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Space environment (natural and artificial) — Guide to process-based implementation of meteoroid and debris environmental models (orbital altitudes below GEO + 2 000 km)

Environnement spatial (naturel et artificiel) — Lignes directrices pour une mise en oeuvre fondée sur les processus des modèles environnementaux des météoroïdes et des débris (altitudes d'orbite inférieures à GEO + 2 000 km)

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14200 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Every spacecraft or launch vehicle orbital stage in an Earth orbit is exposed to a certain flux of micrometeoroids and man-made space debris. Collisions with these particles take place with hypervelocity. The impact risk is evaluated in the design phases of a spacecraft or the launch vehicle orbital stage. Many meteoroid and space debris environment models have been studied and developed which describe populations of meteoroids and/or space debris. These models can be used as interim solutions for impact risk assessments and shielding design purposes. However, there are different methods in existence for reproducing the observed environment by means of mathematical and physical models of release processes, for propagating orbits of release products, and for mapping the propagated environment onto spatial and temporal distributions of objects densities, transient velocities, and impact fluxes. Until a specific standard for the space debris environment is defined, a common implementation process of models should be indicated for impact risk assessment and design of a spacecraft.

Space environment (natural and artificial) — Guide to process-based implementation of meteoroid and debris environmental models (orbital altitudes below GEO + 2 000 km)

1 Scope

This International Standard specifies the common implementation process for meteoroid and debris environment models for risk assessment of spacecraft and launch vehicle orbital stages. This International Standard gives guidelines for the selection process of models for impact risk assessment and ensures the traceability of using models throughout the design phase of a spacecraft or launch vehicle orbital stage.

2 Normative reference

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 17666:2003, *Space systems — Risk management*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17666 and the following apply.

3.1
engineering model
environment model that provides clear and concise information that engineers need

3.2
geostationary Earth orbit
Earth orbit having zero inclination and zero eccentricity; whose orbital period is equal to the Earth's sidereal rotation period

[SOURCE: ISO 24113:2011, definition 3.8]

3.3
geosynchronous Earth orbit
Earth orbit with an orbital period equal to the Earth's sidereal rotation period

3.4
gravitational focusing
force of the Earth's gravitational field that attracts meteoroids, changes their trajectories, and therefore increases the flux

3.5
impact flux
number of impacts per unit area and per unit period

3.6
impact risk
risk of impact against meteoroids and debris on spacecraft

3.7
interplanetary
applicable regime of the meteoroid environment model from Earth with astronomical units (AU)

3.8
launch vehicle orbital stage
stage of a launch vehicle that is designed to achieve orbit

[SOURCE: ISO 24113:2011, definition 3.9]

3.9
low earth orbit
Earth orbit with an apogee altitude that does not exceed 2 000 km

3.10
mass density
mass per unit volume

3.11
meteoroid
particles of natural origin that result from the disintegration and fragmentation of comets and asteroids which orbit round the sun

3.12
meteorid / (space) debris environment(al) model
tool that simulates realistic descriptions of the meteoroid and debris environment of Earth, and performs risk assessment via flux predictions on user defined target orbit

3.13
space debris
<orbital debris> man-made objects, including fragments and elements thereof, in Earth's orbit or re-entering the atmosphere, that are non-functional

[SOURCE: ISO 24113:2011, definition 3.17]

3.14
space system
system consisting of a space segment that includes a launch segment, spacecraft segment and a ground segment with a tracking control segment and a mission segment

[SOURCE: ISO 23041:2007]

3.15
spacecraft
system designed to perform specific tasks or functions in space

[SOURCE: ISO 24113:2011, definition 3.18]

3.16
traceability
ability to trace the history, application or location of that which is under consideration

[SOURCE: ISO 9000:2005]

