The Space Debris Environment Engineering Model SDEEM 2015

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Abstract

Space Debris Environment Engineering Model (SDEEM) is developed by Hypervelocity Impact Research Center, Harbin Institute of Technology in China. High-speed propagation algorithm based on the discussion of comprehensive orbit propagation theories and orbital elements discretization method used is illustrated here, in order to generate the space debris environment data in a highly efficient way. Spatial density and flux are the major outputs. The recent release, SDEEM 2015, enables the calculation of flux against targets operating in time between 1959 to 2050, altitude between 200 km to 2000km. This paper presented the features and results of SDEEM 2015, and the possible update modeling approach.

Keywords: space debris; environment; modeling; orbital element discretization method.

1 Model overview

SDEEM 2015 was developed by Hypervelocity Impact Research Center at Harbin Institute of Technology in China. The purpose of the development of SDEEM 2015 is to provide realistic description of the space debris environment via cross-section flux and spatial density predictions on user defined target orbits or earth-based space debris detection assessments. Overall, over two hundreds of on-orbit breakup events[1], thousands of solid rocket motor firings with aluminum oxide dust and slag ejections[2][3], 16 releases of NaK metal coolant from RORSAT reactors[4], the generation of surface degradation and release of ejecta[5] are considered. The Grün[6] meteoroid model is implemented as an additional section. Table 1 presents an overview of the SDEEM 2015 model.

Table. 1 Overview of the SDEEM 2015 model

Parameter	SDEEM 2015
Model function	Spacecraft and Telescope/Radar Assessment
Time range	1959 to 2050
Altitude range	200 to 2000 km
Model cumulative size thresholds	10μm, 100μm, 1mm, 1cm, 10cm
Space debris source models	Fragments SRM Slag & SRM Dust NaK Droplets Ejecta Paint Flakes
meteoroid	Grün
orbital regime division	5°×10°×50km

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relative velocity distribution under spacecraft assessment mode	0 to 1 km/s, 1 to 2 km/s, … ,22 to 23 km/s
velocity distribution under Telescope /Radar Assessment mode	6 to 7 km/s, 7 to 8 km/s, 8 to 9 km/s, 9 to 10 km/s
Model feature	Cross-section flux from 36 azimuth directions
Local azimuth distribution has 36 bins	-180 °to -170 °, -170 °to -160 °, … ,170 °to 180 °
File size	561MB
Run time	seconds

2 Model descriptions

Fig 1 shows major data processing flow of SDEEM 2015. Various debris source models including on-orbit breakup events, solid rocket motor firings with aluminum oxide dust and slag ejections, the releases of NaK metal coolant from RORSAT reactors, the generation of surface degradation and release of ejecta are considered here, in order to generate the reference population. Based on our high speed propagator, the population at different epoch is then acquired. Combined with orbital element discretization method, the spatial density and flux at different orbital position in each time interval of interest is calculated and saved as a series of data files. The LEO space debris environment engineering model SDEEM is established accordingly.

