

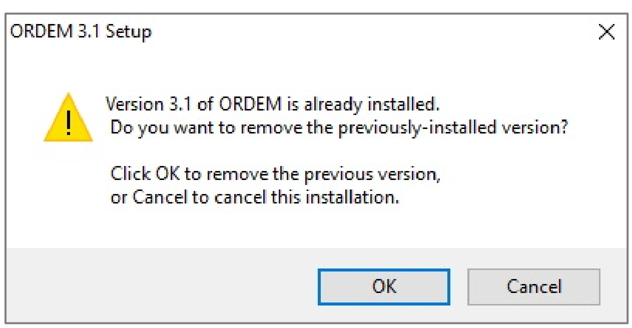

Figure 2-2 Checks if ORDEM 3.1 is Currently Installed

- The **Welcome to ORDEM 3.1 Setup** window (Figure 2-3) verifies that the installation of ORDEM 3.1 is desired. If the user wants to cancel installation at any time, select the *Cancel* button. Otherwise, select *Next*.

Figure 2-3 ORDEM Installation Welcome Screen

- The **Software Usage Agreement** verifies that the user agrees to accept the software usage agreement (Figure 2-4). The user must select *I Agree* in order to proceed to the next step.

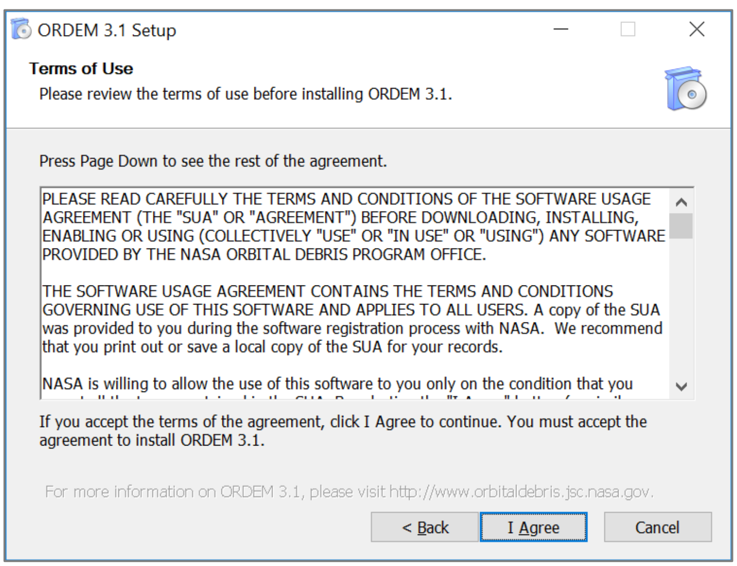

Figure 2-4 ORDEM 3.1 Software Usage Agreement

- **Choose Install Location** defines the location where the application will be installed (Figure 2-5). The *Browse* button will enable the user to view the file structure to define a preferred location. The default location is the current user's profile directory. Once a destination folder is chosen for the ORDEM 3.1 install, select *Next*.

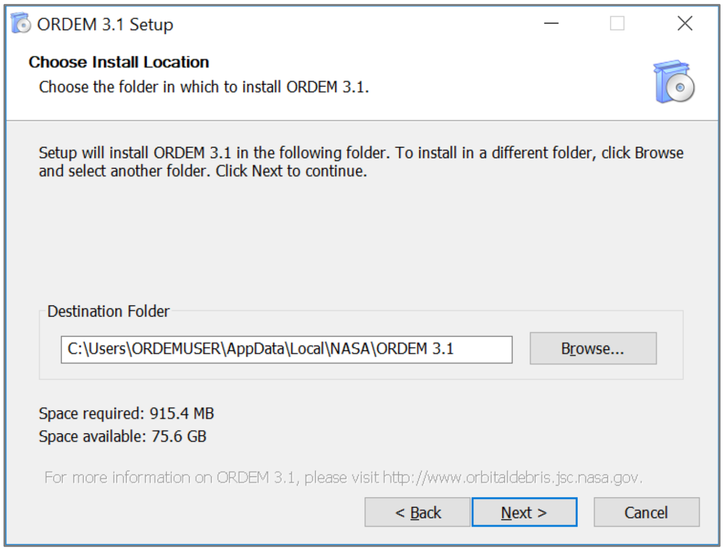

Figure 2-5 Designate Installation Folder Location

- **Choose Start Menu Folder** defines a folder within the **Start → Program** list where the application shortcuts will appear (Figure 2-6). 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 *Install* to continue with installation.

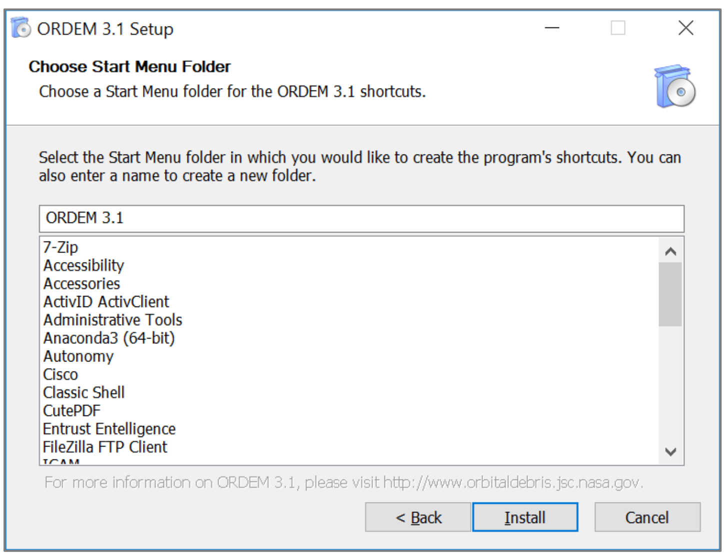

Figure 2-6 Start Menu Folder Selection

- The **Installing** window is then displayed (Figure 2-7). The progress bar displays information on the installation progress. Upon completion (Figure 2-8), select *Next*.

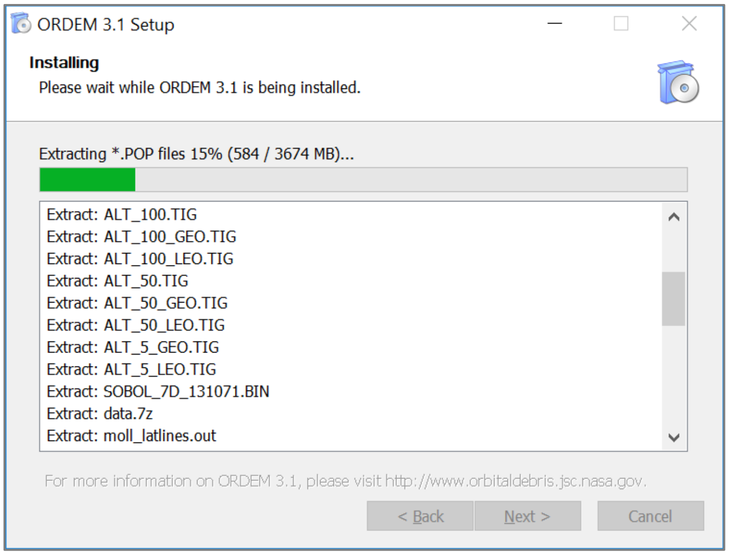

Figure 2-7 ORDEM 3.1 Installing

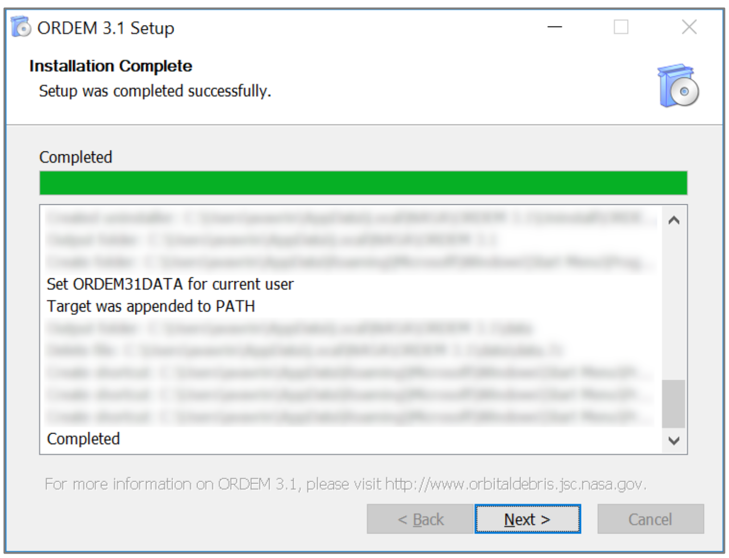

Figure 2-8 ORDEM 3.1 Installing Complete

- **Setup Complete** notifies the user that the setup has been completed (Figure 2-9). The user has the option to create a desktop shortcut of the ORDEM 3.1 GUI and/or to view the README.txt file. After the user makes their selection, click *Finish* to close the installation window.

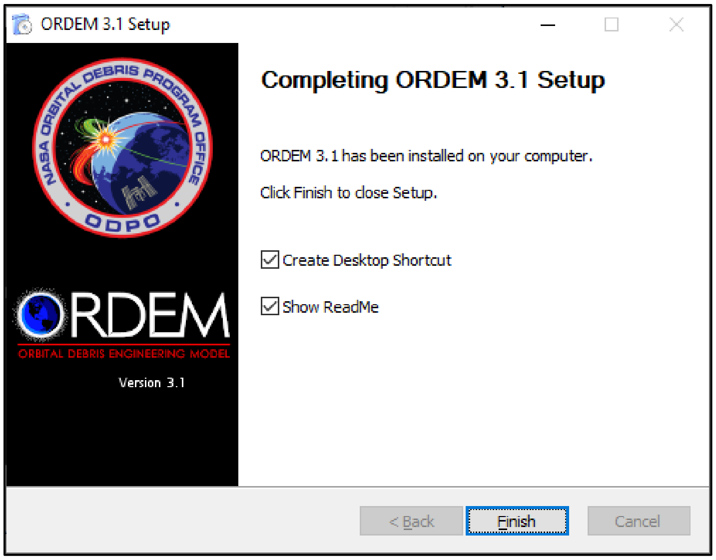

Figure 2-9 Successful Completion of the ORDEM 3.1 Setup

2.2.2 Uninstallation

ORDEM 3.1 includes an automatic removal ("un-installer") feature. To remove ORDEM 3.1, run uninstaller program located in the "uninstall" folder of the ORDEM 3.1 installation directory. A shortcut to this uninstaller in the ORDEM 3.1 program group is in the Start Menu (Figure 2-1).

To uninstall the ORDEM 3.1 software, follow the procedure below:

- The **Welcome to ORDEM 3.1 Uninstall** window (Figure 2-10) verifies that the uninstallation of ORDEM 3.1 is desired. If the user wants to cancel uninstallation at any time, select *Cancel*. Otherwise, select *Next*.

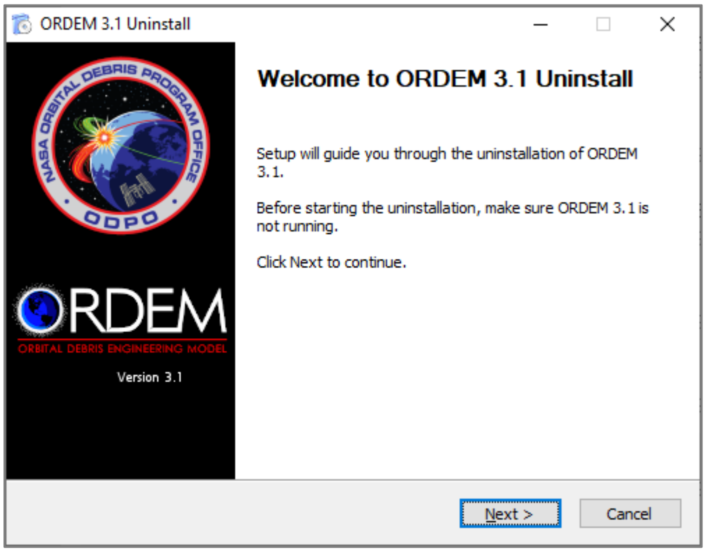

Figure 2-10 ORDEM Uninstallation Welcome Screen

- **Uninstall ORDEM 3.1** defines the location where the application was installed (Figure 2-11). To continue with uninstalling, select *Uninstall*.

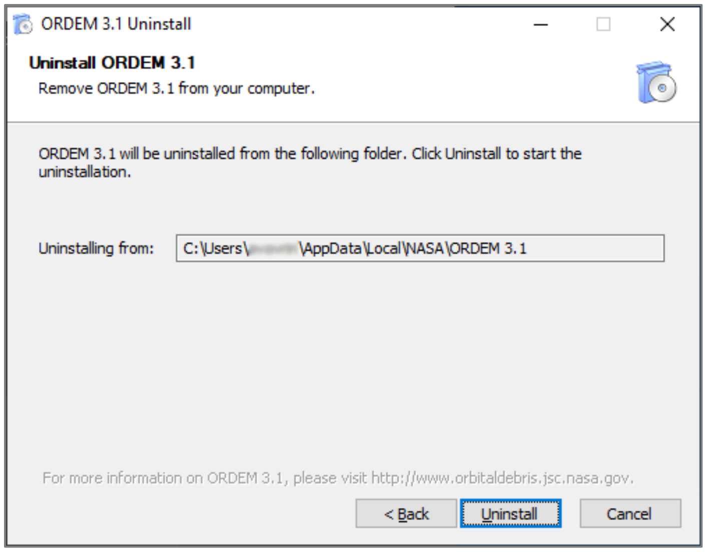

Figure 2-11 ORDEM Uninstallation Folder Location

- The **Uninstalling** window is displayed (Figure 2-12). The progress bar displays information on the uninstallation progress. Upon completion (Figure 2-13), select *Next*.

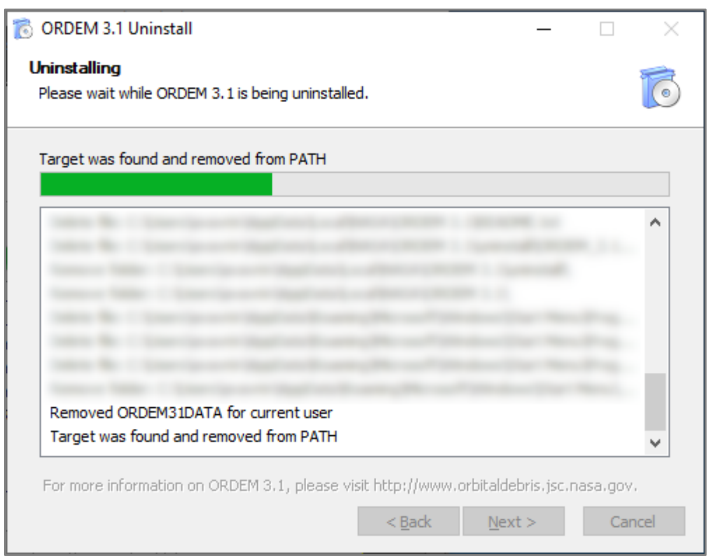

Figure 2-12 ORDEM 3.1 File Uninstallation

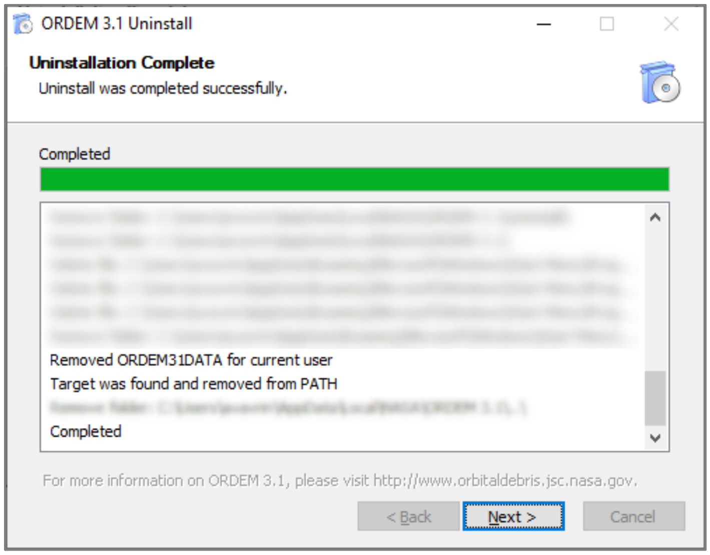

Figure 2-13 ORDEM 3.1 Uninstalling Complete

- **Completing ORDEM 3.1 Uninstall** notifies the user that the installation has been completed (Figure 2-14). Click *Finish* to close the uninstallation window.

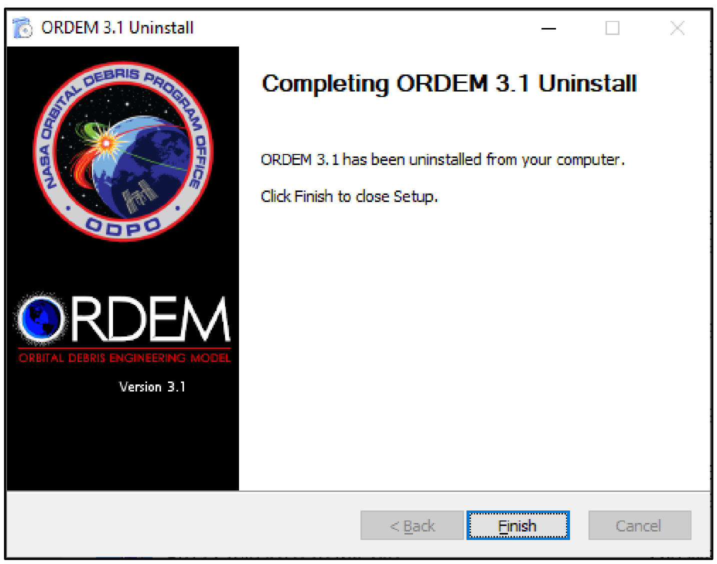

Figure 2-14 Successful Completion of the ORDEM 3.1 Uninstaller

2.3 Software Description

Files from the ORDEM 3.1 installation are stored in the installation directory (Table 2-5). ORDEM 3.1 includes two main programs: a command-line executable that performs the numerical computations (model\ORDEM31.exe) and a GUI frontend application (ORDEM-GUI.exe). The software also includes the subdirectory “data” where the debris population files (YYYY.POP) that form the database of the model reside.

Table 2-5 Files in Installation Directory

File Name	Description
data/YYYY.POP data/*.DAT data/*.BIN data/*.out	Yearly input population data for ORDEM 3.1 calculations Data defining the bin boundaries of the debris populations Binary file containing 7-dimensional Sobol sequences Gridline coordinates for the s/c-mode plot of “2-D Directional Flux”
data/IGLOO_10x10x1.SIG	Spacecraft encompassing igloo with dimensions 10° in azimuth, 10° elevation, 1 km/sec in velocity
data/IGLOO_30x30x2.SIG	Spacecraft encompassing igloo with dimensions 30° in azimuth, 30° elevation, 2 km/sec in velocity
data/ALT_50.TIG data/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)
data/ALT_5_GEO.TIG data/ALT_50_GEO.TIG data/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)
data/ALT_5_LEO.TIG data/ALT_50_LEO.TIG data/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)
help/ORDEM_UserGuide.pdf	User Guide for ORDEM 3.1
model/ORDEM31.exe	Computational model executable
model/*.dll	Dynamic link library files (six in total)
uninstall/ORDEM_3.1-uninstall.exe	Uninstall model executable
LICENSE.txt	Software Usage Agreement (SUA)
ORDEM-GUI.exe	Graphical user interface executable
README.txt	Description of the current updated ORDEM model

The results of an ORDEM 3.1 computation are stored in a user-defined project directory (Table 2-6). It is a writable area for running the computational model and saving all GUI input values. The user may create as many project directories as desired. See Table 3-2 for complete list of ORDEM 3.1 output file names from Spacecraft and Telescope/Radar Assessment modes.