4 Abbreviated terms

AU	Astronomical Units
CME	Chemistry of Meteoroid Experiement
DISCOS	Database and Information System Characterising Objects in Space
ESA	European Space Agency
EuReCa	EUropean REtrievable CArrier
GEO	Geostationary Earth Orbit
GUI	Graphical User Interface
HAX	Haystack Auxiliary Radar
HST	Hubble Space Telescope
HST-SA	Hubble Space Telescope Solar Array
HST (SM1)	Hubble Space Telescope (Service Mission 1)
HST (SM3B)	Hubble Space Telescope (Service Mission 3B)
IDES	Integrated Debris Evolution Suite
IMEM	Interplanetary Meteoroid Engineering Model
ISO	International Organization for Standardization
ISS	International Space Station
LDEF	Long Duration Exposure Facility
LEGEND	LEO- to -GEO Environment Debris Model
LEO	Low Earth Orbit
MASTER	Meteoroid and Space Debris Terrestrial Environment Reference
MEM	Meteoroid Engineering Model
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
ORDEM	Orbital Debris Engineering Model
PROOF	Program for Radar and Observation Forecasting
SDMP	Space Debris Mitigation Plan
SSN	Space Surveillance Network
SSP	Space Station Program
STS	Space Transportation System

5 Guidelines for the implementation of meteoroid and space debris environmental models

5.1 Overview of the implementation concept

5.1.1 If an impact flux assessment is required, it shall be performed in accordance with the risk management process specified by ISO 17666.

5.1.2 The results of an impact flux assessment, the methodology used, and any assumptions made shall be documented.

NOTE Impact flux assessments are sometimes performed in order to satisfy the requirements of a Space Debris Mitigation Plan (SDMP). See Reference [1] for a description of the content of an SDMP.

5.2 Impact fluxes estimation into a project

When a spacecraft or launch vehicle orbital stage is designed or planned, the risk caused by impacts of meteoroids and space debris shall be evaluated. For the risk assessment, impact fluxes of meteoroids and space debris on the spacecraft or launch vehicle orbital stage shall be estimated.

5.3 Meteoroid and debris model implementation procedure

5.3.1 General

Impact fluxes on a spacecraft or launch vehicle orbital stage are calculated using a combination of design data (i.e. configuration, orbit), meteoroid environment model and space debris environment model. When the meteoroid environment model and space debris environment model applies to a spacecraft or launch vehicle orbital stage design; the following procedure should be followed.

5.3.1.1 Step 1: Model selection agreement

The model(s) which is (are) applied to a spacecraft or launch vehicle orbital stage design is (are) selected by mutual agreement between the customer and the supplier of the spacecraft or launch vehicle orbital stage. Moreover, the traceability of the model(s) application shall be ensured.

5.3.1.2 Step 2: Model selection

To select a suitable environment model for the mission of a spacecraft or launch vehicle orbital stage, the customer and the supplier should consider the capabilities of candidate models. Model capabilities are described in 5.4.

When selecting a model, consideration should be given to the fact that environment models have uncertainties which can lead to large differences in the flux results. It is recommended that the customer and the supplier compare the flux results from several models.

5.3.1.3 Step 3: implementation of meteoroid and space debris environment models on a project

When implementing an environment model on a project there are several important considerations, such as traceability of the development of the model, its maintenance, and user convenience. The following approaches are recommended to estimate the impact fluxes on a spacecraft design and/or component design:

a) Engineering models (analysis codes) which are institutionally maintained by national agencies are considered as candidates for applicable models for the design.

b) When a critical component is designed, the model which produces the maximum risk (the worst case) is selected among candidate models.

The use of models other than those listed in 5.4 is permissible.

5.4 Capabilities of meteoroid and space debris environment models

5.4.1 Meteoroid environment models

Capabilities of meteoroid environment models are described in Annex A. Comparison of impact fluxes among models are described in Reference [4].

5.4.2 Space debris environment models

Capabilities of space debris environment models are described in Annex B. Comparison of impact fluxes among three engineering models, which are published by NASA and ESA, are described in References [5],[6],[7],[34]. An example of comparison impact flux among three models is described in Annex C for information.

6 Traceability assurance

6.1 Overview of traceability concept

Traceability of the meteoroid and space debris model application process shall be guaranteed in all design phases of a spacecraft.

6.2 Assurance of traceability in a project

6.2.1 Risk assessments of meteoroid and space debris impacts

When risk assessments of meteoroid and space debris impacts are required, the following items shall be recorded in each design phase of the spacecraft or launch vehicle orbital stage:

a) the justification for the selected spacecraft risk assessment model;

b) all input and output parameters and their values;

c) any assumptions made regarding the input design parameters, and the reasons for those assumptions;

d) any corrections made to output parameters, reasons for the corrections and any assumptions made, and details of correction methods and correction results.