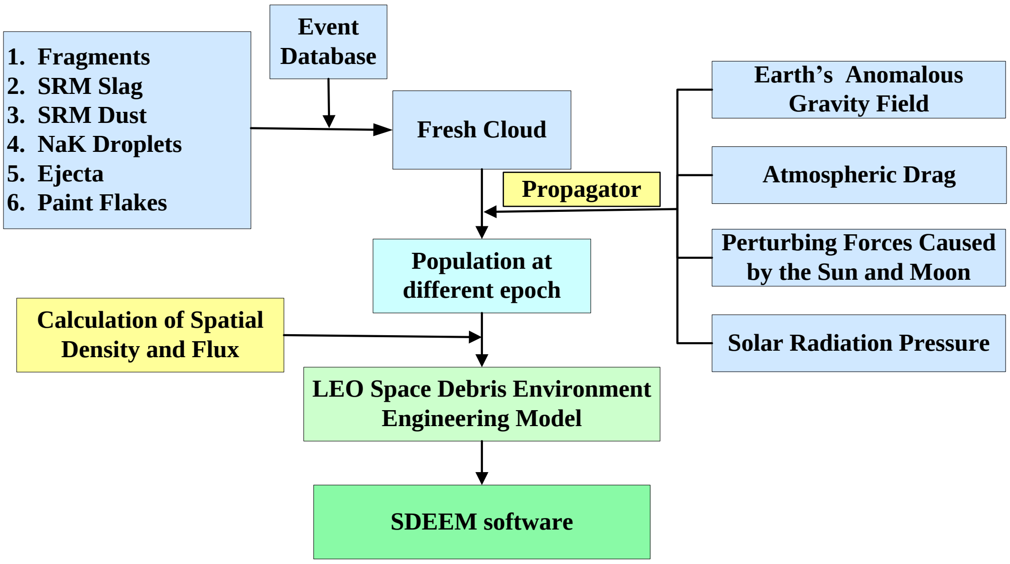


Fig 1 Major data processing flow of SDEEM 2015

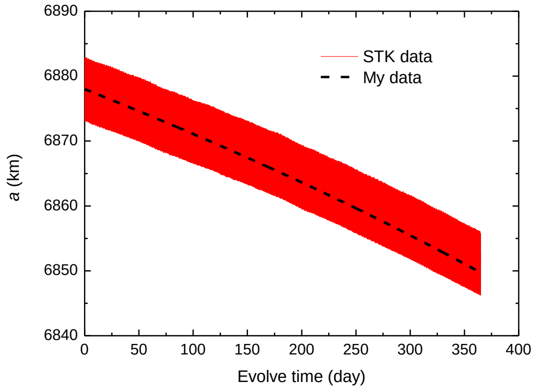
2.1 Approach for high-speed propagator

A high-speed propagator is developed based on the discussion of comprehensive orbit propagation theories, omitting propagation factors which are not significant to the overall space debris environment evolution for engineering model. Only first order long term perturbation factor is considered currently. A comparison between our propagator and STK HPOP (High-Precision Orbit Propagator) is given here. The initial orbit parameters are given in Table. 2. 1976 standard atmosphere model is used in both propagators. Results in Fig 2 shows that our high-speed propagator is able to provide the long term tendency of space debris orbital evolution.

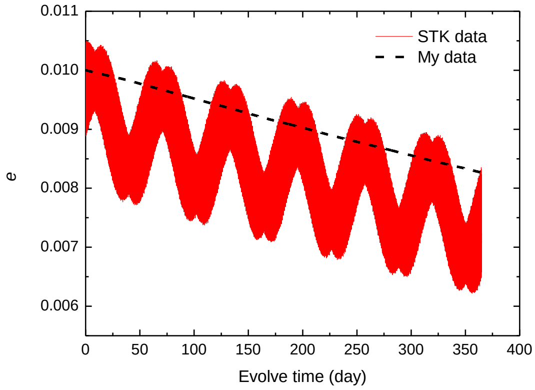
Table. 2 Space debris initial parameters for orbital evolution

Orbit type	LEO
Semi-major axis[km]	6878

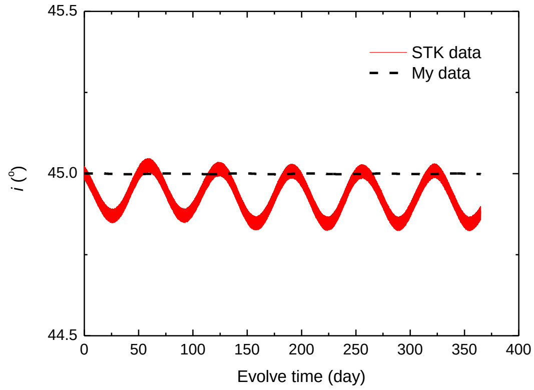
Eccentricity	0.010
Inclination [Degree]	45
Right Ascension of the Ascending Node [Degree]	45
Argument of Perigee [Degree]	45
True Anomaly [Degree]	0
Surface-mass ratio (m^2/kg)	0.010