Table 2-6 Files in a User-Defined 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

2.4 Program Execution

ORDEM 3.1 may be run using the GUI frontend application or the command-line interface. The GUI accepts inputs from the user, sets up and performs a single run, and displays the results as on-screen graphs. Parallel batch processing can also be done through the GUI (see Section 2.4.1.4). The command-line interface requires the user to supply a separate text input file or a driver/batch code for serial batch processing.

2.4.1 GUI-based Computation

The standard method to run ORDEM 3.1 is through the GUI. This is accomplished by running the **Programs → ORDEM 3.1 → ORDEM 3.1 (GUI)** from the Start Menu. Figure 2-15 illustrates the user actions and subsequent program performance associated with the GUI. Red indicates GUI user selections and gray background indicates ORDEM processes. After mode selection, with required inputs, the ORDEM 3.1 code selects the appropriate population bin set and begins the mapping of bins to spacecraft encounter igloos (Spacecraft mode) or segmented bore-sight vectors (Telescope/Radar mode). LEO-to-GTO (i.e., non-GEO) calculations are run for any input parameters, and GEO calculations are also accessed for any orbits whose parameters overlap into GEO igloo bins. Encountered fluxes are compiled and tabulated in output files that can be accessed and plotted via the GUI.

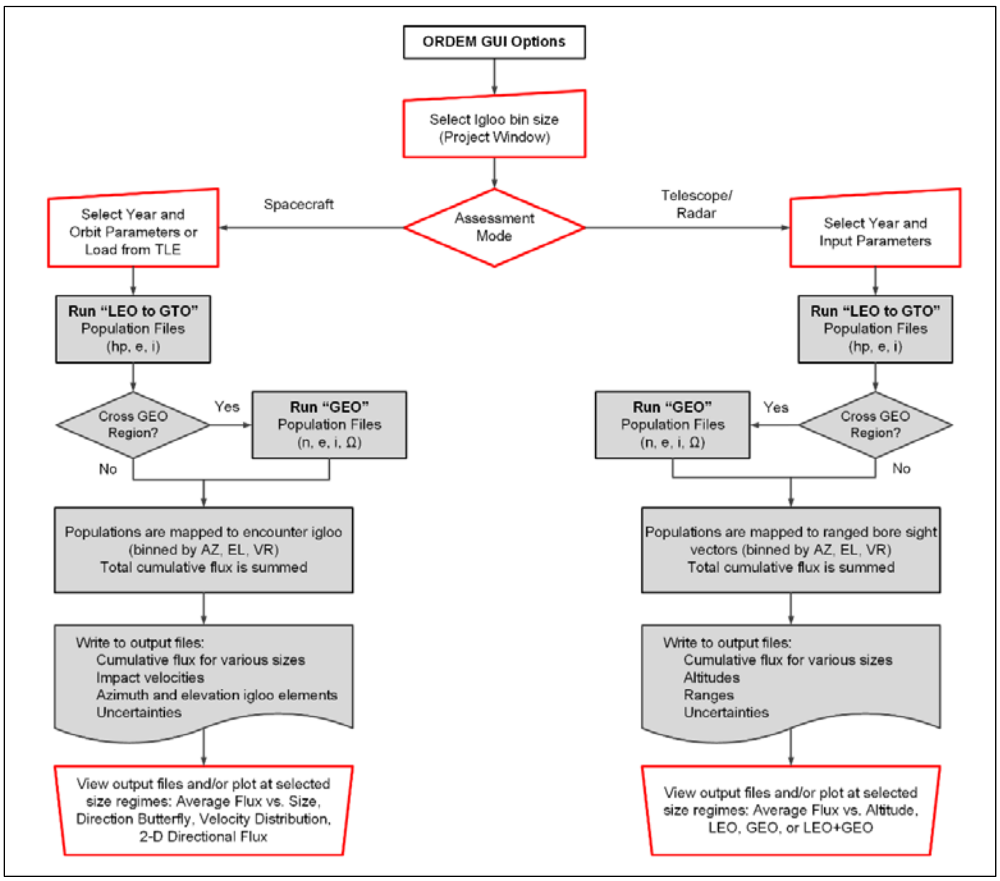

Figure 2-15 ORDEM GUI Options and Coding Structure Flowchart

2.4.1.1 Project

The user defines a project directory where 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. On startup, the GUI will open the project directory that was previously opened by the current user (Figure 2-16). Otherwise, the ORDEM 3.1 current "project window" will be empty (Figure 2-17).

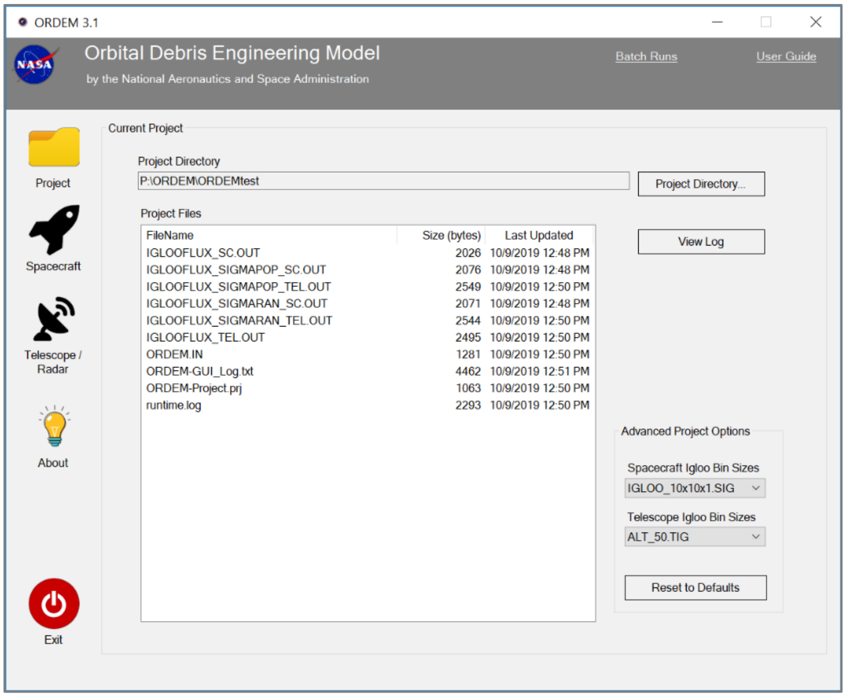

Figure 2-16 ORDEM 3.1 Previously Opened Project

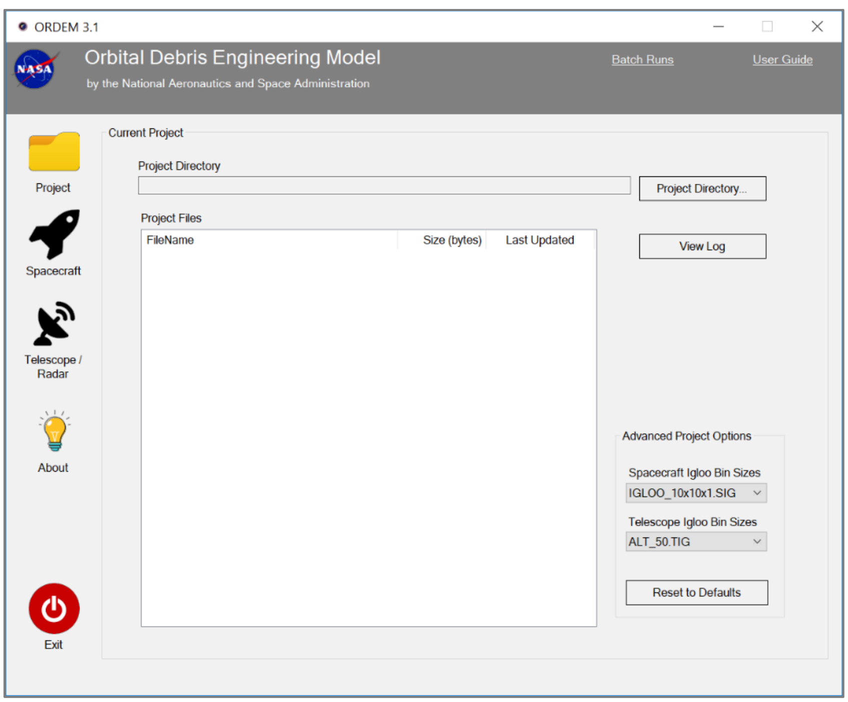

Figure 2-17 ORDEM 3.1 Empty Project

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 3.1 to reject that directory.* Click "*Project Directory…*" to open the Project Directory selection window (Figure 2-18).

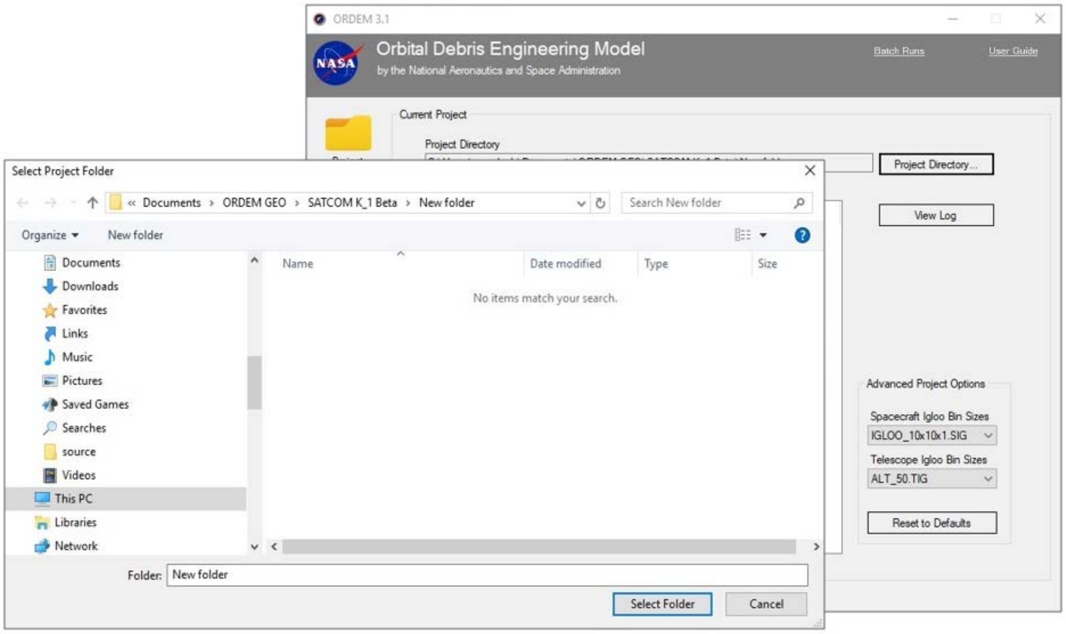

Figure 2-18 Project Directory Window

To start a new project, the user must create a new folder. To open a previously created project, the user selects the desired directory. To create a new project, the user selects *New Folder* in the selected director (Figure 2-19). When the recently created project directory is selected, the user clicks the *Select Folder* button.

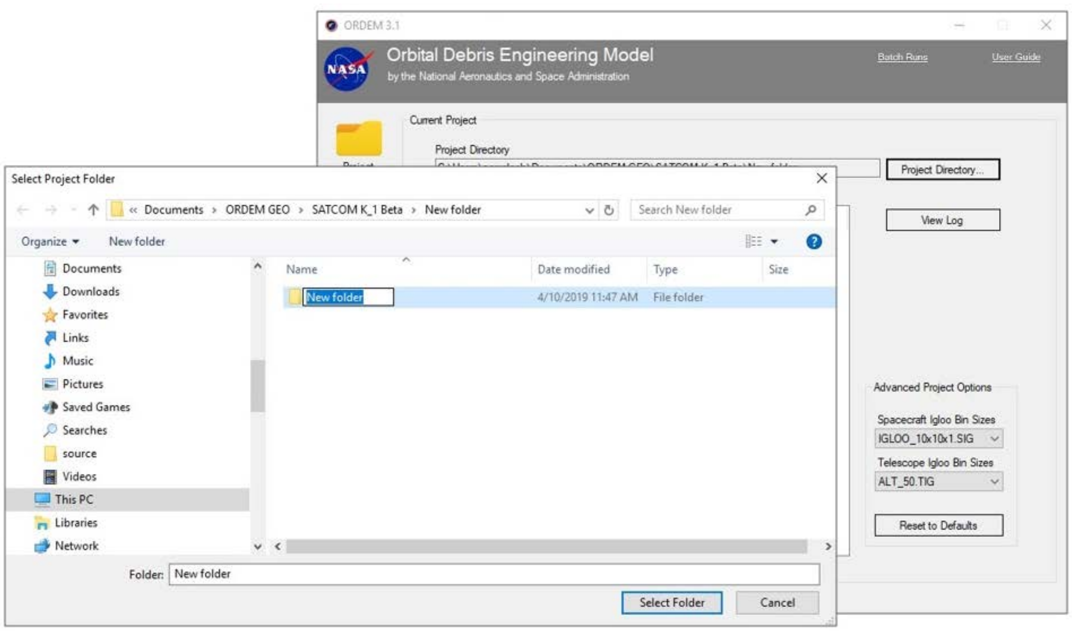

Figure 2-19 Create a New Project Directory

Toward the center of the project window is a box with a list of project files in the current project directory. It provides quick access to view any of the files. If double-clicked, a file will be opened in another window for viewing. The *View Log* button will bring up a window allowing the user to view the log of past activity. The *Reset to Defaults* button will reset all the GUI values to default values. This reset 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 (Figure 2-20). The finer degradations (i.e., IGLOO_10x10x1.SIG and ALT_50.TIG) are the ORDEM 3.1 default values and are recommended for in depth analysis. *Note: the user must make a selection for both fields. If any of the "Advance Project Options" are empty, the program will prompt an error.*

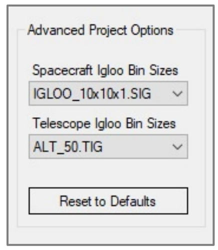

Figure 2-20 Advanced Project Options Drop Down Menu

2.4.1.2 Spacecraft Assessment

The Spacecraft Assessment window (Figure 2-21) is used for evaluating the orbital debris environment for spacecraft and missions. To start, click on the *Spacecraft* button on the left. The Spacecraft Assessment window contains the input fields and the runtime output in the **ORDEM Model Output** window.

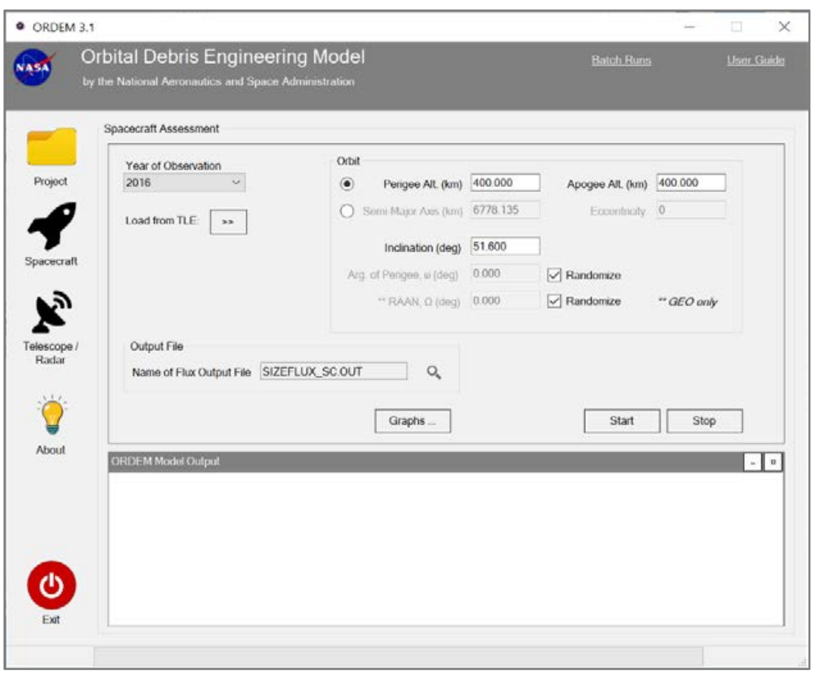

Figure 2-21 ORDEM 3.1 Spacecraft Assessment Window

The input orbit information can be entered as orbital parameters (perigee, apogee), classical orbit elements (semi-major axis, eccentricity), or as a standard two-line element (TLE) set. At a minimum, the user must enter an orbit inclination and either the perigee and apogee altitudes (**not** radii) or the semi-major axis and eccentricity. The user may define the argument of perigee and RAAN or choose a “randomized” value for these elements. 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 is mainly applicable to orbits with fixed perigee, e.g., *Molniya*-type orbits, and a non-random choice of RAAN affects only flux calculations in the GEO regime. The LEO populations are assumed to consist of populations with randomized argument of perigee and RAAN.

To input the orbit as a TLE set, click on the **>>** button. Figure 2-22 shows the pop-up window that is displayed for decomposing a TLE.

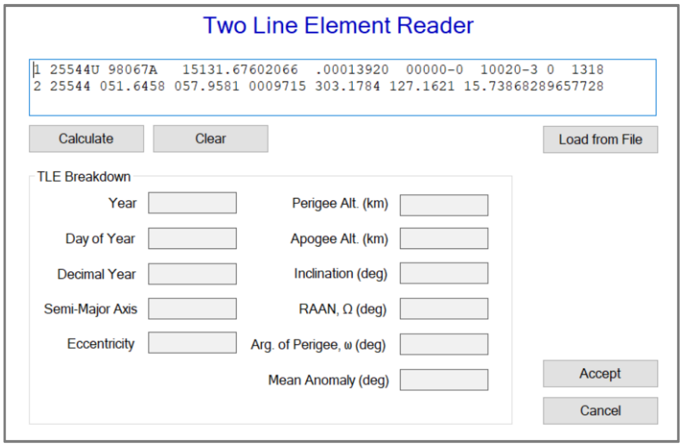

Figure 2-22 TLE Reader Window

The TLE window allows the user to specify the TLE by loading from a text file, manually typing, or pasting into the TLE area. When loading from a text file via the *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 (Figure 2-23). If these values are desired, the user selects *Accept* and 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.