NOTE Output parameters can be corrected by applying a safety factor, life factor or margin of safety. Such corrections can also take into account new information on the debris population. For example, since the publication of space debris environment models, such as ORDEM3.0 and MASTER-2009, there have been a number of important debris generation events. These events could have a significant influence on a risk assessment.

6.2.2 Design Review

The contents of the items listed in 6.2.1, and their validity, shall be evaluated and confirmed by reviewers during the Design Review (DR) in each phase of the design.

7 International project

For an international project, it is recommended that the following items be agreed amongst member bodies before starting the project:

a) applied meteoroid and space debris environment model(s) to the project;

b) method of maintenance of the meteoroid and space debris environment model(s);

c) the procedure for impact risk assessment.

Annex A
(informative)

Capability of meteoroid environment models

A.1 Model overview

A.1.1 Grüen et al. model

The Grüen model[6] assumes an isotropic meteoroid distribution which is based on lunar crater, zodiacal light and *in situ* measurement data.

A.1.2 Divine model

The Divine model[7] assumes a non-isotropic distribution which is based on five populations in particle mass, inclination, eccentricity and perihelion distance.

A.1.3 Divine-Staubach model

The Divine-Staubach model[8] is a follow-up of the Divine model, using new data from GALILEO and ULYSSES dust detectors.

A.1.4 NASA SSP-30425 model

The SSP-30425 (Space Station Program Natural Environment Definition for Design) model[9] describes a space environment for ISS design.

A.1.5 IMEM model

Dikarev used an improved and controlled data set and applied refined mathematical methods in order to describe three-dimensional distributions of orbital elements (instead of the mathematically separable distributions of Divine)[10].

A.1.6 MEM model

Near 1 AU fluxes are calibrated from the Grüen model. A constant mass density of 1,0 g/cm^3 is assumed and the velocity distributions are independent from the particle sizes[11].

A.2 Model specifications

Table 1 — Meteoroid model specifications

Model specifications	Model					
	Grüen et al. Reference [6]	**Divine** Reference [7]	**Divine-Staubach** Reference [8]	**SSP 30425 (ISS)** Reference [9]	**IMEM (ESA)** Reference [10]	**MEM (MSFC)** Reference [11]
Sporadic or stream	Sporadic	Sporadic	Sporadic	Sporadic	Sporadic	Sporadic
Interplanetary	No	0,1 to 20 AU	0,1 to 20 AU	No	0,1 to 10 AU	0,2 to 2 AU

NOTE It was found that the Divine-Staubach approach fits the requirements of the MASTER model best. Thus, only the Divine approach and the extensions introduced by Staubach are implemented in the model[12].