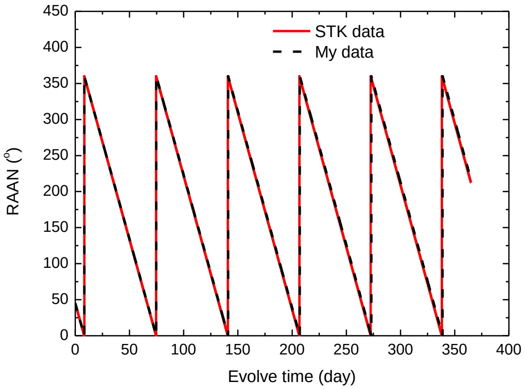
a) Variation of semi-major axis



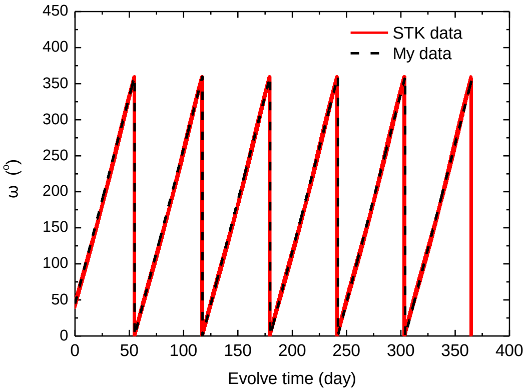
b) Variation of eccentricity



c) Variation of inclination



d) Variation of RAAN



e) Variation of argument of perigee

Fig 2 Comparison of orbital evolve results between this paper and STK (LEO typical case)

2.2 Orbital elements discretization method

Suppose the motion model of space debris is two-body, namely semi-major axis (a), eccentricity (e), inclination (i), right ascension of the ascending node (Ω) and argument of perigee (ω) remain stable during the model time step (one year). The main steps of orbital elements discretization method are as follows: Discretize space debris orbit elements according to its trajectory: discrete the whole orbit with respect to mean anomaly into a serious of orbit positions (set total number as N). As mean anomaly is directly proportional to time, the residence probability for each position equals $1/N$. Count orbit positions inside certain orbit bin. The sum number equals space debris residence probability in the bin. Calculate spatial density and flux accordingly. Fig 3 shows the schematic diagram of space debris discretization in an inertial bin [7].

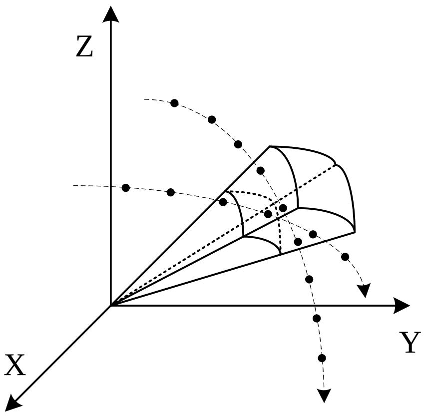


Fig 3 Particles in an inertial spatial bin

2.3 SDEEM meteoroid model

Meteoroid environment is another threat towards space activities. Since the meteoroid environment and space debris environment shows significant different with each other (mainly in velocity range and impact direction, etc), the risk assessment of meteoroid environment is set up as a standalone section in SDEEM model. Grün approach is the implement in SDEEM. Fig 4 shows the algorithm flow of meteoroid environment assessment for target orbit.