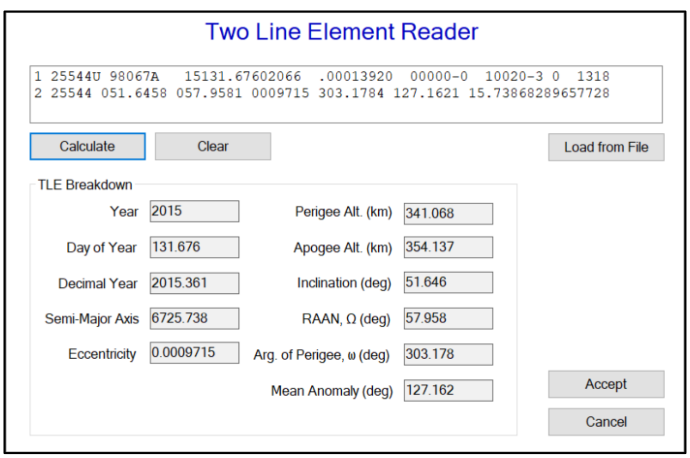

Figure 2-23 TLE Reader Window with Calculated Orbital Elements

After all input parameters are set in the Spacecraft Assessment window, the user must click the *Start* button to begin the computations. After clicking the *Start* button, the GUI will generate the requisite ORDEM.IN file that is needed for the computation model to run properly. The user can also generate the ORDEM.IN file manually with the CTRL+S keyboard shortcut in the Spacecraft Assessment window, prior to clicking the *Start* button. After clicking the *Start* button, the model process will begin, and the output messages will be redirected into the **ORDEM Model Output** area (Figure 2-24). 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 in the underlying model code.) A progress bar is located at the bottom of the GUI indicating the percentage complete; for GEO runs, however, the status bar resets after completing the LEO-to-GTO portion of the computation and continues to progress until reaching completion of the GEO computation. The *Stop* button is provided to abort a run.

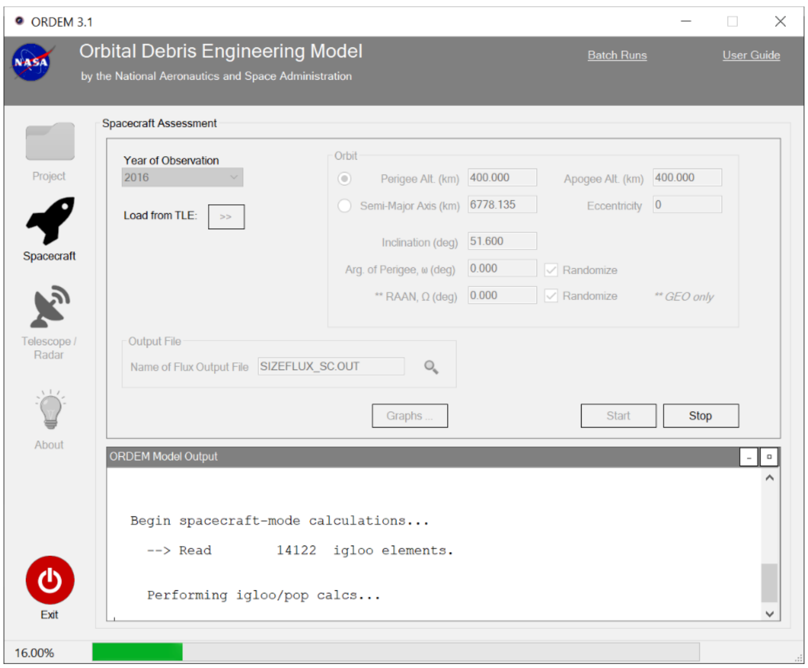

Figure 2-24 Spacecraft Assessment Window, Run in Progress

After running the computational model, the files listed in the “Output File" area of the project panel may be viewed by clicking the magnifying glass icon to the right of the file name in the “Name of Flux Output File” field. 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. See Section 4.1 for more details.

2.4.1.3 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 2-25). To start, click on the *Telescope/Radar* button on the left. The Telescope/Radar Assessment window contains the input fields and the runtime output in the **ORDEM Model Output** window.

This window is very similar in functionality to the Spacecraft Assessment window. The fields for the inputs include Year of Observation, Latitude of Instrument, Telescope Azimuth, and Telescope Elevation. There are also *Start* and *Stop* buttons for running the model, and buttons for viewing the output. After clicking the *Start* button, the GUI will generate the requisite ORDEM.IN file that is needed for the computation model to run properly. The user can also generate the ORDEM.IN file with the CTRL+S keyboard shortcut in the Telescope/Radar Assessment window. A progress bar occupies the bottom line indicating the telescope assessment mode's current instance of completion. Figure 2-26 shows the Telescope/Radar Assessment window during a telescope mode run. The user can view three types of flux vs. altitude graphs by clicking the *Graphs…* button: LEO-only, LEO+GEO, and GEO-only. See Section 4.2 for more details.

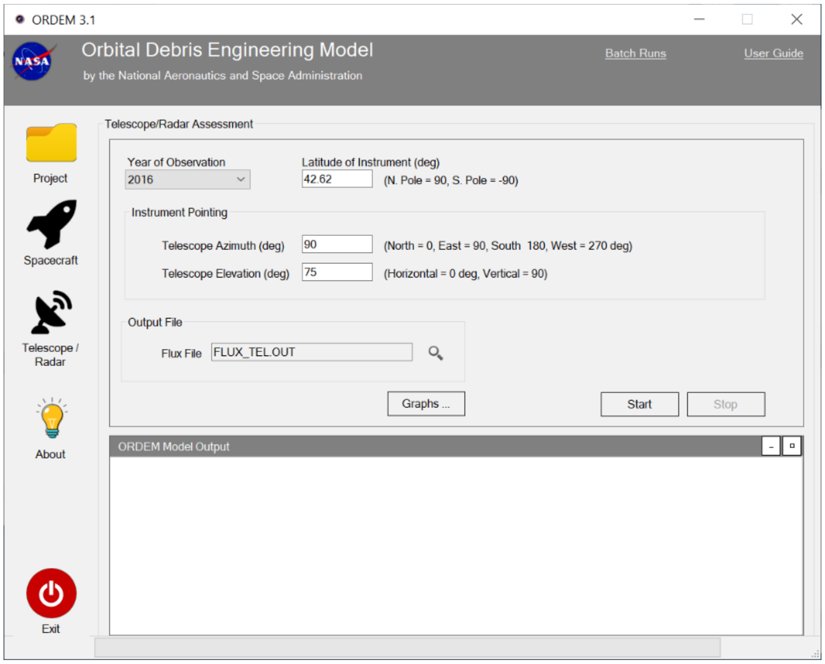

Figure 2-25 Telescope/Radar Assessment Window

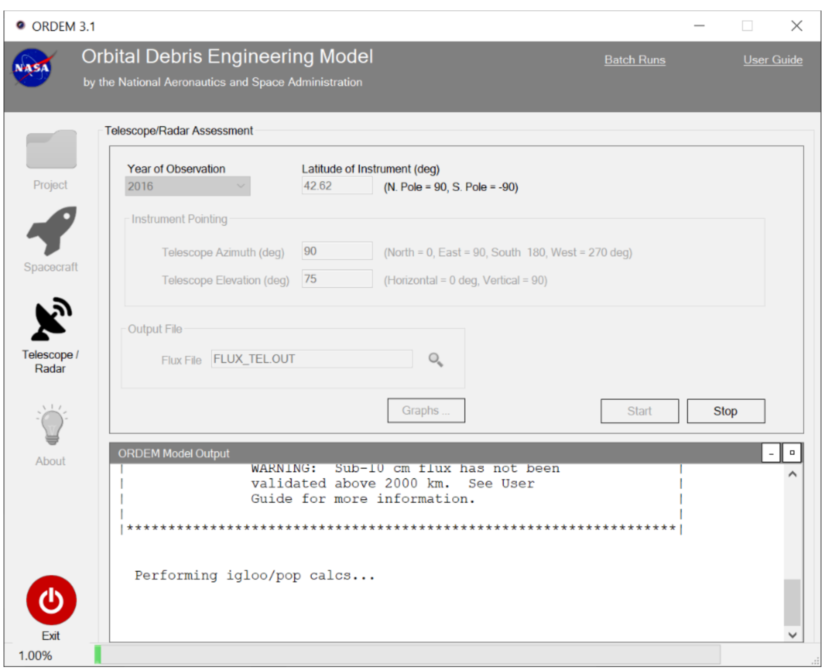

Figure 2-26 Telescope/Radar Assessment Window, Run in Progress

2.4.1.4 *Batch Runs*

A new feature of the GUI for ORDEM 3.1 is the addition of a batch run capability. The Batch Runs interface is designed for advanced users of the ORDEM software that need to run several ORDEM projects with the fewest steps possible. The user can access the Batch Runs window by clicking the *Batch Runs* link on the top right corner of the ORDEM 3.1 window (Figure 2-27).

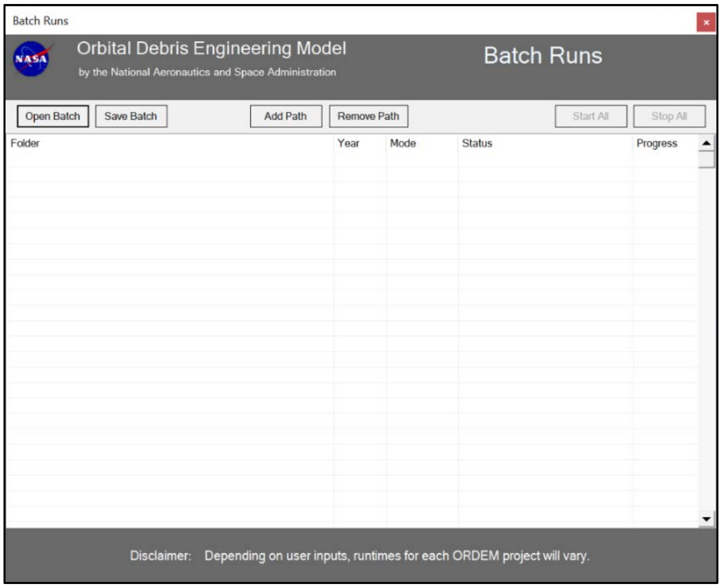

Figure 2-27 Batch Runs Window, Empty List

This interface provides the user a way to add as many ORDEM project paths as desired but will only run up to eight ORDEM sessions in parallel at a time. Project paths can be loaded and/or saved in a batch file, which are text files that contain ORDEM project paths on each line. These files can be created manually by the user in a text editor or in the Batch Runs window. Figure 2-28 shows the Batch Runs window with valid ORDEM project paths listed in the table.

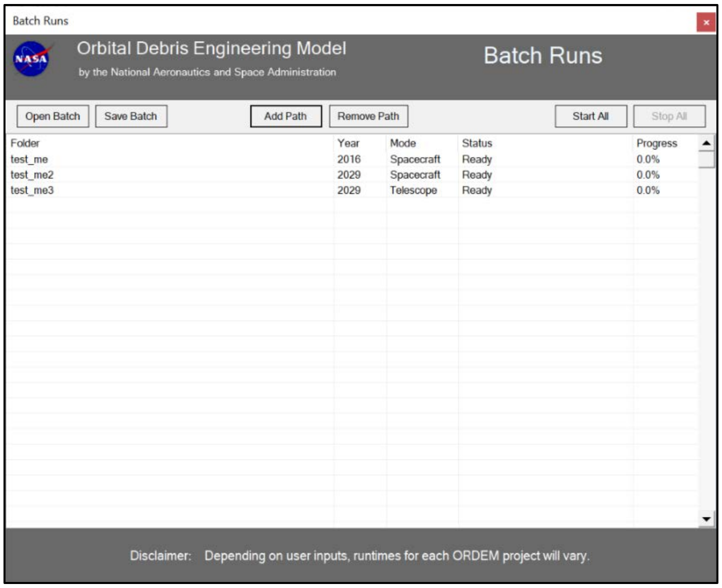

Figure 2-28 Batch Runs Window, ORDEM Projects Listing

The table columns are described as follows. The *Folder* column displays the base folder name of the ORDEM project path. The full directory path of the ORDEM project can be viewed by hovering the mouse over each row. The *Year* column displays the population year of the ORDEM project. The *Mode* column displays the assessment type (Spacecraft or Telescope). The *Status* column shows the status during an ORDEM run and the *Progress* column shows percentage complete for an ORDEM run.

The user can click *Add Path* to add an ORDEM project path to the table or *Remove Path* to remove a project path from the table. The user can also open an existing batch file via *Open Batch* button. If the user-specified file is a valid batch file (i.e., existing ORDEM project directories listed, one per line), then each project directory is added as a row to the table. To save all of the project paths that are displayed to a text file, click the *Save Batch* button. If there is no previously opened batch file, then a new batch file will be created that includes the displayed ORDEM project paths (file format `o31BatchFile_yyyyMMdd_HHmmss.txt`). The *Start All* button starts the ORDEM runs in parallel and *Stop All* button cancels running ORDEM projects.

Once the user clicks the *Start All* button, the ORDEM runs will start and the *Status* and *Progress* columns will be updated during the ORDEM run (Figure 2-29). Each project's output files from a previous run will be overwritten. If this behavior is not desired, the user is encouraged to either make a backup of their output files from a previous ORDEM run or to complete their ORDEM runs in the Spacecraft Assessment or Telescope/Radar windows.

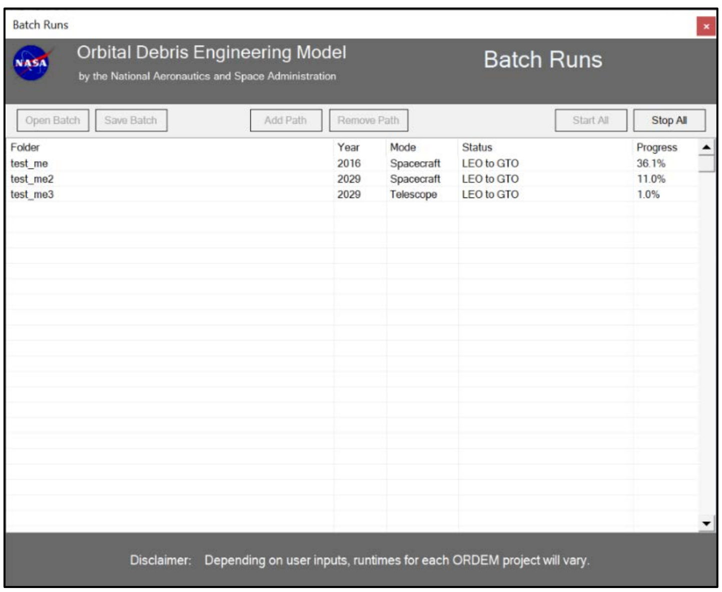

Figure 2-29 Batch Runs Window, Batch Runs in Progress

2.4.1.5 User Guide

The user can access the ORDEM 3.1 Software User Guide by clicking the *User Guide* link on the top right corner of the ORDEM 3.1 window.

2.4.1.6 Exit

If the user selects the *Exit* button (or manually closes the ORDEM GUI window), a dialog popup will display to confirm if the user wishes to exit the application. Select *Yes* to close the application.

2.4.1.7 About

When the user selects the *About* button, a window will display containing information regarding the ORDEM 3.1 software (Figure 2-30).

Figure 2-30 About ORDEM 3.1

2.4.2 Command-line based Computation

The second method of running ORDEM 3.1 is via the command-line interface. This approach is possible because the computational model is a separate executable program.

2.4.2.1 Setup

Running from the command line requires the user to manually edit the ORDEM.IN input file of their chosen ORDEM project. A sample ORDEM.IN file is shown in Table 3-1. The file holds all values needed to run the simulation and is annotated to assist in editing if needed. The ORDEM 3.1 GUI creates an ORDEM.IN file based on the user's "ORDEM-Project.prj" project file. Therefore, it is recommended that the user verifies that the ORDEM.IN file exists in their project directory before proceeding to run ORDEM 3.1 from the command line.

2.4.2.2 Operations

To start a nominal ORDEM run via the command-line, the user should enter the following:

```
[CURRENT-DIRECTORY]>> ORDEM31.exe <project directory path>
```

This command will run the model and the output messages will print to the command window as it is running. Output files will be written to the project directory. No graphs are produced when ORDEM 3.1 is run from the command line. However, the user can use the GUI to view graphs from output files generated in command-line mode.

To check the ORDEM release version, the user enters the name of the executable followed by the `/?` argument at the command prompt:

```
[CURRENT-DIRECTORY]>> ORDEM31.exe /?
```

The following text is displayed on the screen:

```
NASA Orbital Debris Program Office
      Johnson Space Center
ORDEM 3.1   Released on XXXX-XX-XX
```

2.4.2.3 Command Line Batch File

Using a batch file eliminates the need to enter input parameters in the GUI at the beginning of each ORDEM 3.1 run; this 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, as described in Section 2.4.2.1. After the inputs are ready, the user will write and execute a batch file (*.BAT file), which is a simple driver program to run ORDEM 3.1 for each of the series of user project directory paths.

Below is a sample batch file named `batchrun.bat` that performs a series of ORDEM 3.1 spacecraft assessment runs from years 2017 to 2019. Each line in the batch file starts with ORDEM31.exe, followed by a user project directory path.

```
ORDEM31.exe D:\2017_folder\
ORDEM31.exe D:\2018_folder\
ORDEM31.exe D:\2019_folder\
```

The batch file can be run by typing the following at the command prompt: `batchrun.bat`

2.5 **Warning Message for Sub-10cm Flux**

The calculated debris fluxes below 10 cm have not been validated for apogee altitudes higher than 2000 km (in Spacecraft mode) and for altitudes higher than 2000 km (in Telescope/Radar mode). Any fluxes below that 10 cm threshold above these altitudes are primarily due to GTO objects, as discussed in Section 2. During an ORDEM 3.1 run in Spacecraft and/or Telescope/Radar modes for these special cases, a warning message (Figure 2-31) is displayed in the following locations:

- **ORDEM Model Output** window, at the beginning of the run
- Console window, if running ORDEM31.exe from command line
- Top of each *.OUT output files
- Footer on all graphs

```
|******************************************************************|
|                                                                  |
|              WARNING:  Sub-10 cm flux has not been               |
|              validated above 2000 km.  See User                  |
|              Guide for more information.                         |
|                                                                  |
|******************************************************************|
```

Figure 2-31 Warning Message for Sub-10 cm Flux Validation

3 ORDEM 3.1 INPUT/OUTPUT FILE FORMATS

This section contains sample file formats and descriptions of ORDEM 3.1 input and output files.

3.1 Input File Format

The ORDEM 3.1 input file containing all user-specified parameters is “ORDEM.IN”. This file is in the project directory. The ORDEM 3.1 GUI creates this file as input for the computational run. When running ORDEM 3.1 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 3.1 reads specific values from specific lines of the file, so the format (as produced by the GUI) must be strictly followed. Table 3-1 shows the file format and line-by-line descriptions, where line numbers are represented in bold. The first group of values (lines 2 and 3) specify the type and year of assessment. The second group of values (lines 5 - 13) specify the orbit and spacecraft encounter igloo file 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 - 18) specify the observer’s latitude and viewing angle and “segmented bore-sight vector” for Telescope/Radar Assessment mode.