Table 1 *(continued)*

Model specifications	Model					
	Grüen et al. Reference [6]	**Divine** Reference [7]	**Divine-Staubach** Reference [8]	**SSP 30425 (ISS)** Reference [9]	**IMEM (ESA)** Reference [10]	**MEM (MSFC)** Reference [11]
Mass/range	10^{-18} to 10^{2} g	10^{-18} to 1 g	10^{-18} to 1 g	10^{-18} to 10^{2} g	10^{-12} to 10^{2} g	10^{-6} to 10 g
Near Earth	Yes	Yes	Yes	Yes	Yes	Yes
Gravitational focusing	No	Earth only	Earth only	Earth only	Earth only	Earth only
Planetary shielding	No	Earth only	Earth only	Earth only	Earth only	Earth only
Sources of meteoroids	Not identified explicitly	-Asteroidal, -Core, -Halo, -Inclined, -Eccentric populations	-A, B, C , -Asteroidal, -Core, -Inter-stellar dust populations	Not identified explicitly	-Asteroids, -"Jupiter-crossing comets", -Inter-stellar dust (<10^{-9} g)	6 radar/ photographic meteor sources (Helion, Anti-Helion, North Apex, South Apex, North Toroidal, South Toroidal)
Velocity distribution	Single value (20 km/s)	Yes	Yes	Yes (Kessler)	Yes	Yes
Mass density	Single value (2,5 g/cm^3)	2 g/cm^3 ($m < 10^{-6}$ g); 1 g/cm^3 (10^{-6} - 10^{-2} g); 0.5 g/cm^3 ($m > 10^{-2}$ g)	2 g/cm^3 ($m < 10^{-6}$ g); 1 g/cm^3 (10^{-6} - 10^{-2} g); 0.5 g/cm^3 ($m > 10^{-2}$ g)	2 g/cm^3 ($m < 10^{-6}$ g); 1 g/cm^3 (10^{-6} - 10^{-2} g); 0.5 g/cm^3 ($m > 10^{-2}$ g)	Single value (2,5 g/cm^3)	Single value (1 g/cm^3)
Primary data source	-*In situ* experiments, -zodiacal light, lunar crater record. -Gruen et al. flux is iden-tical to the 1970 Zook flux for $m > 10^{-7}$ g	-Zodiacal light, -Harvard Radio Meter Project (HRMP) data	-Staubach refit the probability densities, taking account into Ulysses and Galileo spacecraft	Not identified explicitly	-*In situ* experiments (Ulysses, Galileo), -COBER IR, -lunar crater record. -No zodiacal light data. -Disregard AMOR data	Canadian Meteor Orbit Radar (CMOR) data
Key assumptions	Flux on Earth is isotropic	Calibrated to the Grüen flux	Calibrated to the Grü en flux	Grüen flux with Kessler's velocity distribution and modified mass density	Calibrated to the Grüen flux	Calibrated to the Grüen flux
Release data	1985	1993	1996	1994 (Revi-sion)	2004	2006 (MEM 1.6, EarthMEM 1.0)
NOTE It was found that the Divine-Staubach approach fits the requirements of the MASTER model best. Thus, only the Divine approach and the extensions introduced by Staubach are implemented in the model[12].						

Annex B
(informative)

Capability of space debris environment models

B.1 General

This Annex provides guidance for engineers in the selection and use of models that are suitable for his/her specific mission needs.

In regards to impact risk assessment, debris flux models (See B.2) should be considered for spacecraft or launch vehicle orbital stage design. Debris propagation (evolutionary) models (See B.3) should be considered for the study of a long-term debris environment and should not be applicable for impact risk assessment in the design phase.

B.2 Debris flux models

B.2.1 Model overview

B.2.1.1 DAMAGE model

The DAMAGE model[13] [14] [15] aims to account for the unique characteristics involved in modelling the full LEO to GEO environment.

B.2.1.2 IDES model

The IDES model[16] [17] [18] [19] [20] [21] is able to study historical, current and future space debris populations, in addition to providing directional collision risk assessments for satellites in the full LEO to GEO debris environment.

B.2.1.3 MASTER2005 model

The MASTER2005 model[12] is based on semi-deterministic analysis that includes orbit propagation of debris from all major debris sources and can estimate the meteoroid environment. The applicable scope of MASTER2005 is an altitude between 186 km and 36 786 km and an impact object diameter between 1 μm and 10 m.

B.2.1.4 MASTER2009 model

The MASTER2009 model[22] is an upgraded version of MASTER2005. The applicable scope of MASTER2009 is an altitude between 186 km and 36 786 km and an impact object diameter between 1 μm and 10 m.

B.2.1.5 MASTER8 model

The MASTER8 model[35] is an upgrade version of MASTER2009. The applicable scope of MASTER8 is an altitude from between 186 km and 500 000km.

B.2.1.6 ORDEM3.0 model

The ORDEM3.0 model[23] is an empirical model based on ground-based observation data and surface inspection results of objects retrieved from orbit. improvements over its predecessor, ORDEM2000, which was released in 2002. For the first time, ORDEM includes uncertainties in the flux estimates. The model includes material density classes. It has also been extended to describe the orbital debris environment from low Earth orbit past geosynchronous orbit (100 to 400 000 km altitude).

The SPDA model[12] [22] [23] is a semi-analytical stochastic model for medium- and long-term forecast of the debris environment (larger than 1 mm), for construction of spatial density, and velocity distribution in LEO and GEO, as well as, for risk evaluation.