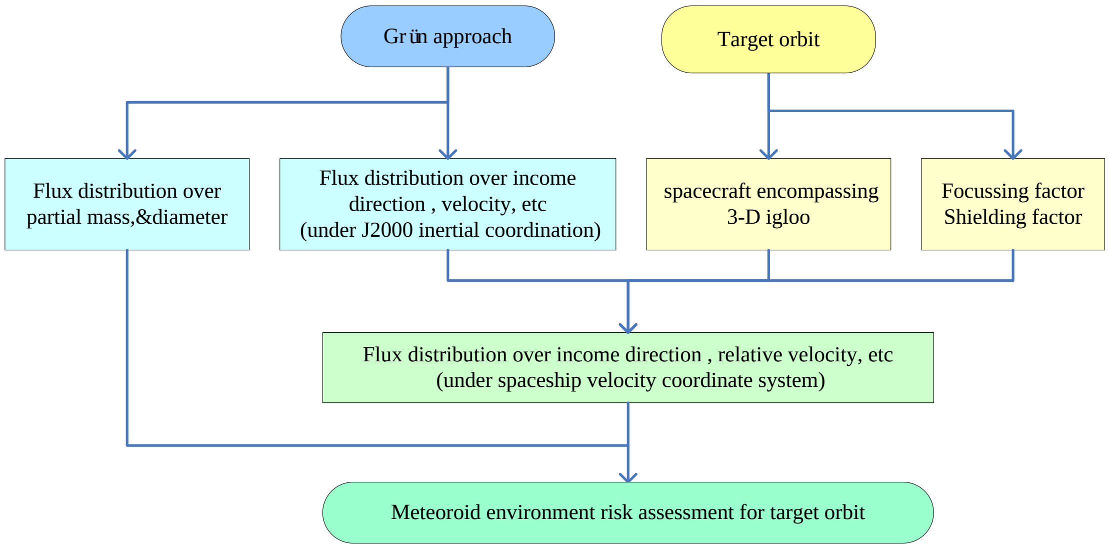


Fig 4 Algorithm flow of meteoroid environment assessment for target orbit

3 Model output

SDEEM 2015 covers space debris environment data from 200km to 2000km in altitude. Fig 5 to Fig 9 gives the comparison of spatial density distribution versus altitude in year 2015 between the outputs of MASTER 2009 [5], ORDEM2K [8], SDEEM 2015. For debris with diameter larger than 10cm, the spatial density distribution of TLE (Two Line Element) data provided by the US Space

Surveillance Network (SSN) [9] is also included here.