Table 3-1 Example of ORDEM 3.1 Input File, ORDEM.IN

```
1   !file=ORDEM.IN file
2   1                       ! type of assessment (1=spacecraft 2=telescope/radar)
3   2029                    ! year of observation (2016-2050)
4   !---------- Spacecraft assessment -------------------------------------
5   1                       ! way to determine orbit (1=apogee/perigee, 2=semi-major axis/eccentricity)
6   223.451                 ! perigee altitude (km)
7   329.811                 ! apogee altitude (km)
8   0.0                     ! semi-major axis (km)
9   0.0                     ! eccentricity (0-1)
10  0.0                     ! inclination (0 to 180 deg)
11  0.0                     ! argument of perigee (0 to 360 deg, -1=random)
12  0.0                     ! right ascension of the ascending node, RAAN (0 to 360 deg, -1=random)
13  IGLOO_10x10x1.SIG       ! file defining all 'igloo' element boundaries (az,el,vel)
14  !---------- Telescope/Radar assessment ---------------------------------
15  0.000                   ! sensor latitude (SP=-90 to NP=90)
16  0.000                   ! azimuth (0 deg=North, 90 deg=East, to 360 deg)
17  0.000                   ! elevation (0 deg=horz to 90 deg=zenith)
18  ALT_50.TIG              ! file defining all 'igloo' element boundaries (alt)
```

3.2 Output File Formats

The ORDEM 3.1 output files are plain text and column-separated for easy transfer into spreadsheets or other visualization programs. The files are generated for the two assessment modes: Spacecraft and Telescope/Radar. The files represent the debris fluxes (categorized by size) encountered by the chosen Spacecraft or Telescope/Radar.

This section has sample file formats of ORDEM 3.1 output and the file names are listed in Table 3-2. These text files may be used for external analysis, but their main purpose is as an interface between the program executable and the GUI.

Table 3-2 Files Output by ORDEM 3.1 Modes (*.OUT)

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. local azimuth (collapsed in local elevation) 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 by debris size and material type. 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.

3.2.1 Spacecraft Assessment

3.2.1.1 SIZEFLUX_SC.OUT

This is the output file of the average cumulative flux as a function of particle size. It is used for generating the Spacecraft Assessment plot “Average Flux vs. Size” in the ORDEM 3.1 GUI. The file has 12 header lines, with the data starting on line 13 (Figure 3-1). 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.

```
ORDEM 3.1   -  ORDEM Spacecraft Mode
Debris Flux (#/m^2/yr)
 Year: 2016  Perigee Altitude =   1143.890  Apogee Altitude =  1143.890  inc =   44.58
*
*
*
*
*
*
*
 Size (m)   Flux       -Sigma     +Sigma
 --------   --------   --------   --------
 1.00E-05   2.32E+01   4.80E-01   4.80E-01
 1.02E-05   2.27E+01   4.79E-01   4.79E-01
 1.05E-05   2.22E+01   4.77E-01   4.77E-01
 1.07E-05   2.17E+01   4.75E-01   4.75E-01
 1.10E-05   2.13E+01   4.73E-01   4.73E-01
 1.12E-05   2.08E+01   4.70E-01   4.70E-01
 1.15E-05   2.03E+01   4.67E-01   4.67E-01
 1.17E-05   1.98E+01   4.64E-01   4.64E-01
 1.20E-05   1.94E+01   4.60E-01   4.60E-01
 1.23E-05   1.89E+01   4.57E-01   4.57E-01
 1.26E-05   1.85E+01   4.53E-01   4.53E-01
 1.29E-05   1.80E+01   4.48E-01   4.48E-01
 1.32E-05   1.75E+01   4.44E-01   4.44E-01
 1.35E-05   1.71E+01   4.39E-01   4.39E-01
 1.38E-05   1.67E+01   4.34E-01   4.34E-01
 1.41E-05   1.62E+01   4.28E-01   4.28E-01
 1.45E-05   1.58E+01   4.23E-01   4.23E-01
 1.48E-05   1.53E+01   4.17E-01   4.17E-01
 1.51E-05   1.49E+01   4.12E-01   4.12E-01
 1.55E-05   1.45E+01   4.06E-01   4.06E-01
 1.58E-05   1.41E+01   4.00E-01   4.00E-01
```

Figure 3-1 Example of SIZEFLUX_SC.OUT

3.2.1.2 VELFLUX_SC.OUT

This is the output file for debris flux as a function of impact relative velocity. It is used for generating the Spacecraft Assessment plot “Velocity Distribution” in the ORDEM 3.1 GUI. The file has 12 header lines, with the data starting on line 13 (Figure 3-2). It includes minimum and maximum values for each flux data column (useful for axis scaling) on lines 13 and 14. The first two columns define the lower and upper velocity bin bounds in km/s. Subsequent columns list the debris flux for each of six size thresholds, as shown in the column headers.

```
ORDEM 3.1   -  ORDEM Spacecraft Mode
Debris Flux (#/m^2/yr/kps)
 Year: 2016  Perigee Altitude =   1143.890  Apogee Altitude =  1143.890  inc =   44.58
*
*
*
*
*
*
*
Vel 1   Vel 2    >10um      >100um     >1mm       >1cm       >10cm      >1m
------  ------   --------   --------   --------   --------   --------   --------
  Min.:          1.01E-06   2.66E-15   2.66E-15   6.42E-18   4.90E-13   3.72E-13
  Max.:          1.10E+01   2.16E-01   8.90E-05   2.43E-09   1.05E-10   3.19E-11
------  ------   --------   --------   --------   --------   --------   --------
  0.0     0.1    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.1     0.2    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.2     0.3    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.3     0.4    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.4     0.5    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.5     0.6    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.6     0.7    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.7     0.8    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.8     0.9    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  0.9     1.0    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.0     1.1    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.1     1.2    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.2     1.3    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.3     1.4    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.4     1.5    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.5     1.6    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.6     1.7    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
  1.7     1.8    2.78E-02   2.28E-04   3.02E-07   1.82E-11   6.07E-13   3.72E-13
```

Figure 3-2 Example of VELFLUX_SC.OUT

3.2.1.3 BFLY_SC.OUT

This is the output file for debris flux as a function of local impact azimuth angle (collapsed in local elevation). It is used for generating the Spacecraft Assessment plot “Direction Butterfly” in the ORDEM 3.1 GUI. Note that the “local azimuth” is the angle measured in the local horizontal plane running from port (left) to starboard (right) with respect to the spacecraft velocity-vector (ram) direction. The file has 12 header lines with data starting on line 13 (Figure 3-3). It includes minimum and maximum values for each flux data column (useful for axis scaling) on lines 13 and 14. 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 six size thresholds, as shown in the column headers.

```
ORDEM 3.1   -  ORDEM Spacecraft Mode
Debris Flux (#/m^2/yr/deg)
 Year: 2016  Perigee Altitude =   1143.890  Apogee Altitude =  1143.890  inc =   44.58
*
*
*
*
*
*
*
 Az 1    Az 2     >10um      >100um     >1mm       >1cm       >10cm      >1m
------  ------   --------   --------   --------   --------   --------   --------
  Min.:          1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
  Max.:          7.64E-01   1.47E-02   6.24E-06   2.20E-10   1.19E-11   3.16E-12
------  ------   --------   --------   --------   --------   --------   --------
 -180    -179    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -179    -178    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -178    -177    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -177    -176    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -176    -175    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -175    -174    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -174    -173    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -173    -172    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -172    -171    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -171    -170    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -170    -169    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -169    -168    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -168    -167    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -167    -166    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -166    -165    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
 -165    -164    1.37E-04   9.89E-07   1.49E-09   9.75E-14   2.18E-15   1.88E-15
```

Figure 3-3 Example of BFLY_SC.OUT

3.2.1.4 DIRFLUX_SC.OUT

This is the output file for debris flux as a function of local impact azimuth angle and elevation angle. It is used for generating the Spacecraft Assessment plot “2-D Directional Flux,” also known as a Mollweide projection, in the ORDEM 3.1 GUI. Note that the “local azimuth” is the angle measured in the local horizontal plane, running from port (left) to starboard (right) with respect to the spacecraft velocity-vector (ram) direction and “local elevation” is measured in a plane perpendicular to the local horizontal, running from bottom to top.

The file has 12 header lines with the data starting on line 13 (Figure 3-4). It includes minimum and maximum values for each flux data column (useful for axis scaling) on lines 13 and 14. 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, respectively, 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 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 six size thresholds, as shown in the column headers. (Note not all columns are shown in Figure 3-4.)

```
ORDEM 3.1   -  ORDEM Spacecraft Mode
Debris Flux (#/m^2/yr/kps)
 Year: 2016  Perigee Altitude =   1143.890  Apogee Altitude =  1143.890  inc =   44.58
*
*
*
*
*
*
*
  X_NE     Y_NE     X_SE     Y_SE     X_SW     Y_SW     X_NW     Y_NW     X-mid    Y-mid     >10um
-------  -------  -------  -------  -------  -------  -------  -------  -------  -------   --------
  Min.:                                                                                   1.65E-17
  Max.:                                                                                   2.58E-02
-------  -------  -------  -------  -------  -------  -------  -------  -------  -------   --------
 -12.71   -89.77    -0.00   -90.00    -0.00   -90.00   -12.78   -89.77   -10.12   -89.86   6.12E-07
 -20.17   -89.43   -12.71   -89.77   -12.78   -89.77   -20.28   -89.43   -17.30   -89.58   1.84E-06
 -26.40   -89.02   -20.17   -89.43   -20.28   -89.43   -26.55   -89.02   -23.76   -89.21   3.06E-06
 -31.95   -88.56   -26.40   -89.02   -26.55   -89.02   -32.12   -88.56   -29.52   -88.77   4.28E-06
 -37.03   -88.05   -31.95   -88.56   -32.12   -88.56   -37.23   -88.05   -34.77   -88.30   5.51E-06
 -41.76   -87.52   -37.03   -88.05   -37.23   -88.05   -41.99   -87.52   -39.65   -87.78   6.73E-06
 -46.21   -86.95   -41.76   -87.52   -41.99   -87.52   -46.47   -86.95   -44.22   -87.23   7.94E-06
 -50.44   -86.35   -46.21   -86.95   -46.47   -86.95   -50.72   -86.35   -48.56   -86.64   9.16E-06
 -54.47   -85.73   -50.44   -86.35   -50.72   -86.35   -54.78   -85.73   -52.68   -86.04   1.04E-05
 -58.34   -85.09   -54.47   -85.73   -54.78   -85.73   -58.67   -85.09   -56.64   -85.40   1.16E-05
 -62.06   -84.42   -58.34   -85.09   -58.67   -85.09   -62.41   -84.42   -60.43   -84.75   1.28E-05
 -65.65   -83.73   -62.06   -84.42   -62.41   -84.42   -66.02   -83.73   -64.09   -84.07   1.40E-05
 -69.12   -83.02   -65.65   -83.73   -66.02   -83.73   -69.51   -83.02   -67.62   -83.37   1.52E-05
 -72.48   -82.29   -69.12   -83.02   -69.51   -83.02   -72.89   -82.29   -71.05   -82.65   1.64E-05
 -75.75   -81.54   -72.48   -82.29   -72.89   -82.29   -76.17   -81.54   -74.36   -81.91   1.76E-05
```

Figure 3-4 Example of DIRFLUX_SC.OUT

3.2.1.5 IGLOOFLUX_SC.OUT

The IGLOOFLUX_SC.OUT is an intermediate output file used to derive all output files in a Spacecraft Assessment run. The file has 12 header lines with the data starting on line 13 (Figure 3-5). 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. The next 55 columns list the individual sub-population fluxes for the defined igloo element. (Note not all columns are shown in Figure 3-5). Each column name is listed as “*Flux_**XXYY***”, where ***XX*** is one of the five population density types abbreviated using two letters (previously listed in Table 3-3) and ***YY*** is the debris half-decade size bin code.

Table 3-3 Debris Half-Decade Size Bin Codes (2-Digit)

Code	Debris Size (Powers of 10)	Debris Size (meters)	Debris Size
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**

```
ORDEM 3.1   : ORDEM Debris flux through spacecraft 'igloo'.
 Igloo Debris Populations Flux in Bin (no./m^2/yr)
 Year: 2016  Elements:      744  Populations:  55  a =   7522.025  e =  0.000000  inc =   44.58
 *
 *
 *
 *
 *
 *
 *
Element  az_low    az_high   el_low    el_high   vel_low   vel_high       Flux_NK10      Flux_NK15      Flux_NK20      Flux_NK25
-------  --------  --------  --------  --------  --------  --------  -------------  -------------  -------------  -------------
      1  -180.000  180.000   -90.000   -75.000     0.000     2.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2  -180.000  180.000   -90.000   -75.000     2.000     4.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      3  -180.000  180.000   -90.000   -75.000     4.000     6.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      4  -180.000  180.000   -90.000   -75.000     6.000     8.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      5  -180.000  180.000   -90.000   -75.000     8.000    10.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      6  -180.000  180.000   -90.000   -75.000    10.000    12.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      7  -180.000  180.000   -90.000   -75.000    12.000    14.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      8  -180.000  180.000   -90.000   -75.000    14.000    16.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      9  -180.000  180.000   -90.000   -75.000    16.000    18.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     10  -180.000  180.000   -90.000   -75.000    18.000    20.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     11  -180.000  180.000   -90.000   -75.000    20.000    22.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     12  -180.000  180.000   -90.000   -75.000    22.000    23.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     13  -180.000  180.000    75.000    90.000     0.000     2.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     14  -180.000  180.000    75.000    90.000     2.000     4.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     15  -180.000  180.000    75.000    90.000     4.000     6.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     16  -180.000  180.000    75.000    90.000     6.000     8.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
```

Figure 3-5 Example of IGLOOFLUX_SC.OUT

3.2.1.6 IGLOOFLUX_SIGMAPOP_SC.OUT

The format of this file is the same as that of IGLOOFLUX_SC.OUT; however, the flux values are replaced by estimated population uncertainty value (Figure 3-6). The column names are also the same format as IGLOOFLUX_SC.OUT, except "*Flux_*" is replaced by "*Sig(pop)_*".

```
ORDEM 3.1    : ORDEM Population uncertainties of debris passing through spacecraft 'igloo'.
 Sigma(population) of Igloo Debris Populations Flux in Bin (1/m^2/yr)
 Year: 2016  Elements:      744  Populations:  55   a =    7522.025   e =  0.000000   inc =    44.58
 *
 *
 *
 *
 *
 *
 *
Element  az_low    az_high   el_low    el_high   vel_low   vel_high  Sig(pop)_NK10  Sig(pop)_NK15  Sig(pop)_NK20  Sig(pop)_NK25
-------  --------  --------  --------  --------  --------  --------  -------------  -------------  -------------  -------------
      1  -180.000   180.000   -90.000   -75.000     0.000     2.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2  -180.000   180.000   -90.000   -75.000     2.000     4.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      3  -180.000   180.000   -90.000   -75.000     4.000     6.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      4  -180.000   180.000   -90.000   -75.000     6.000     8.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      5  -180.000   180.000   -90.000   -75.000     8.000    10.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      6  -180.000   180.000   -90.000   -75.000    10.000    12.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      7  -180.000   180.000   -90.000   -75.000    12.000    14.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      8  -180.000   180.000   -90.000   -75.000    14.000    16.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      9  -180.000   180.000   -90.000   -75.000    16.000    18.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     10  -180.000   180.000   -90.000   -75.000    18.000    20.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     11  -180.000   180.000   -90.000   -75.000    20.000    22.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     12  -180.000   180.000   -90.000   -75.000    22.000    23.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     13  -180.000   180.000    75.000    90.000     0.000     2.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     14  -180.000   180.000    75.000    90.000     2.000     4.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     15  -180.000   180.000    75.000    90.000     4.000     6.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     16  -180.000   180.000    75.000    90.000     6.000     8.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
```

Figure 3-6 Example of IGLOOFLUX_SIGMAPOP_SC.OUT

3.2.1.7 IGLOOFLUX_SIGMARAN_SC.OUT

The format of this file is the same as that of IGLOOFLUX_SC.OUT; however, the flux values are replaced by estimated random uncertainty values (Figure 3-7). The column names are also the same format as IGLOOFLUX_SC.OUT, except "*Flux_*" is replaced by "*Sig(ran)_*".

```
ORDEM 3.1    : ORDEM Random (calculation) error in debris flux through spacecraft 'igloo'.
 Sigma(random) of Igloo Debris Populations Flux in Bin (1/m^2/yr)
 Year: 2016  Elements:      744  Populations:  55   a =    7522.025   e =  0.000000   inc =    44.58
 *
 *
 *
 *
 *
 *
 *
Element  az_low    az_high   el_low    el_high   vel_low   vel_high  Sig(ran)_NK10  Sig(ran)_NK15  Sig(ran)_NK20  Sig(ran)_NK25
-------  --------  --------  --------  --------  --------  --------  -------------  -------------  -------------  -------------
      1  -180.000   180.000   -90.000   -75.000     0.000     2.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2  -180.000   180.000   -90.000   -75.000     2.000     4.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      3  -180.000   180.000   -90.000   -75.000     4.000     6.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      4  -180.000   180.000   -90.000   -75.000     6.000     8.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      5  -180.000   180.000   -90.000   -75.000     8.000    10.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      6  -180.000   180.000   -90.000   -75.000    10.000    12.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      7  -180.000   180.000   -90.000   -75.000    12.000    14.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      8  -180.000   180.000   -90.000   -75.000    14.000    16.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      9  -180.000   180.000   -90.000   -75.000    16.000    18.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     10  -180.000   180.000   -90.000   -75.000    18.000    20.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     11  -180.000   180.000   -90.000   -75.000    20.000    22.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     12  -180.000   180.000   -90.000   -75.000    22.000    23.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     13  -180.000   180.000    75.000    90.000     0.000     2.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     14  -180.000   180.000    75.000    90.000     2.000     4.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     15  -180.000   180.000    75.000    90.000     4.000     6.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
     16  -180.000   180.000    75.000    90.000     6.000     8.000  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
```