B.2.2 Model specifications

Table 1 — Debris flux model specifications

Model specifications		**Model**					
	DAMAGE References[13] [14] [15]	**IDES** References[16] [17] [18] [19] [20] [21]	**MASTER 2005** Reference [12]	**MASTER 2009** Reference [22]	**MASTER 8** Reference [35]	**ORDEM 3.0** Reference [23]	**SPDA** Reference [12] [22] [23]
Source	Southampton University	DERA	ESA	ESA	ESA	NASA	RSA
Modelling approach	Statistical and near-deterministic methods	Semi deterministic analysis	Semi deterministic analysis	Semi deterministic analysis	Semi deterministic analysis	Measurement data	Semi deterministic analysis
	Applicable regime						
a) minimum size	1 mm	> 10 µm	> 1 µm	> 1 µm	> 1 µm	> 10 µm	> 1 mm
b) orbital regime	120 to 37 786 km	LEO to GEO	186 to 36 786 km	186 to 36 786 km	186 to 500 000 km	100 to 40 000 km (>10 µm) (LEO to GTO) 34 000 to 40 000 km (> 10cm) (GEO)	400 to 2 000, 35 300 to 36 200 km
c) evolutionary period	Long term	Short and long term	1958 to 2050	1957 to 2055	1957 to 2055	2010 to 2035	Medium and long term
Input parameter	Target orbit semi-major axis: - -Eccentricity, -Inclination, -Right ascension of ascending node, -Argument of perigee	—	Target orbit scenario: -Semi-major axis, -Eccentricity, -Inclination, -Right asc. of asc. node, -Argument of perigee Inertial Volume Scenario: -Geocentric distance, -Right ascension, -Declination Spatial Density Scenario: -Lower/ upper altitude limit, -Lower/ upper decline. limit	Target orbit scenario: -Semi-major axis, -Eccentricity, -Inclination, -Right asc. of asc. node, -Argument of perigee Inertial Volume Scenario: -Geocentric distance, -Right ascension, -Declination Spatial Density Scenario: -Lower/ upper altitude limit, -Lower/ upper decline. limit	Target orbit scenario: -Semi-major axis, -Eccentricity, -Inclination, -Right asc. of asc. node, -Argument of perigee Inertial Volume Scenario: -Geocentric distance, -Right ascension, -Declination Spatial Density Scenario: -Lower/ upper altitude limit, -Lower/ upper decline. Limit	-Apo/Peri -Altitude -Semi-major axis -Eccentricity -Inclination -Argument of perigee	—

Table 1 *(continued)*

Model specifications		**Model**					
	DAMAGE References[13] [14] [15]	**IDES** References[16] [17] [18] [19] [20] [21]	**MASTER 2005** Reference [12]	**MASTER 2009** Reference [22]	**MASTER 8** Reference [35]	**ORDEM 3.0** Reference [23]	**SPDA** Reference [12] [22] [23]
Output data	-Spatial density versus altitude, -Spatial density versus inclination, -Number of objects versus time, -Cumulative number of collisions versus time	—	Flux versus size, -Mass, -Semi-major axis, -Eccentricity, -Inclination, -Altitude, -Latitude, -Impact velocity, -Impact declination, -Time, etc. Spatial density versus size: -Mass, -Altitude, -Declination, -Time	Flux versus size, -Mass, -Semi-major axis, -Eccentricity, -Inclination, -Altitude, -Latitude, -Impact velocity, -Impact declination, -Time, etc. Spatial density versus size: -Mass, -Altitude, -Declination, -Time	Flux versus size, -Mass, -Semi-major axis, -Eccentricity, -Inclination, -Altitude, -Latitude, -Impact velocity, -Impact declination, -Time, etc. Spatial density versus size: -Mass, -Altitude, -Declination, -Time	-Flux versus size, -Orbit position, -Altitude, -Latitude	—
	Debris source terms						
a) TLE background	Yes (or simulated from historical launch and fragmentation data)	—	Yes	Yes	Yes	Density discrimination	All sources together
b) Fragments	Yes	—	Yes	Yes	Yes	Density discrimination	All sources together
c) SRM dust/slag	TBC	—	Yes	Yes	Yes	Density discrimination	All sources together
d) NaK droplets	TBC	—	Yes	Yes	Yes	Density discrimination	All sources together
e) Paint flakes	no (TBC)	—	Yes	Yes	Yes	Density discrimination	All sources together
f) West ford needles	TBC (Currently included if catalogued)	—	Yes	Yes	Yes	Density discrimination	All sources together
g) MLI fragments	—	—	None	Yes	Yes	Density discrimination	All sources together
	Meteroid						
a) background	None	None	Divine-Staubach	Diving-Staubach	Diving-Staubach	None	None
b) streams	None	None	Jenniskens-McBride, Cour-Palais	Jenniskens-McBride, Cour-Palais	Jenniskens-McBride, Cour-Palais	None	None