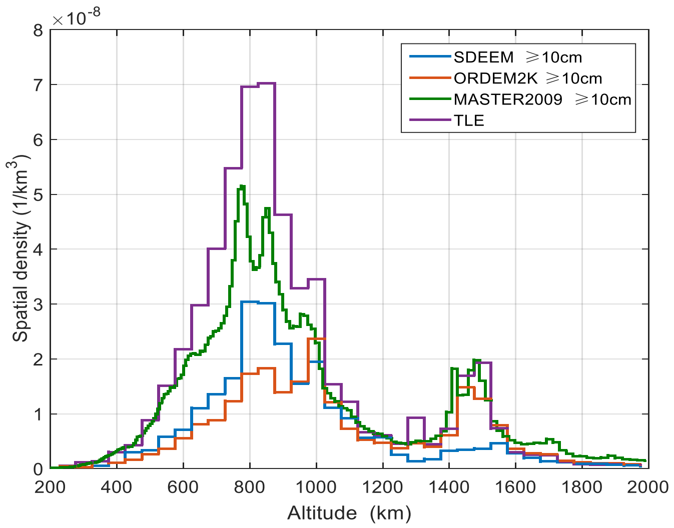


Fig 5 Spatial Density distribution against altitude （≥10cm）

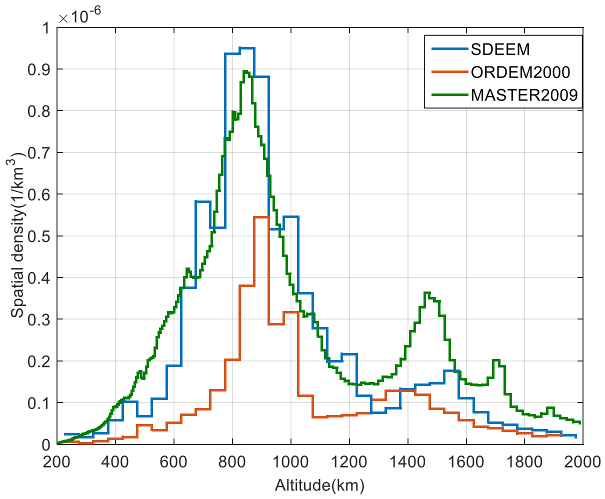


Fig 6 Spatial Density distribution against altitude （≥1cm）

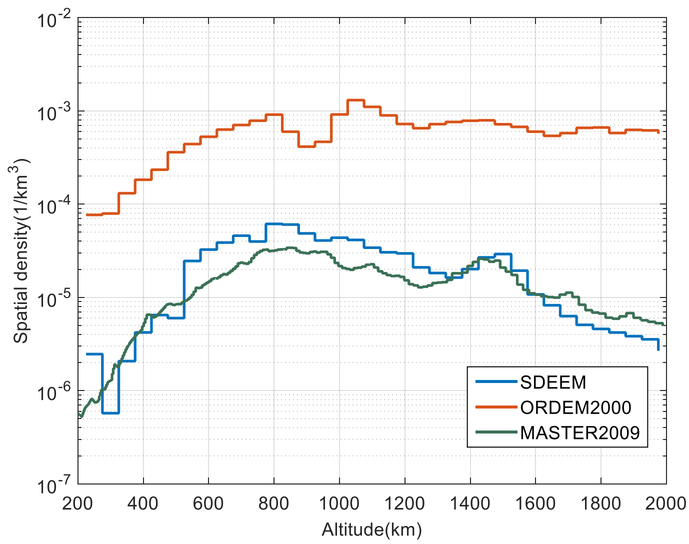


Fig 7 Spatial Density distribution against altitude （≥1mm）

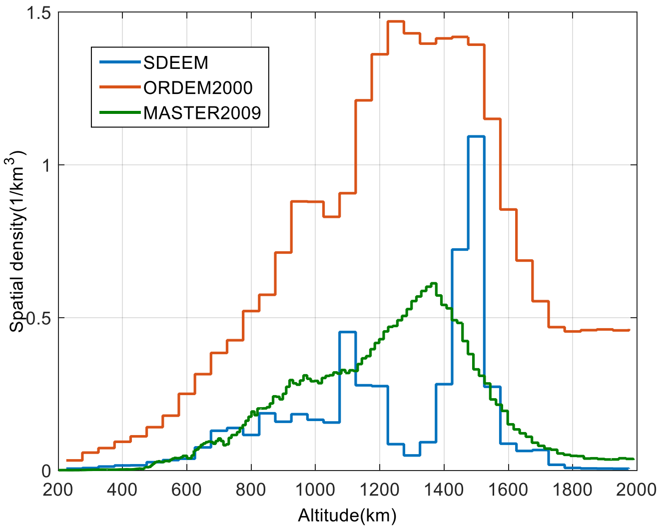


Fig 8 Spatial Density distribution against altitude （≥100μm）

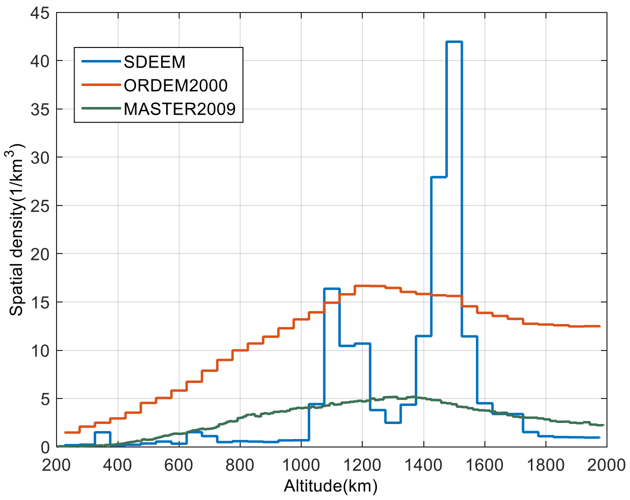


Fig 9 Spatial Density distribution against altitude （≥10μm）

The results show that for 10cm debris the outputs from all three models are smaller than the result gain from TLE data, especially around 800km in altitude. This may be due to the inaccurate prediction of recent on-orbit breakup events. Another reason could be that for LEO region, TLE data covers some debris with diameter smaller than 10cm.

The outputs of these models match with each other, expect for debris ≥1mm in size. For such debris the output of ORDEM2K is magnitudes larger than SDEEM 2015 and MASTER 2009. This may because that unlike SDEEM 2015 and MASTER 2009, ORDEM2K is developed base on detecting data. Since no direct measurement at 1 mm is available back then, the 1mm debris population in the model is based on an interpolation between the 100μm and 1cm populations, possibly leading to the generation of error.

4 SDEEM 2015 Software

Double click the file “SDEEM 2015.exe” to start the GUI. A dialog like Fig 10 should appear.

Click one of the radio buttons in the “Mode” box to proceed. The default initial interface is Spacecraft Assessment mode. The design of the software is that you can only operate on the current, top-most window. You must exit it before you can operate on panels hidden beneath. Beyond the main panel are several basic panel types, including Data Input panels, Computation Result panels, and Graphic Display panels. Fig 11 shows the software process of SDEEM 2015. For extra information, click “help” opens the help document, which includes several example sequences (telescope mode and spacecraft mode).