Figure 3-7 Example of IGLOOFLUX_SIGMARAN_SC.OUT

3.2.2 Telescope/Radar Assessment

3.2.2.1 FLUX_TEL.OUT

This is the output file of the average cumulative flux as a function of particle size. It is used for used for generating the Telescope/Radar Assessment plot “Flux vs. Altitude” in the ORDEM 3.1 GUI. The file has 12 header lines, with the data starting on line 13 (Figure 3-8). 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 six size thresholds, as shown in the column headers.

```
ORDEM 3.1   :  ORDEM Telescope/Radar Mode
 Surface Area Debris Flux (#/m^2/yr)
  Year: 2016  Sensor lat. =  59.250  Pointing AZ = 147.860  Pointing EL =  20.010
  |****************************************************************|
  |                                                                |
  |                WARNING:  Sub-10 cm flux has not been           |
  |                validated above 2000 km.  See User's            |
  |                Guide Table 2-1 for information.                |
  |                                                                |
  |****************************************************************|
 Alt       Rng        >10um      >100um     >1mm       >1cm       >10cm      >1m
 --------  --------   --------   --------   --------   --------   --------   --------
    100.0     316.2   2.49E+02   1.79E-01   1.01E-04   4.61E-08   2.80E-09   1.04E-09
    150.0     442.7   2.49E+02   1.79E-01   1.01E-04   4.61E-08   2.80E-09   1.04E-09
    150.0     442.7   3.22E+02   2.36E-01   2.59E-04   1.33E-07   7.88E-09   3.86E-09
    200.0     564.2   3.22E+02   2.36E-01   2.59E-04   1.33E-07   7.88E-09   3.86E-09
    200.0     564.2   3.82E+02   3.80E-01   7.06E-04   3.08E-07   2.01E-08   1.08E-08
    250.0     681.5   3.82E+02   3.80E-01   7.06E-04   3.08E-07   2.01E-08   1.08E-08
    250.0     681.5   4.60E+02   6.51E-01   1.14E-03   4.57E-07   3.57E-08   1.56E-08
    300.0     795.0   4.60E+02   6.51E-01   1.14E-03   4.57E-07   3.57E-08   1.56E-08
    300.0     795.0   6.61E+02   1.14E+00   2.11E-03   6.59E-07   5.89E-08   2.67E-08
    350.0     905.2   6.61E+02   1.14E+00   2.11E-03   6.59E-07   5.89E-08   2.67E-08
    350.0     905.2   1.23E+03   2.00E+00   4.15E-03   1.05E-06   1.16E-07   6.09E-08
    400.0    1012.4   1.23E+03   2.00E+00   4.15E-03   1.05E-06   1.16E-07   6.09E-08
    400.0    1012.4   2.29E+03   3.90E+00   7.99E-03   1.90E-06   1.88E-07   8.20E-08
    450.0    1116.8   2.29E+03   3.90E+00   7.99E-03   1.90E-06   1.88E-07   8.20E-08
    450.0    1116.8   3.21E+03   7.15E+00   1.52E-02   3.76E-06   4.06E-07   1.77E-07
    500.0    1218.8   3.21E+03   7.15E+00   1.52E-02   3.76E-06   4.06E-07   1.77E-07
    500.0    1218.8   4.43E+03   1.33E+01   2.76E-02   6.68E-06   7.01E-07   3.10E-07
    550.0    1318.5   4.43E+03   1.33E+01   2.76E-02   6.68E-06   7.01E-07   3.10E-07
    550.0    1318.5   5.73E+03   2.33E+01   4.61E-02   1.03E-05   9.11E-07   3.63E-07
    600.0    1416.2   5.73E+03   2.33E+01   4.61E-02   1.03E-05   9.11E-07   3.63E-07
    600.0    1416.2   6.93E+03   3.88E+01   7.32E-02   1.52E-05   1.23E-06   4.58E-07
    650.0    1512.0   6.93E+03   3.88E+01   7.32E-02   1.52E-05   1.23E-06   4.58E-07
    650.0    1512.0   8.04E+03   5.97E+01   1.15E-01   2.12E-05   1.49E-06   3.39E-07
    700.0    1606.0   8.04E+03   5.97E+01   1.15E-01   2.12E-05   1.49E-06   3.39E-07
```

Figure 3-8 Example of FLUX_TEL.OUT

3.2.2.2 IGLOOFLUX_TEL.OUT

The IGLOOFLUX_TEL.OUT is an intermediate output file used to derive all output files in a Telescope/Radar Assessment run. The file has 12 header lines with the data starting on line 13 (Figure 3-9). 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 are identical to those defined in Section 3.2.1.5.

```
 ORDEM 3.1   - ORDEM Debris flux through telescope/radar 'igloo'.
 Igloo Debris Populations Flux in Bin (no./m^2/yr)
 Year: 2016  Elements:      798  Populations:  55  Sensor lat. =  42.600  Pointing AZ =  90.000  Pointing EL =  75.000
  |*******************************************************************|
  |                                                                   |
  |              WARNING:  Sub-10 cm flux has not been                |
  |              validated above 2000 km.  See User's                 |
  |              Guide Table 2-1 for information.                     |
  |                                                                   |
  |*******************************************************************|
Element  alt_low    alt_high   rng_low    rng_high   Flux_NK10      Flux_NK15      Flux_NK20      Flux_NK25      Flux_NK30
-------  ---------  ---------  ---------  ---------  -------------  -------------  -------------  -------------  -------------
      1    100.000    150.000    113.556    165.244  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2    150.000    200.000    165.244    216.906  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      3    200.000    250.000    216.906    268.540  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      4    250.000    300.000    268.540    320.149  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      5    300.000    350.000    320.149    371.734  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      6    350.000    400.000    371.734    423.293  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      7    400.000    450.000    423.293    474.829  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      8    450.000    500.000    474.829    526.341  1.1186804E-06  1.1186804E-06  1.1186804E-06  1.1186804E-06  1.1186804E-06
      9    500.000    550.000    526.341    577.831  3.9722252E-06  3.9722252E-06  3.9722252E-06  3.9722252E-06  3.9722252E-06
     10    550.000    600.000    577.831    629.298  3.3898468E-06  3.3898468E-06  3.3898468E-06  3.3898468E-06  3.3898468E-06
     11    600.000    650.000    629.298    680.743  8.9543565E-06  8.9543565E-06  8.9543565E-06  8.9543565E-06  8.9543565E-06
     12    650.000    700.000    680.743    732.168  1.7098312E-05  1.7098312E-05  1.7098312E-05  1.7098312E-05  1.7098312E-05
     13    700.000    750.000    732.168    783.571  3.3786088E-05  3.3786088E-05  3.3786088E-05  3.3786088E-05  3.3786088E-05
     14    750.000    800.000    783.571    834.954  6.4970818E-05  6.4970818E-05  6.4970818E-05  6.4970818E-05  6.4970818E-05
     15    800.000    850.000    834.954    886.317  1.2099673E-04  1.2099673E-04  1.2099673E-04  1.2099673E-04  1.2099673E-04
     16    850.000    900.000    886.317    937.660  1.8844832E-04  1.8844832E-04  1.8844832E-04  1.8844832E-04  1.8844832E-04
```

Figure 3-9 Example of IGLOOFLUX_TEL.OUT

3.2.2.3 IGLOOFLUX_SIGMAPOP_TEL.OUT

The format of this file is the same as that of IGLOOFLUX_TEL.OUT; however, the flux values are replaced by estimated population uncertainty values (Figure 3-10). The column names are also the same format as IGLOOFLUX_TEL.OUT, except "*Flux_*" is replaced by "*Sig(pop)_*".

```
 ORDEM 3.1   - ORDEM Population uncertainties of debris passing through telescope/radar 'igloo'.
 Sigma(population) of Igloo Debris Populations Flux in Bin (1/m^2/yr)
 Year: 2016  Elements:      798  Populations:  55  Sensor lat. =  42.600  Pointing AZ =  90.000  Pointing EL =  75.000
  |*****************************************************************|
  |                                                                 |
  |              WARNING:  Sub-10 cm flux has not been              |
  |              validated above 2000 km.  See User's               |
  |              Guide Table 2-1 for information.                   |
  |                                                                 |
  |*****************************************************************|
Element  alt_low    alt_high   rng_low    rng_high   Sig(pop)_NK10  Sig(pop)_NK15  Sig(pop)_NK20  Sig(pop)_NK25  Sig(pop)_NK30
-------  ---------  ---------  ---------  ---------  -------------  -------------  -------------  -------------  -------------
      1    100.000    150.000    113.556    165.244  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2    150.000    200.000    165.244    216.906  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      3    200.000    250.000    216.906    268.540  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      4    250.000    300.000    268.540    320.149  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      5    300.000    350.000    320.149    371.734  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      6    350.000    400.000    371.734    423.293  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      7    400.000    450.000    423.293    474.829  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      8    450.000    500.000    474.829    526.341  7.9365836E-07  7.9365836E-07  7.9365836E-07  7.9365836E-07  7.9365836E-07
      9    500.000    550.000    526.341    577.831  1.8093951E-06  1.8093951E-06  1.8093951E-06  1.8093951E-06  1.8093951E-06
     10    550.000    600.000    577.831    629.298  1.6127642E-06  1.6127642E-06  1.6127642E-06  1.6127642E-06  1.6127642E-06
     11    600.000    650.000    629.298    680.743  2.4475498E-06  2.4475498E-06  2.4475498E-06  2.4475498E-06  2.4475498E-06
     12    650.000    700.000    680.743    732.168  3.3369573E-06  3.3369573E-06  3.3369573E-06  3.3369573E-06  3.3369573E-06
     13    700.000    750.000    732.168    783.571  4.4831876E-06  4.4831876E-06  4.4831876E-06  4.4831876E-06  4.4831876E-06
     14    750.000    800.000    783.571    834.954  6.0319801E-06  6.0319801E-06  6.0319801E-06  6.0319801E-06  6.0319801E-06
     15    800.000    850.000    834.954    886.317  7.9727785E-06  7.9727785E-06  7.9727785E-06  7.9727785E-06  7.9727785E-06
     16    850.000    900.000    886.317    937.660  9.7614104E-06  9.7614104E-06  9.7614104E-06  9.7614104E-06  9.7614104E-06
```

Figure 3-10 Example of IGLOOFLUX_SIGMAPOP_TEL.OUT

3.2.2.4 IGLOOFLUX_SIGMARAN_TEL.OUT

The format of this file is the same as that of IGLOOFLUX_TEL.OUT; however, the flux values are replaced by estimated random uncertainty values (Figure 3-11).The column names are also the same format as IGLOOFLUX_TEL.OUT, except "*Flux_*" is replaced by "*Sig(ran)_*".

```
 ORDEM 3.1   - ORDEM Random (calculation) error in debris flux through telescope/radar 'igloo'.
 Sigma(random) of Igloo Debris Populations Flux in Bin (1/m^2/yr)
 Year: 2016  Elements:      798  Populations:  55  Sensor lat. =  42.600  Pointing AZ =  90.000  Pointing EL =  75.000
  |*****************************************************************|
  |                                                                 |
  |              WARNING:  Sub-10 cm flux has not been              |
  |              validated above 2000 km.  See User's               |
  |              Guide Table 2-1 for information.                   |
  |                                                                 |
  |*****************************************************************|
Element  alt_low    alt_high   rng_low    rng_high   Sig(ran)_NK10  Sig(ran)_NK15  Sig(ran)_NK20  Sig(ran)_NK25  Sig(ran)_NK30
-------  ---------  ---------  ---------  ---------  -------------  -------------  -------------  -------------  -------------
      1    100.000    150.000    113.556    165.244  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      2    150.000    200.000    165.244    216.906  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      3    200.000    250.000    216.906    268.540  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      4    250.000    300.000    268.540    320.149  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      5    300.000    350.000    320.149    371.734  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      6    350.000    400.000    371.734    423.293  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      7    400.000    450.000    423.293    474.829  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
      8    450.000    500.000    474.829    526.341  1.3983286E-07  1.3983286E-07  1.3983286E-07  1.3983286E-07  1.3983286E-07
      9    500.000    550.000    526.341    577.831  3.8736123E-07  3.8736123E-07  3.8736123E-07  3.8736123E-07  3.8736123E-07
     10    550.000    600.000    577.831    629.298  3.1106198E-07  3.1106198E-07  3.1106198E-07  3.1106198E-07  3.1106198E-07
     11    600.000    650.000    629.298    680.743  8.1335413E-07  8.1335413E-07  8.1335413E-07  8.1335413E-07  8.1335413E-07
     12    650.000    700.000    680.743    732.168  1.6152627E-06  1.6152627E-06  1.6152627E-06  1.6152627E-06  1.6152627E-06
     13    700.000    750.000    732.168    783.571  3.1389748E-06  3.1389748E-06  3.1389748E-06  3.1389748E-06  3.1389748E-06
     14    750.000    800.000    783.571    834.954  6.4368581E-06  6.4368581E-06  6.4368581E-06  6.4368581E-06  6.4368581E-06
     15    800.000    850.000    834.954    886.317  1.1034195E-05  1.1034195E-05  1.1034195E-05  1.1034195E-05  1.1034195E-05
     16    850.000    900.000    886.317    937.660  1.7800609E-05  1.7800609E-05  1.7800609E-05  1.7800609E-05  1.7800609E-05
```

Figure 3-11 Example of IGLOOFLUX_SIGMARAN_TEL.OUT

3.3 Managing the Uncertainty Files

The ORDEM 3.1 output produces three files that capture the computations of the flux for each igloo or bore-sight vector bin. The first file, IGLOOFLUX_*_.OUT, includes a table of the flux values, grouped by size, material density, and igloo or bore-sight vector element. The other two files, IGLOOFLUX_SIGMARAN_*.OUT and IGLOOFLUX_SIGMAPOP_*.OUT, represent the flux error estimates. 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

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

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

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

4 ORDEM 3.1 GRAPHS

The ORDEM 3.1 GUI uses TeeChart charting library (Steema 2019) to display and manipulate graphs of the output data. TeeChart.NET is a standard graphical software product licensed from Steema Software for distribution with ORDEM 3.1. 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 (Figure 4-1) provides the following functions:

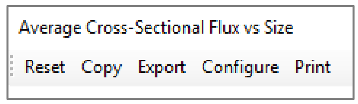

Figure 4-1 Graph Options Menu

- ***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.
- ***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.
- ***Export*** – selecting this button presents the user with a dialog (Figure 4-2) containing a number of image format choices for exporting, such as JPEG, etc.

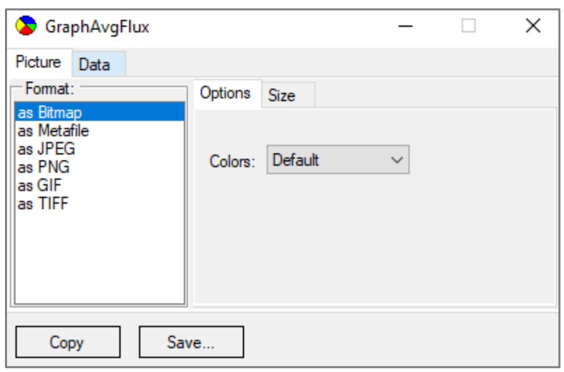

Figure 4-2 Graph Export Dialog Window

- ***Configure*** – selecting this option presents a graph editor window (Figure 4-3) 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:

  a) ***Chart*** provides options for altering the graph's appearance. Options from legend titles, background color, axis labels, and line styles may be found here.
  b) ***Series*** provides options with respect to the plotted data. Here may be found opportunities to alter the appearance of line and plotted points.
  c) ***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.
  d) ***Print*** provides additional functionality in printing the graph to the user's available printers.
  e) ***Export*** provides the ability to export the selected graph to a variety of file formats, as well as some other limited features such as resizing the image.
  f) ***Tools*** provides miscellaneous tools for manipulating the graph.
  g) ***Themes*** provides a set of pre-set themes that the user may select.

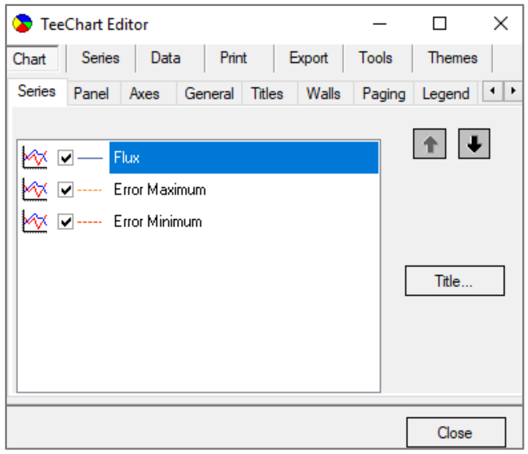

Figure 4-3 Graph Configuration Dialog Window

- ***Print*** – choosing this button causes a print preview window to be displayed (Figure 4-4). The user will be able to make page or format changes before sending the graph to the printer. The user can then select the print button when ready.

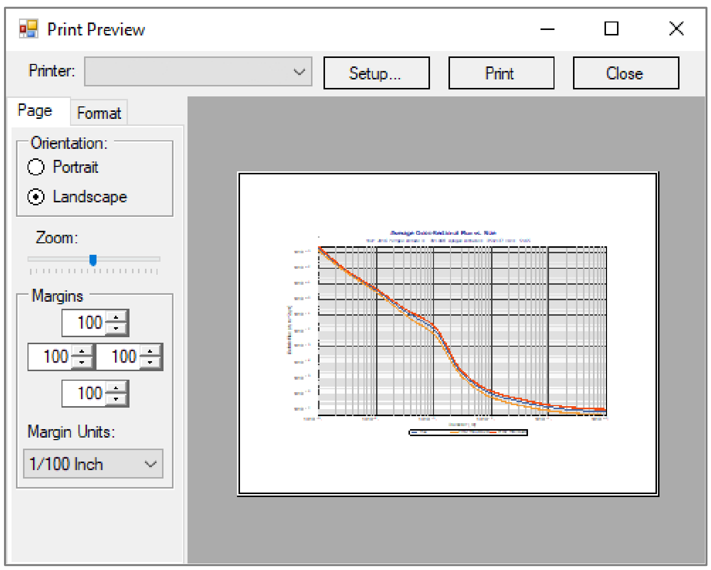

Figure 4-4 Graph Print Preview Window

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.

4.1 Spacecraft Mode Graphs

After completing a computation, clicking the *Graphs…* button in the Spacecraft Assessment window initiates a new window (Figure 4-5) from which a different graphical output is generated.

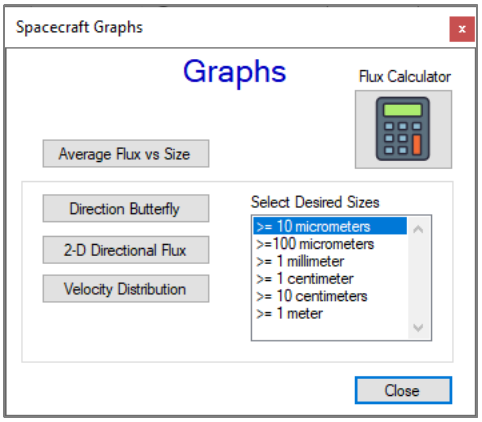

Figure 4-5 Spacecraft Assessment Graphs Selection Window

An example of the ***Average Flux vs. Size*** along the chosen spacecraft orbit is shown in Figure 4-6. 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 European Space Agency Meteoroid and Space Debris Terrestrial Environment Reference (MASTER) series (Oswald 2006). The graph has a key that differentiates the flux from both the minimum and maximum margin of error (i.e., lower and upper one sigma uncertainties).