Table 1 *(continued)*

Model specifications	Model						
	DAMAGE References[13] [14] [15]	**IDES** References[16] [17] [18] [19] [20] [21]	**MASTER 2005** Reference [12]	**MASTER 2009** Reference [22]	**MASTER 8** Reference [35]	**ORDEM 3.0** Reference [23]	**SPDA** Reference [12] [22] [23]
Primary data source/ validation	-DISCOS Database, -IDES, -MASTER, -LEGEND	—	-LDEF, -CME, -HST (SM1, SM3B), -EuReCa, -PROOF 2005	-LDEF, -CME, -HST (SM1, SM3B), -EuReCa, -PROOF 2009	-LDEF, -CME, -HST (SM1, SM3B), -EuReCa, -PROOF 2009	-SSN, catalogue, -LDEF, -Haystack radar, -HST-SA. -STS window and radiator, -MOSEZT telescope -HAX, -Goldstone radar	—
Model features	-LEO-to-GEO (including GTO), -Mitigation and removal strategies, -GUI	—	-Flux to spheres, -Orientated surf., -GUI, -Time browser	-Flux to spheres, -Orientated surf., -GUI, -Time browser	-Flux to spheres, -Orientated surf., -GUI, -Time browser	—	—
Engineering model available for intentional use	No engineering model but Particles-in-a-box model (called FADE) is available (Further details on request).	No	Yes	Yes	Yes	Yes	No

B.3 Debris propagation (evolutionary) models

B.3.1 Model overview

B.3.1.1 LEGEND model

The LEGEND model[27] [28] is capable of reproducing the historical debris environment as well as performing future debris environment projection. The applicable scope of LEGEND is an altitude between 200 and 40 000 km and outputs debris distributions in one-dimensional (altitude), two-dimensional (altitude, latitude), and three-dimensional (altitude, latitude, longitude) formats.

B.3.1.2 LEODEEM model

The LEODEEM model[29] [30] calculates LEO debris evolution (less than 2 000 km altitude of perigee) taking into account collisions, and future launch traffic. It becomes possible to predict a long term LEO environment and investigate future mission hazard evaluation by using this model.

B.3.1.3 GEODEEM model

The GEODEEM model[31] calculates GEO debris evolution taking into account collisions, and future launch traffic. Emphasis has been placed on the rate of collisions in the geosynchronous Earth orbit and in the higher collection orbits and on the significance of cross-regime contamination.

NOTE Some models identified in B.2 (DAMAGE, IDES, SPAD) can also be used for long-term evolutionary analyses.

Annex C
(informative)

Example of Comparison of Debris Flux Values among ORDEM2000, MASTER-2005 and MASTER2009

Figure C.1 provides examples of debris flux results from three different models (i.e. ORDEM2000, MASTER2005 and MASTER2009). Details are discussed in References [12],[22],[23].

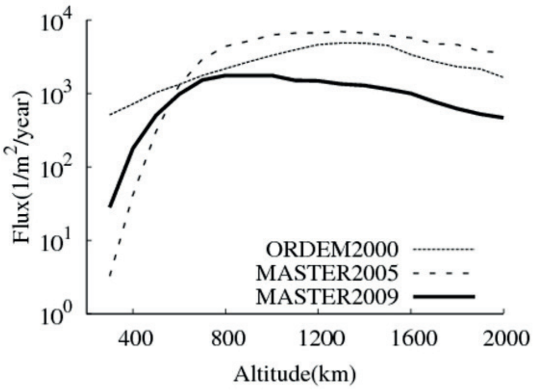
The calculation conditions, shown in Table C.1, are altitudes between 300 km and 2 000 km with a step size of 100 km, inclinations of 100 degrees, circular orbit, and an epoch of 2 000. The calculation results of the cumulative flux of debris > 10 µm in diameter, > 100 µm, > 1 mm, > 1 cm, > 10 cm, and > 1 m, as the function of altitude are shown in Figure C.1.