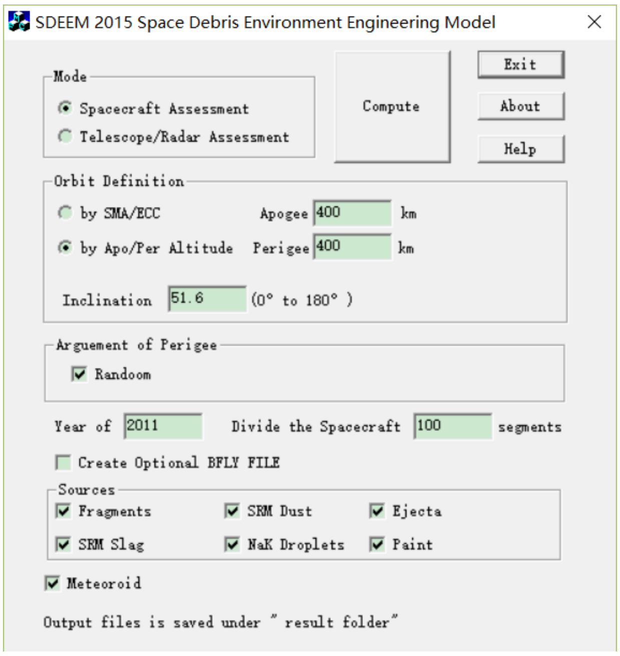


Fig 10 SDEEM user interface

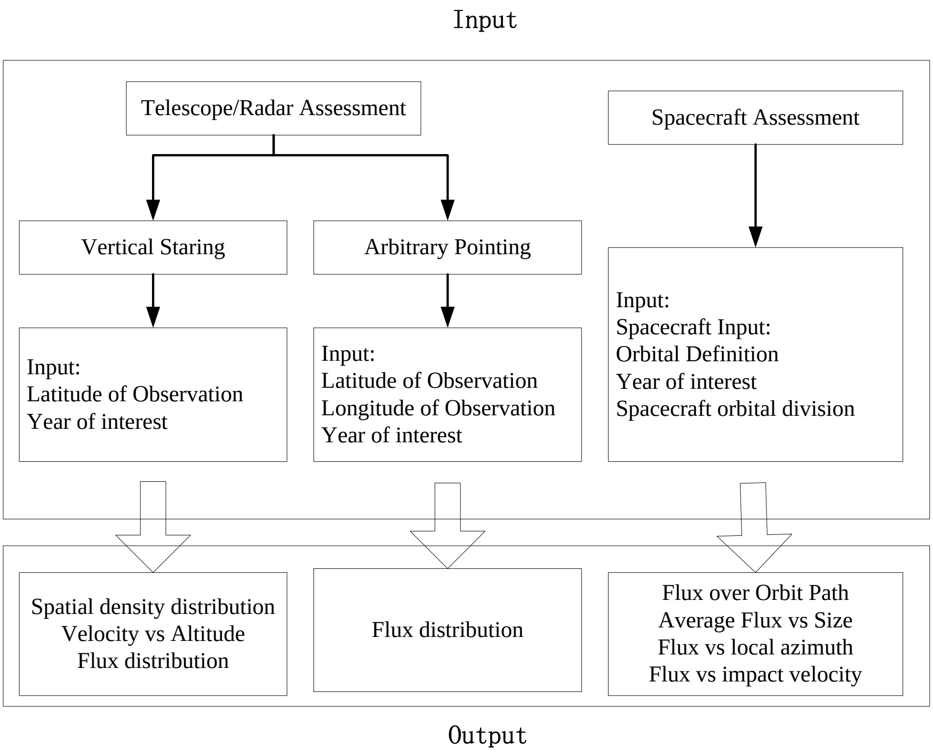


Fig 11 SDEEM 2015 software process

5 Discussion

SDEEM 2015 covers space debris of size range down to 10μm, altitude range form 200km to 2000km, time range from 1959 to 2050, both for space debris and meteoroid particulates. The approach for high-speed propagator and orbital element discretization method allow convenient and efficient update and upgrade of current version. SDEEM 2015 is produced as software compatible with the usual PC, intended for a wide used of researcher and students in related area.

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