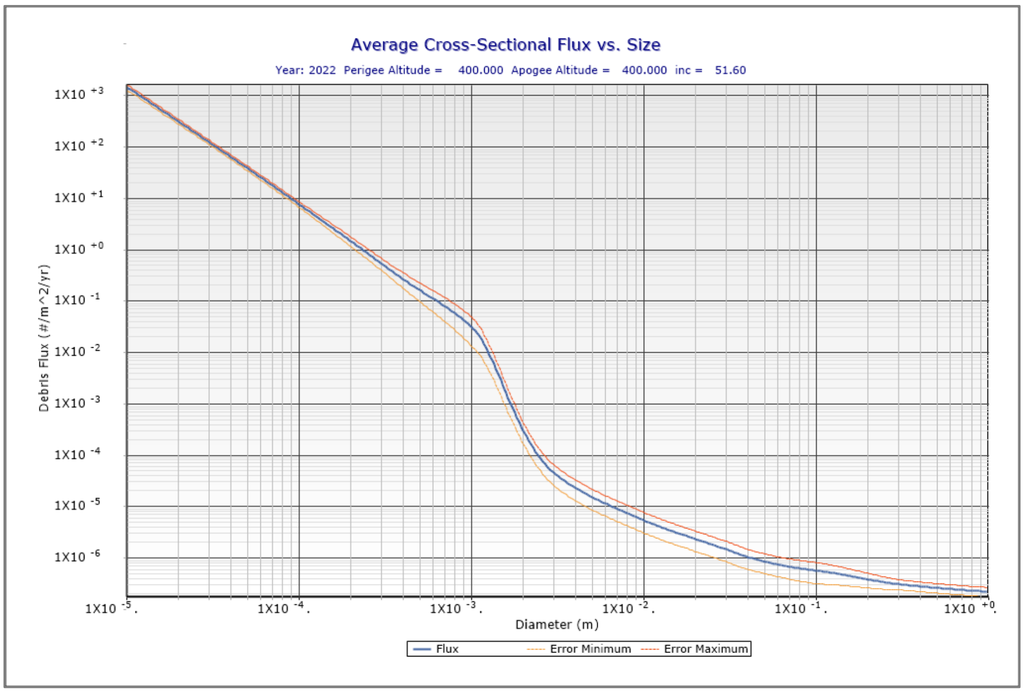

Figure 4-6 Spacecraft Assessment Average Flux vs. Size Graph

Given the proved utility of this type of graph and underlying data, a flux calculator is also included as an option associated with the Spacecraft assessment graphs that may be accessed by clicking the  button (Figure 4-7). This function calculates flux given a particle size value and a chosen uncertainty of up to three standard deviations (i.e., 3 sigma, 3σ). Debris size and sigma values can be edited either using the number pad in the Flux Calculator window or through direct keyboard input.

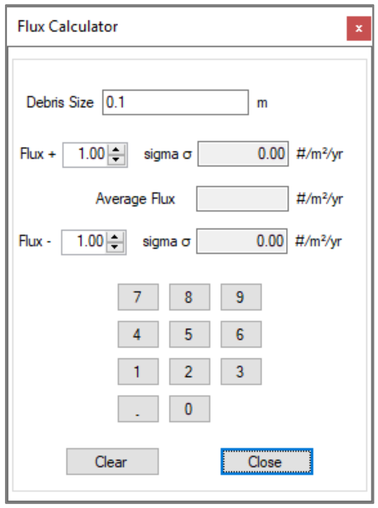

Figure 4-7 Spacecraft Assessment Flux Calculator

Two ***Direction Butterfly*** graphs, “Skyline” and “Butterfly,” are available, accessible from tabs toward the upper left of the main ***Direction Butterfly*** graph window. Examples of the “Skyline” and “Butterfly” graphs are presented in Figure 4-8 and Figure 4-9, respectively. 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 Distribution*** graph, displaying the velocity flux distribution on the spacecraft, is shown in Figure 4-10.

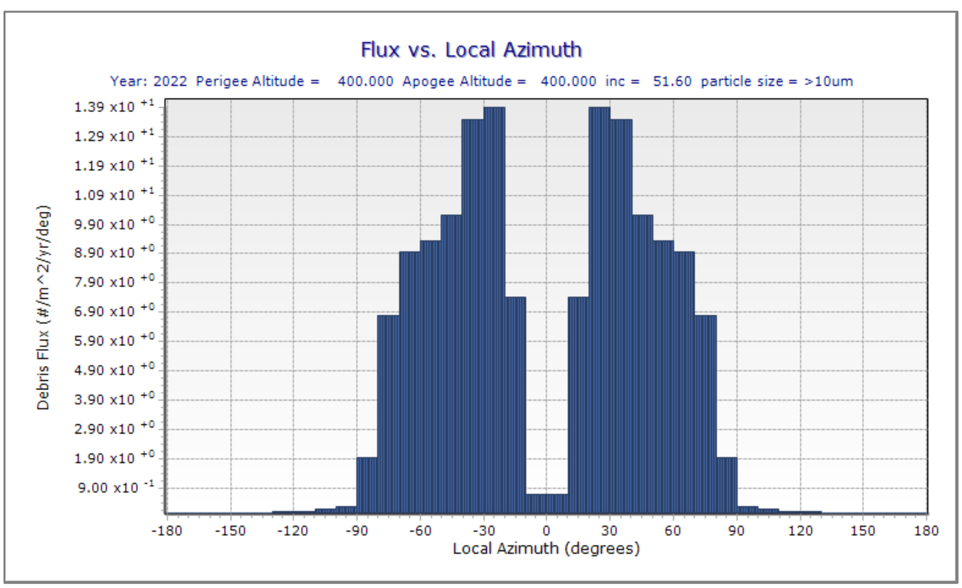

Figure 4-8 Spacecraft Assessment Skyline Butterfly Graph

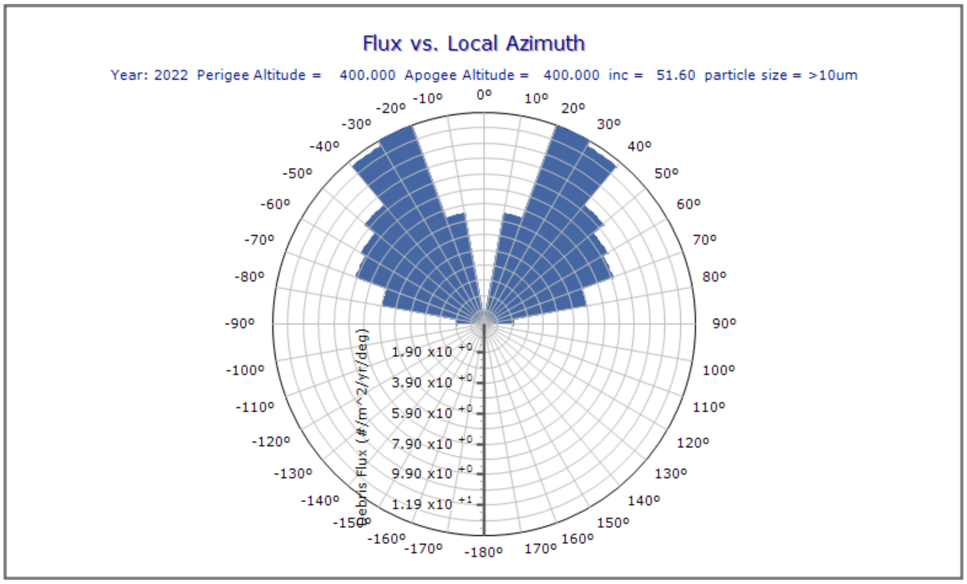

Figure 4-9 Spacecraft Assessment Radial Butterfly Graph

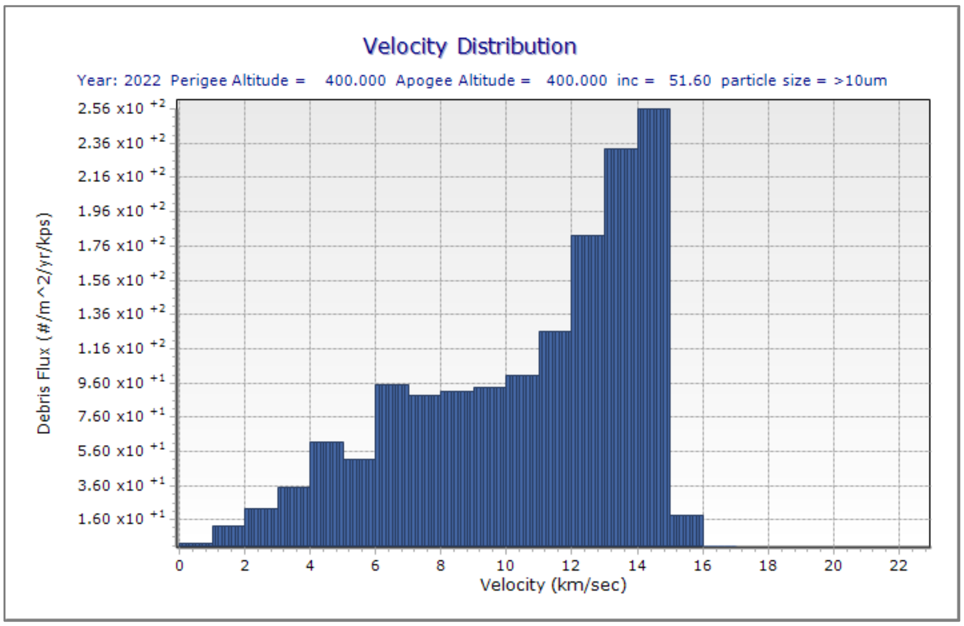

Figure 4-10 Spacecraft Assessment Velocity Flux Distribution

The average flux on the spacecraft is fully realized in the mapped ***2-D Directional Flux*** projection in Figure 4-11. Direction relative to the spacecraft is noted in coordinates (local azimuth and local elevation) where azimuth runs along the horizontal from left to right (with respect to the spacecraft velocity-vector (ram) direction) and ranges from -180° to 180° and elevation runs vertically from bottom to top and ranges from -90° to 90°.

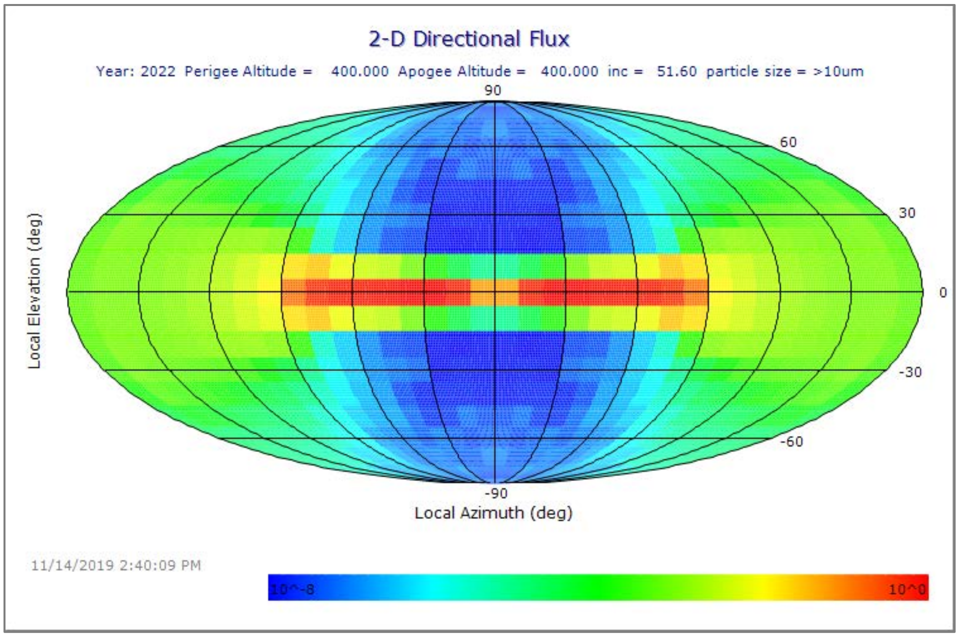

Figure 4-11 Spacecraft Assessment 2-D Directional Flux Projection

Another way to understand the reference frame used in this projection is illustrated in Figure 4-12, which shows a sample 2-D directional flux (from a separate ORDEM run) projected on a sphere encompassing a spacecraft. In this representation, for ease of viewing, the local azimuth runs from -90° to 90°, and the local elevation runs from -XX° to XX°. The velocity vector ($\vec{v}$), position vector ($\vec{r}$), and the angular momentum vector ($\vec{u}$) are shown. Note that the spacecraft travels along the velocity vector in a NTW coordinate frame (Vallado 1997).

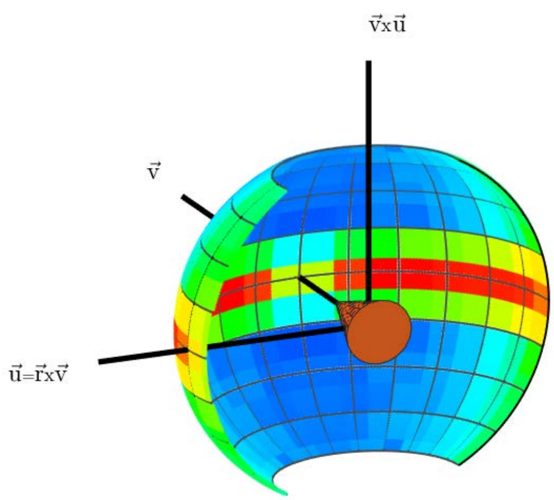

Figure 4-12 Two-dimensional directional flux projected on sphere encompassing spacecraft

4.2 Telescope/Radar Mode Graph

After completing a computation, clicking the *Graphs…* button in the Telescope/Radar Assessment window initiates a new window (Figure 4-13) from which a different graphical output is generated.

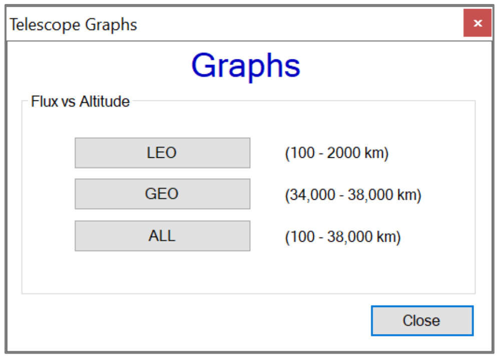

Figure 4-13 Telescope/Radar Assessment Graph Selection Window

Two examples of ***Flux vs. Altitude*** graphs are displayed for LEO altitudes (Figure 4-14) and GEO altitudes (Figure 4-15), while Figure 4-16 shows a combined graph for both LEO and GEO cases. These figures represent the surface area flux at specific sizes over altitude ranges in the Telescope/Radar mode. The flux curves below 10 cm represent GTO objects at GEO altitudes.

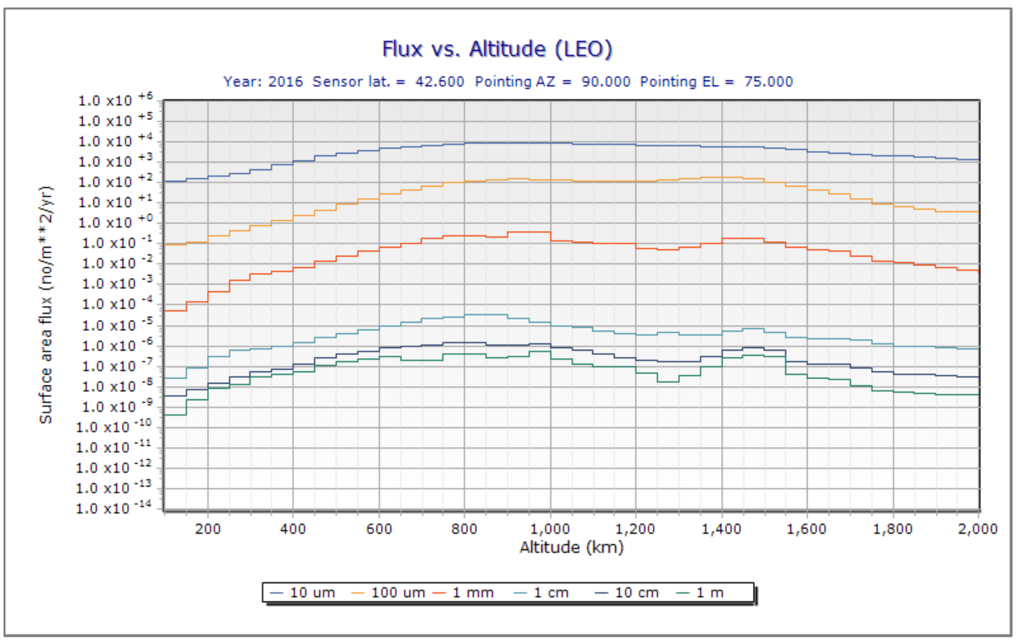

Figure 4-14 Telescope/Radar Assessment Flux vs. Altitude Graph, LEO Region-Only

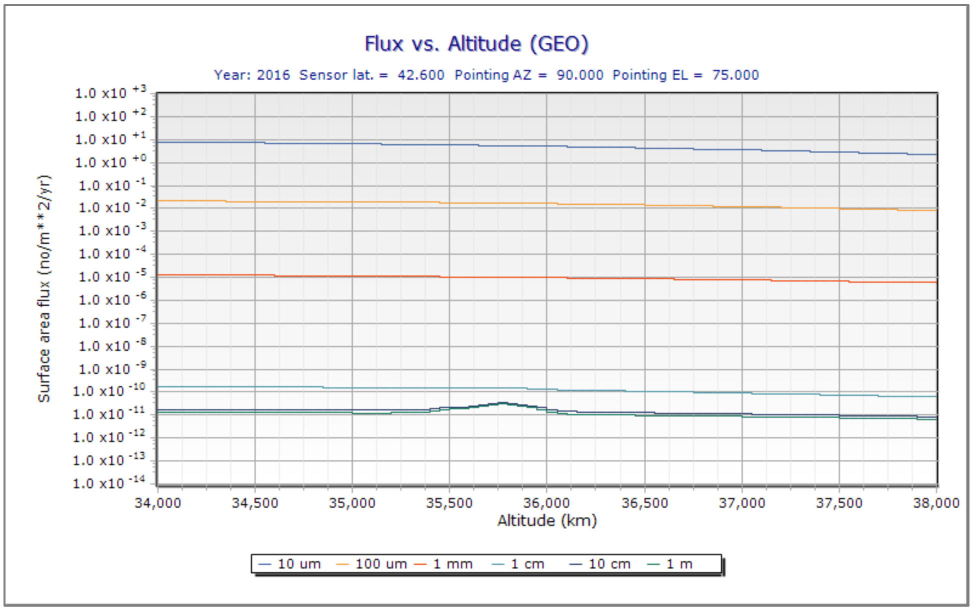

Figure 4-15 Telescope/Radar Assessment Flux vs. Altitude Graph, GEO Region-Only

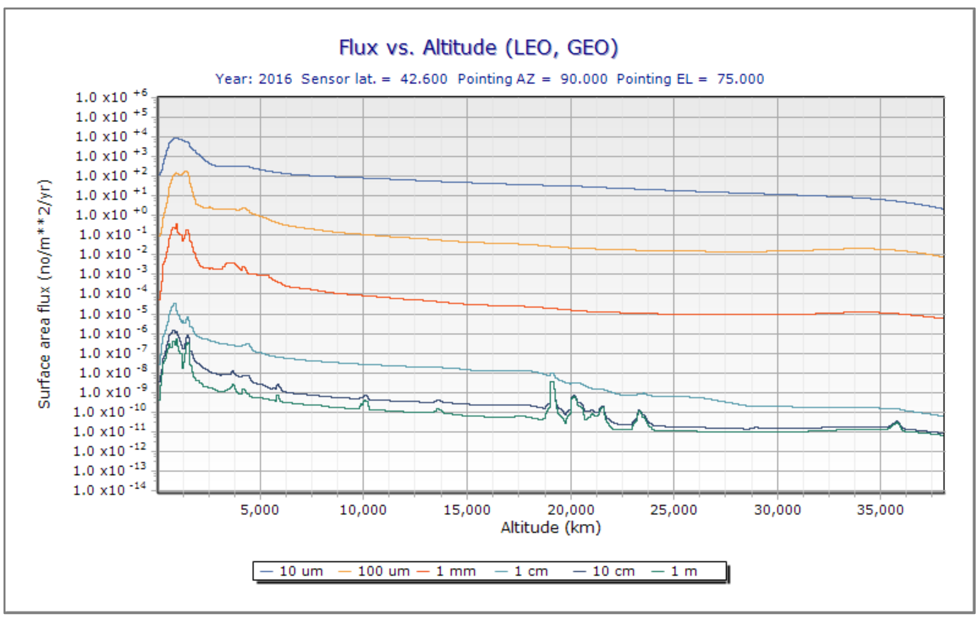

Figure 4-16 Telescope/Radar Assessment Flux vs. Altitude Graph, LEO and GEO

5 ORDEM 3.1 RUNTIME ESTIMATES

All runs listed in this section used the ORDEM 3.1 GUI on a Windows 10 64-bit operating system, consisting of an Intel i5 core and 8GB of random-access memory (RAM).