Table 1 — Calculation conditions of models comparison

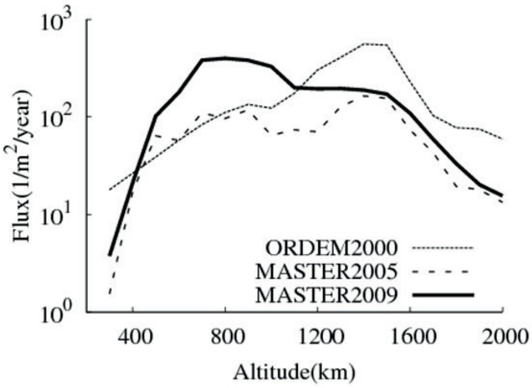
Parameter	Calculation condition
Altitude (km)	300 - 2 000
Inclination (degree)	110
Size range (m)	10^{-5} - 1
Step size[a] (km)	100
Step size[b] (log scale)	1
Resulting data	Cumulative flux
Debris	Yes
Meteoroids	None

[a] Altitude

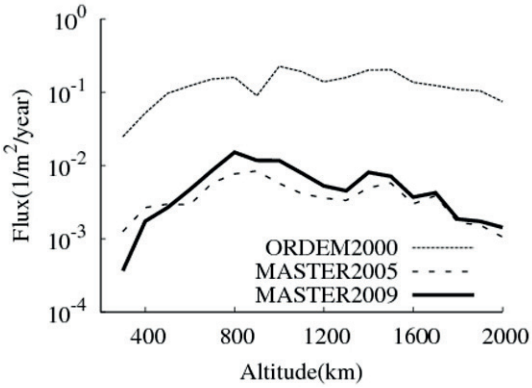
[b] Size range



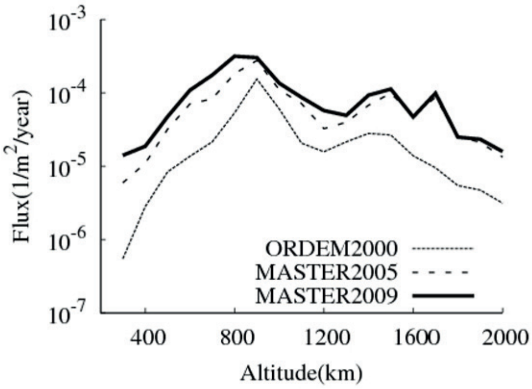
a) Diameter > 10 µm



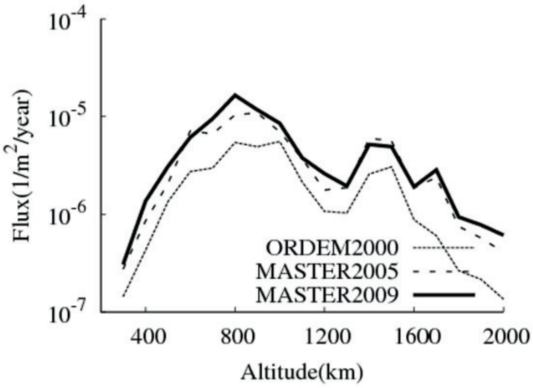
b) Diameter > 100 µm



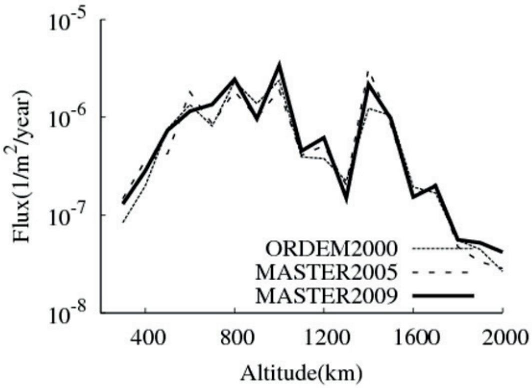
c) Diameter > 1 mm



d) Diameter > 1 cm



e) Diameter > 10 cm



f) Diameter > 1 m

Figure C.1 — Flux against altitude at inclination 100°

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