5.1 Spacecraft Assessment

ORDEM 3.1 runtime estimates depend heavily on the user-chosen encounter igloo dimensions and the orbit being assessed, as shown in Table 5-1. 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 uncertainty 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.

Table 5-1 Spacecraft Assessment Runtime Estimates (H:MM:SS format)

Orbit	Year	Perigee (km)	Apogee (km)	i (°)	Random ω (°), Ω (°)	Fixed ω (°), Ω (°)
ISS	2016	400.00	400.00	51.6	0:00:50	0:00:56
GTO	2016	353.095	33774.28	27.2269	1:27:56	1:17:14
MOLNIYA	2022	1764.275	38591.13	64.8345	1:08:13	0:43:34
GEO	2020	35785.77	35786.89	0.031	0:07:30	0:07:59

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°x10°x1 km/s, runtime performance of the ORDEM 3.1 model should generally be between 1 minute and 2 hours. 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 GEO objects, it is possible for the model to take over 6 hours on a modestly equipped PC. These runtimes would generally decrease when the 30°x30°x2 km/s igloo is used.

5.2 Telescope/Radar Assessment

The runtime performance of the Telescope/Radar mode is also dependent on the binned population space examined. However, in general, the runtimes are easier to predict (Table 5-2). For a given latitude of the sensor, the runtime is dependent on the pointing direction (i.e., bore-sight vector). Runtime varies 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.

Table 5-2 Telescope/Radar Runtime Estimates (H:MM:SS format)

Sensor	Year	Latitude (°)	Azimuth (°)	Elevation (°)	Runtime
HAY75E	2016	42.6	90	75	0:37:12
ASCENSION	2020	-7	0	80	6:05:17
HAY20S	2018	42.6	180	20	0:56:11

For instance, if a Telescope/Radar is located at a latitude of 42.6° 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. The runtimes observed used a segmented bore-sight vector graduated in 50 km increments in altitude from LEO to GEO (ALT_50.TIG). The user will notice shorter runtimes if the 100 km (ALT_100.TIG) gradation is chosen instead.

6 REFERENCES

Hyde, J.L., E.L. Christiansen, D.M. Lear, *et al*. “Overview of Recent Enhancements to the BUMPER-II Meteoroid & Orbital Debris Risk Assessment Tool,” IAC-06-B6.3.03. Available at https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20060047566.pdf. Accessed 26 October 2019

Liou, J.-C., *et al.* 2002. *The New NASA Orbital Debris Engineering Model ORDEM2000*. NASA/TP-2002-210780.

Liou, J.-C., Hall, D. T., Krisko, P. H., and Opiela, J. N. 2005. LEGEND – A Three-Dimensional LEO-to-GEO Debris Evolutionary Model, *Adv. Space Res*., Vol. 34, pp. 981-986.

Liou, J.-C., *et al.* 2019. *Debris Assessment Software User’s Guide: Version 3.0.* NASA/TP-2019-220300.

Moorhead, A.V, Koehler, H.M., and Cooke, W.J. 2015. “NASA Meteoroid Engineering Model Release 2.0.” NASA/TM-2015-218214, October 2015

Oswald, M., *et al.* 2006. Upgrade of the MASTER Model, included in the MASTER-2005 package.

Sdunnus, H., *et al.* 2001. *The ESA MASTER’99 Space Debris and Meteoroid Reference Model*, Proceedings of the 3rd European Space Debris Conference, ESA SP-473.

Stansbery, E., et al. "NASA Orbital Debris Engineering Model ORDEM 3.0 - User’s Guide." NASA/TP-2014-217370, 2014.

Steema Software SL. "Steema Software Company Page", www.steema.com. Retrieved 11 January 2019.

Vallado, D., 2013. Fundamentals of Astrodynamics and Applications, 4th ed. Space Technology Library, pp.44-45.

7 TROUBLESHOOTING

Contact the NASA Orbital Debris Program Office at http://orbitaldebris.jsc.nasa.gov/ or the ODPO Point of Contact if any issues occur while running the ORDEM 3.1 software.

7.1 Frequently Asked Questions

"Can I open an ORDEM 3.0 project in the ORDEM 3.1 GUI?"

- Yes. The ORDEM 3.1 GUI, as well as the computational model executable, is backwards compatible with ORDEM 3.0 projects.

"Can I install ORDEM 3.1 on the same Windows machine as ORDEM 3.0?"

- Yes. However, because ORDEM 3.0 is considered legacy software, it is recommended to uninstall ORDEM 3.0 before installing ORDEM 3.1.

"How do I obtain the ORDEM 3.1 installer?"

- Obtain the software through the NASA Software Catalog (https://software.nasa.gov/) and agree to the terms in the Software Usage Agreement (SUA). If the user does not accept the terms and conditions of the SUA, the user should not download, install, or use the software.
- Please contact the NASA Orbital Debris Program Office for any concerns about the SUA.

"How do I know ORDEM 3.1 installed correctly?"

- See Section 2.2.2 for installation instructions.
- Verify that the installer added the environment variable *ORDEM31DATA*. Right-click on **This PC** (or **My Computer** on Windows 7), then select **Properties → Advanced System Settings → Environment Variables**. In the System Variables window, select the *ORDEM31DATA* option in the System Variables list and click the "Edit" button. It should contain the "data" folder from the installation directory that was specified by the ORDEM 3.1 installer. If not, the user needs to reinstall the ORDEM 3.1 software.
- Verify that the installer added the "NASA\ORDEM 3.1\model" directory to the PATH environment variable. To verify PATH, right-click on **This PC** (or **My Computer** on Windows 7), 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. If the NASA\ORDEM 3.1\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-ORDEM3.1>\NASA\ORDEM 3.1\model;%PATH%
```

"My ORDEM run exited unexpectedly."

- See Section 7.2 for more information on ORDEM 3.1 error codes and their meaning.
- If the error code is not listed, please contact the NASA Orbital Debris Program Office and provide the following: name, department, email address, hardware specifications (specifically number of processors and memory), a detailed description of the issue, and/or screenshots of the displayed error message.

"How do I save my project to an ORDEM.IN file?"

- This file is automatically created when the user clicks on the Start button on the Spacecraft or Telescope/Radar Assessment window.
- The user can also generate the ORDEM.IN file with the CTRL+S keyboard shortcut in the Spacecraft or Telescope/Radar Assessment window.

"Why is my ORDEM run taking so long?"

- Depending on user inputs, the ORDEM 3.1 runtimes will vary from approximately 1 minute (for low LEO circular orbits) to over 6 hours (for high apogee GTO orbits). See Section 5 for runtime estimates for specific input parameters. A faster central processing unit (CPU) will reduce runtime, but the computational method cannot take advantage of multiple CPUs/cores.

"Can I install ORDEM 3.1 software for *All Users* on my workstation?"

- The ORDEM 3.1 software is installed locally in the current user's profile. There is no option to install ORDEM 3.1 for all users.

"ORDEM did not write any output files to my project directory."

- The user-specified folder might be write-protected. The user should check to see if they have write permissions to the folder.

7.2 Error Code Messages

Table 7-1 lists the message codes that may appear in the ORDEM 3.1 output. These codes are useful when diagnosing or reporting errors.

Table 7-1 Error Code 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

Code	Message ID	Description
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
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

Code	Message ID	Description
63	sc_calcs_GEO_MM_read	Cannot read GEO mean motion bin definition file
64	sc_calcs_sobol	General Sobol failure
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
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

Code	Message ID	Description
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

7.3 GUI Dialog Boxes

This section references the error/warning dialog boxes that can display during the execution of the ORDEM 3.1 GUI.

7.3.1 *Dialog Boxes in Main Window*

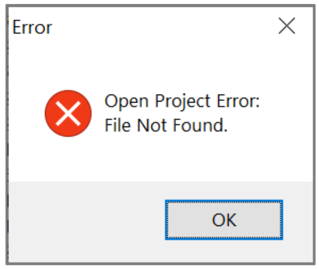

Figure 7-1 Open Project Error

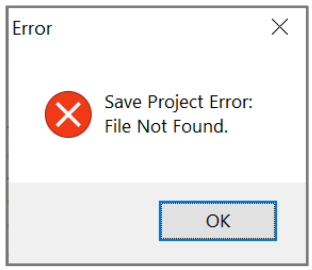

Figure 7-2 Save Project Error

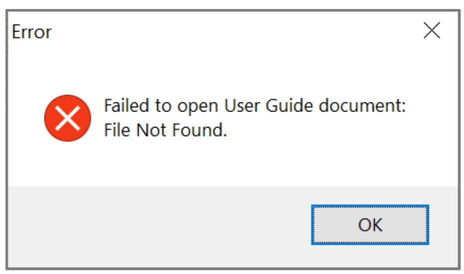

Figure 7-3 Open User Guide Error

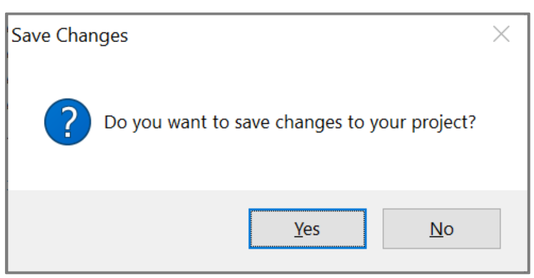

Figure 7-4 Save Changes Confirmation

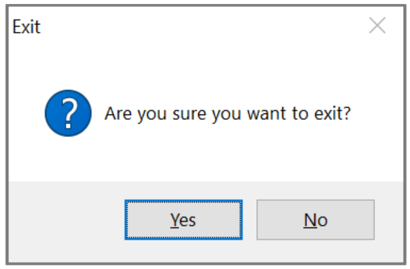

Figure 7-5 Exit Confirmation

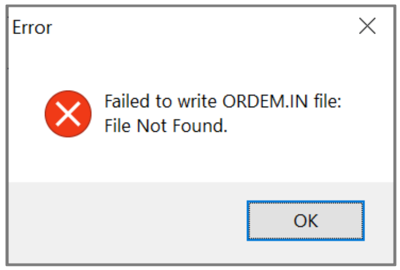

Figure 7-6 Failed to write ORDEM.IN Error

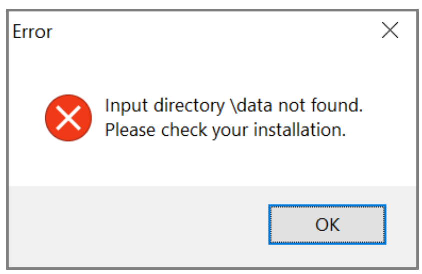

Figure 7-7 Directory DATA Not Found Error

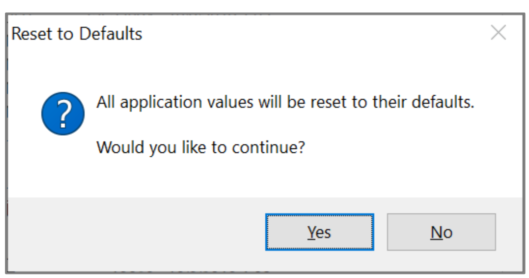

Figure 7-8 Reset to Defaults Confirmation

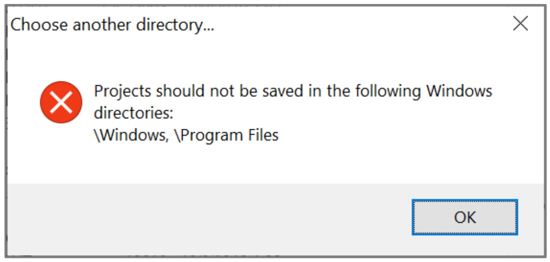

Figure 7-9 Choose another Directory Error

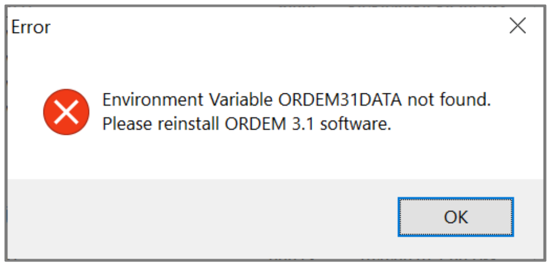

Figure 7-10 ORDEM31DATA Not Found Error

7.3.2 Dialog Boxes in TLE Window

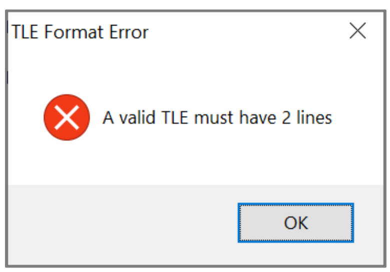

Figure 7-11 TLE Format, Number of Lines Error

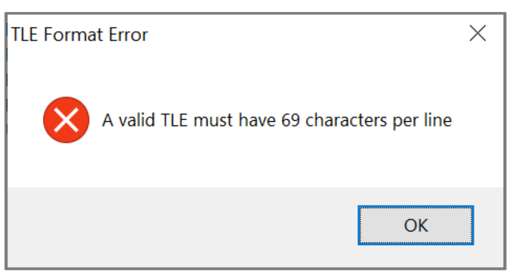

Figure 7-12 TLE Format, Line Length Error

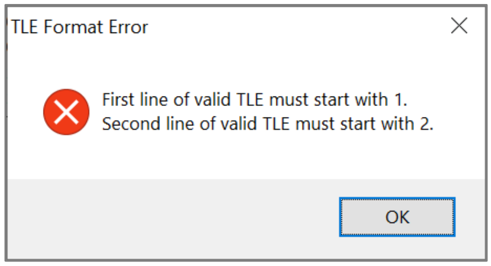

Figure 7-13 TLE Format, First Character Error

7.3.3 Dialog Boxes in Flux Calculator Window

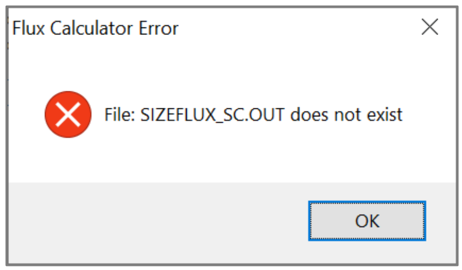

Figure 7-14 SIZEFLUX_SC.OUT Not Found Error

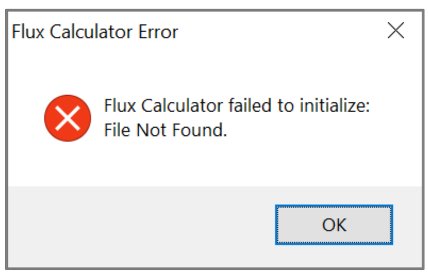

Figure 7-15 File Not Found Error

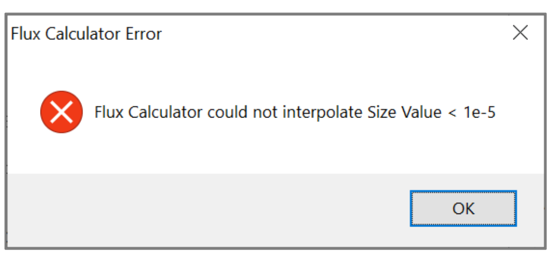

Figure 7-16 Interpolate Size Value Error

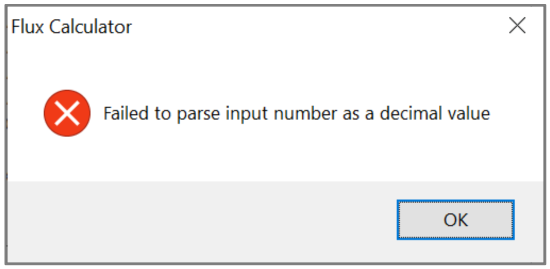

Figure 7-17 Input number Error

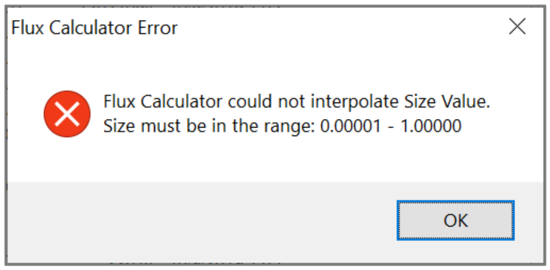

Figure 7-18 Flux Size out of range Error

7.3.4 Dialog Boxes in Spacecraft Assessment Window

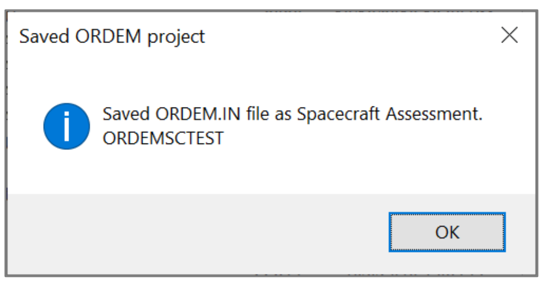

Figure 7-19 Saved ORDEM.IN file, Spacecraft Assessment

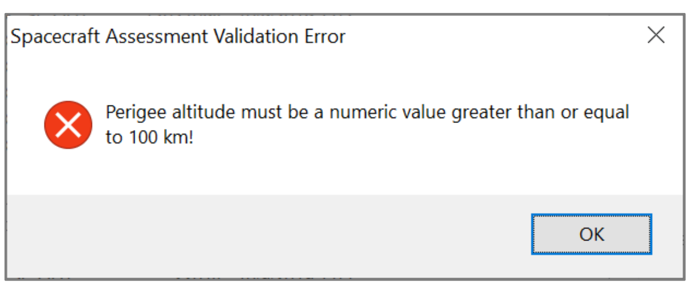

Figure 7-20 Low Perigee Error

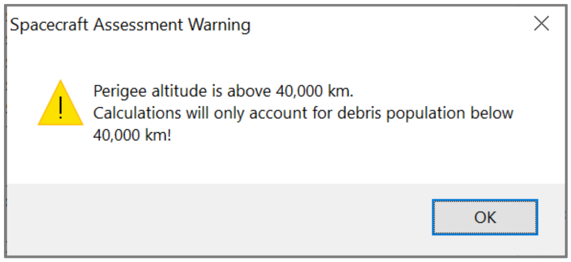

Figure 7-21 High Perigee Warning

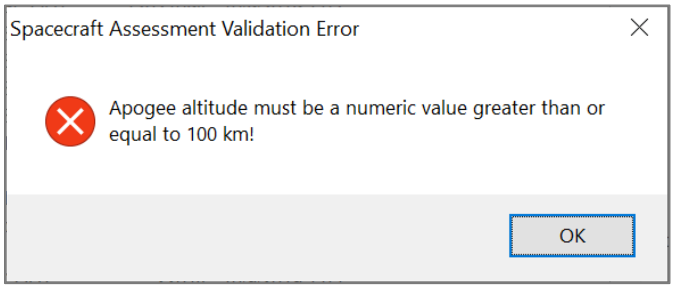

Figure 7-22 Low Apogee Error

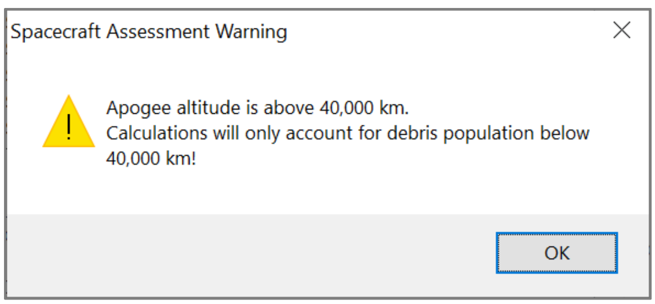

Figure 7-23 High Apogee Warning

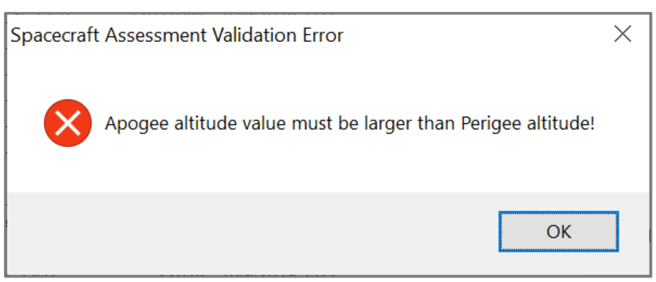

Figure 7-24 Switched Apogee and Perigee Error

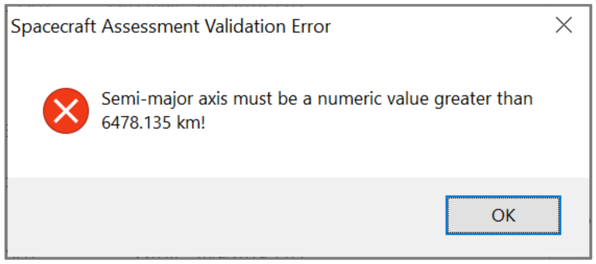

Figure 7-25 Low Semi-Major Axis Error

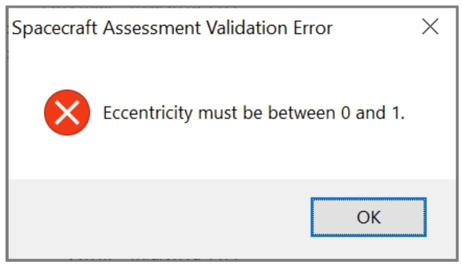

Figure 7-26 Eccentricity Out of Range Error

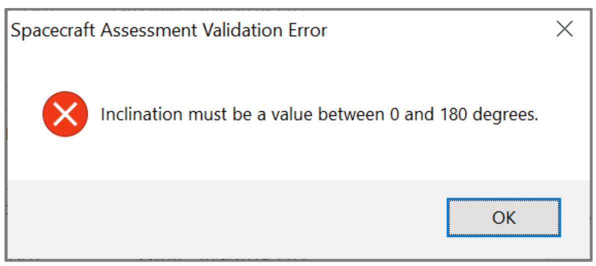

Figure 7-27 Inclination Out of Range Error

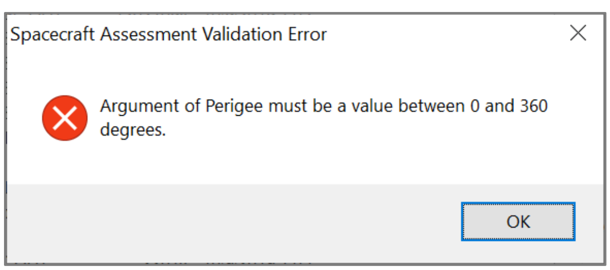

Figure 7-28 Argument of Perigee Out of Range Error

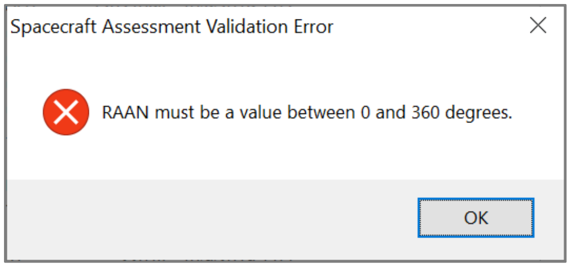

Figure 7-29 RAAN Out of Range Error

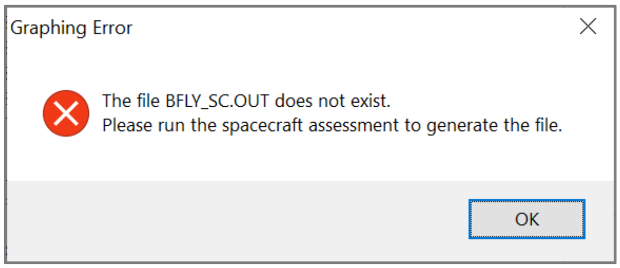

Figure 7-30 Graphing Error, BFLY_SC.OUT Not Found

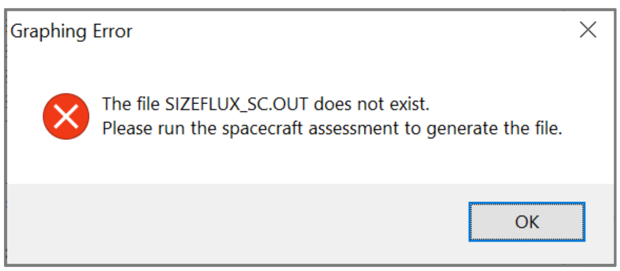

Figure 7-31 Graphing Error, SIZEFLUX_SC.OUT Not Found

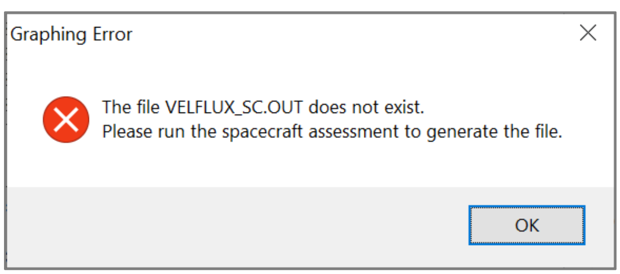

Figure 7-32 Graphing Error, VELFLUX_SC.OUT Not Found

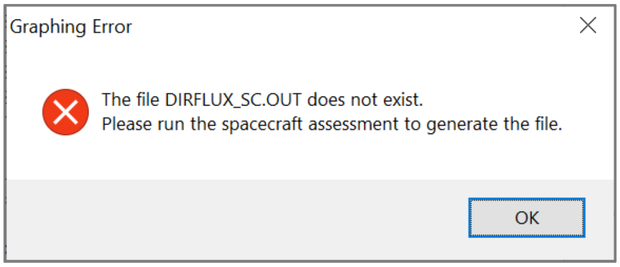

Figure 7-33 Graphing Error, DIRFLUX_SC.OUT Not Found

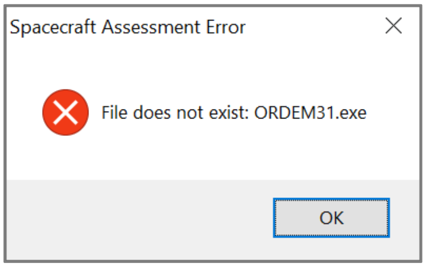

Figure 7-34 ORDEM31.exe Not Found Error

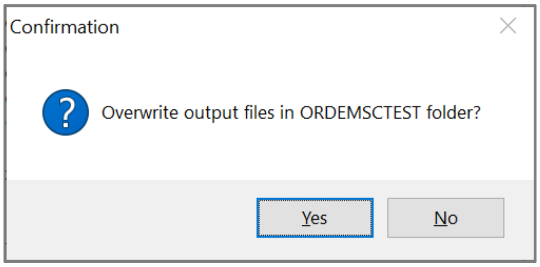

Figure 7-35 Overwrite Output Files Confirmation

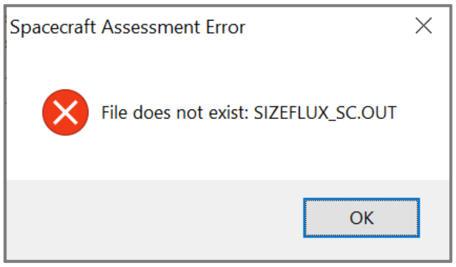

Figure 7-36 SIZEFLUX_SC.OUT Not Found Error

7.3.5 Dialog Boxes in Telescope/Radar Assessment Window

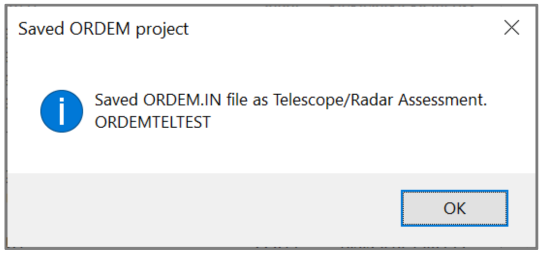

Figure 7-37 Saved ORDEM.IN file, Telescope/Radar Assessment

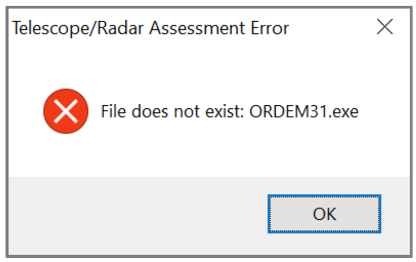

Figure 7-38 ORDEM31.exe Not Found Error

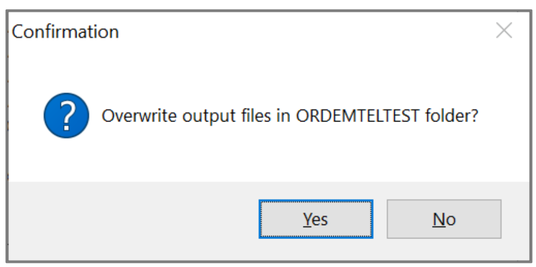

Figure 7-39 Overwrite Output Files Confirmation

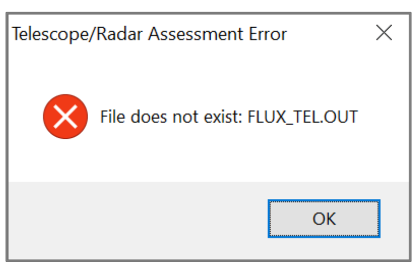

Figure 7-40 FLUX_TEL.OUT Not Found Error

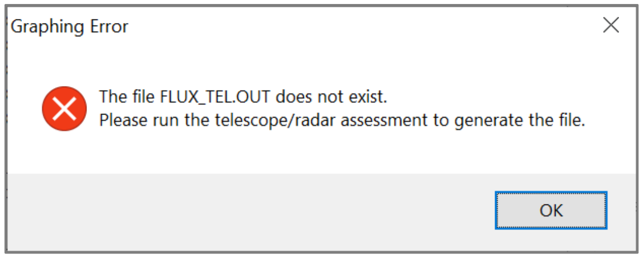

Figure 7-41 FLUX_TEL.OUT Not Found, Graphing Error

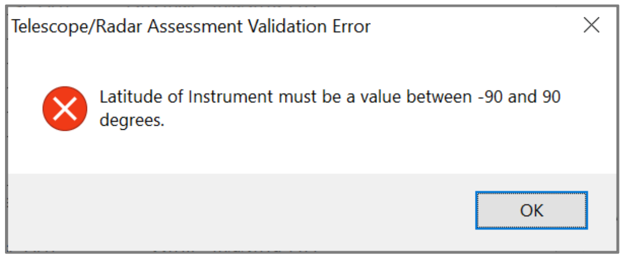

Figure 7-42 Latitude Range Error

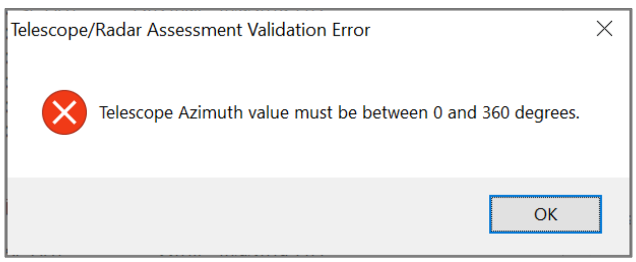

Figure 7-43 Azimuth Range Error

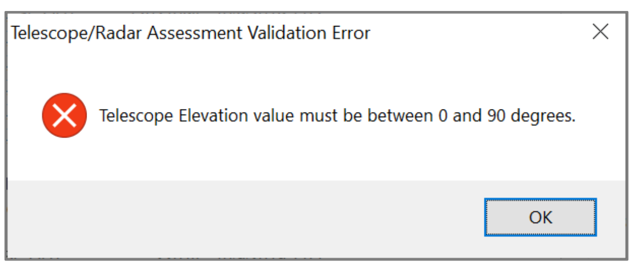

Figure 7-44 Elevation Range Error

7.3.6 Dialog Boxes in Batch Runs Window

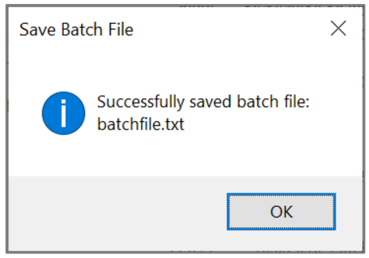

Figure 7-45 Successfully Saved Batch File

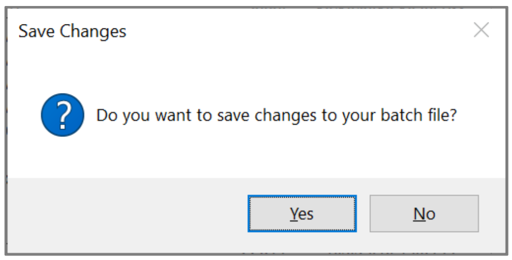

Figure 7-46 Save Changes to Batch File Confirmation

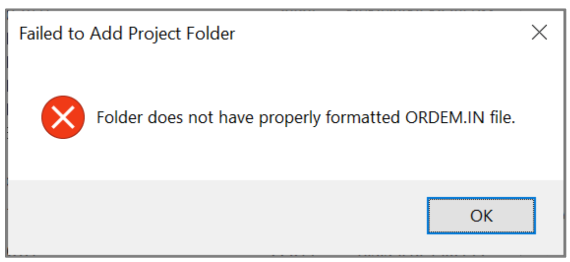

Figure 7-47 Invalid ORDEM.IN Error

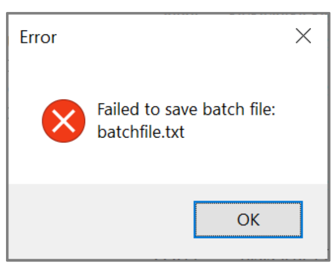

Figure 7-48 Failed to Save Batch File Error

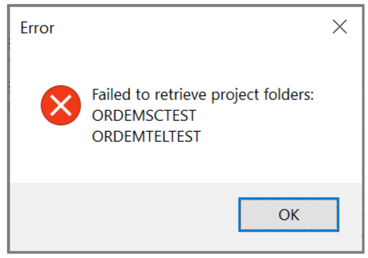

Figure 7-49 Failed to Retrieve Project Folders Error

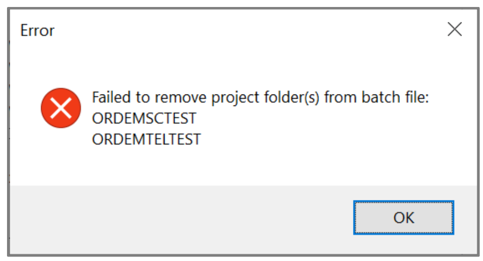

Figure 7-50 Failed to Remove Project Folders Error

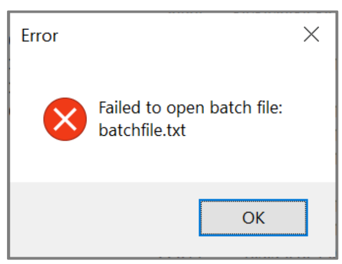

Figure 7-51 Failed to Open Batch File Error

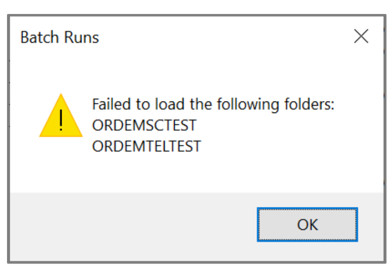

Figure 7-52 Failed to Load Folders Error

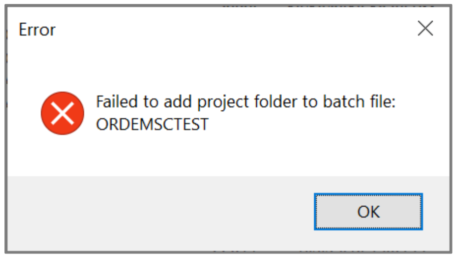

Figure 7-53 Failed to Add Folder Error

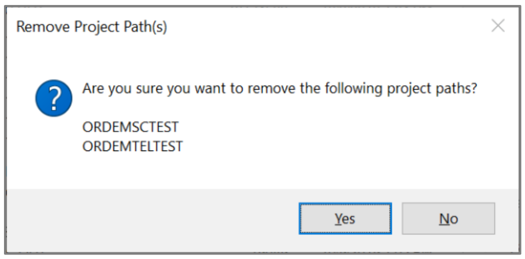

Figure 7-54 Remove Project Folders Confirmation

8 TERMS AND CONDITIONS

PLEASE READ CAREFULLY THE TERMS AND CONDITIONS OF THE SOFTWARE USAGE AGREEMENT (THE "SUA" OR "AGREEMENT") BEFORE DOWNLOADING, INSTALLING, ENABLING OR USING (COLLECTIVELY "USE" OR "IN USE" OR "USING") ANY SOFTWARE PROVIDED BY THE NASA ORBITAL DEBRIS PROGRAM OFFICE.

THE SOFTWARE USAGE AGREEMENT CONTAINS THE TERMS AND CONDITIONS GOVERNING USE OF THIS SOFTWARE AND APPLIES TO ALL USERS. A copy of the SUA was provided to you during the software registration process with NASA. We recommend that you print out or save a local copy of the SUA for your records.

NASA is willing to allow the use of this software to you only on the condition that you accept all the terms contained in the SUA. By selecting the "I Agree" button (or similar language provided by us) or by downloading, installing or using this software, you acknowledge and agree that you have read and understand the SUA and accept all of its terms.

This software is provided "as is" without any expressed or implied warranty. In no event shall NASA or its contributors or affiliates be liable for any direct, indirect, incidental, special, exemplary, or consequential damages arising in any way out of the use of this software, even if advised of the possibility of such damage.

IF YOU DO NOT AGREE TO THE TERMS AND CONDITIONS OF THE SOFTWARE USAGE AGREEMENT, PLEASE DO NOT DOWNLOAD, INSTALL, OR USE THIS SOFTWARE.