FINAL DRAFT

INTERNATIONAL STANDARD

ISO/FDIS 14200

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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Contents

Foreword

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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, *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

[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

[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
debris environment model
⟨meteroid or space⟨ man-made objects, including fragments and elements thereof, in Earth's orbit or re-entering the atmosphere that are non-functional

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

[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

[ISO 23041:2007]

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

[ISO 24113:2011, definition 3.18]

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

[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 ISO 24113 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 are 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 and launch vehicle orbital stages 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 spacecraft's design data (ex. 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

The customer and the supplier should consider model capabilities and should select suitable environment model(s) for the mission of the spacecraft and/or launch vehicle orbital stages. Model capabilities are described in Clause 5.4. When model(s) selection is performed, it is recognized that the environment models have uncertainties and there are large differences in the flux values among each model. And it is recommended that the customer and the supplier prepare several models, and the comparison of flux values among models.

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

When impact fluxes are estimated for spacecraft design and/or component design, the following approaches are recommended, in point of view of traceability of development of model, maintenance of model, and convenience of model user (design engineer).

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 [1].

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 Reference [2]. 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 ORDEM2000 and MASTER-2005, 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[3] 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[4] 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[5] 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[6] 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).[7]

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.[8]

A.2 Model specifications

Table A.1 — Meteoroid model specifications

Model specifications	Model					
	Grüen et al. Reference [1]	Divine Reference [2]	Divine-Staubach Reference [3]	SSP 30425 (ISS) Reference [4]	IMEM (ESA) Reference [5]	MEM (MSFC) Reference [6]
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
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 identical 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 (Revision)	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.

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[10] [11] [12] 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[13] [14] [15] [16] [17] [18] 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[19] 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[20] 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 ORDEM2000 model

The ORDEM2000 model[21] is an empirical model based on ground-based observation data and surface inspection results of objects retrieved from orbit. The applicable scope of ORDEM2000 is an altitude between 200 km and 2 000 km and a debris diameter between 10 μm and 1 m.

B.2.1.6 SPDA model

The SPDA model[22] [23] [24] 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 B.1 — Debris flux model specifications

Model specifications	Model					
	DAMAGE Reference [1] - [3]	**IDES** Reference [4] - [9]	**MASTER 2005** Reference [10]	**MASTER 2009** Reference [11]	**ORDEM 2000** Reference [12]	**SPDA** Reference [13] - [15]
Source	Southampton University	DERA	ESA	ESA	NASA	RSA
Modelling approach	Statistical and near-deterministic methods	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	> 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	200 to 2 000 km	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	1991 to 2030	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	-Apo/Peri -Altitude -Semi-major axis -Eccentricity -Inclination -Argument of perigee	—

Table B.1 *(continued)*

Model specifications	Model					
	DAMAGE Reference [1] - [3]	**IDES** Reference [4] - [9]	**MASTER 2005** Reference [10]	**MASTER 2009** Reference [11]	**ORDEM 2000** Reference [12]	**SPDA** Reference [13] - [15]
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, -Orbit position, -Altitude, -Latitude	—
Debris source terms						
a) TLE background	Yes (or simulated from historical launch and fragmentation data)	—	Yes	Yes	All sources together	All sources together
b) Fragments	Yes	—	Yes	Yes	All sources together	All sources together
c) SRM dust/slag	TBC	—	Yes	Yes	All sources together	All sources together
d) NaK droplets	TBC	—	Yes	Yes	All sources together	All sources together
e) Paint flakes	no (TBC)	—	Yes	Yes	All sources together	All sources together
f) West ford needles	TBC (Currently included if catalogued)	—	Yes	Yes	All sources together	All sources together
g) MLI fragments	—	—	None	Yes	All sources together	All sources together
Meteroid						
a) background	None	None	Divine-Staubach	Diving-Staubach	None	None
b) streams	None	None	Jenniskens-McBride, Cour-Palais	Jenniskens-McBride, Cour-Palais	None	None
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	-SSN, catalogue, -LDEF, -Haystack radar, -HST-SA. -STS window and radiator, -HAX, -Goldstone radar	—

Table B.1 *(continued)*

Model specifications	Model					
	DAMAGE Reference [1] - [3]	**IDES** Reference [4] - [9]	**MASTER 2005** Reference [10]	**MASTER 2009** Reference [11]	**ORDEM 2000** Reference [12]	**SPDA** Reference [13] - [15]
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	—	—
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	No

B.3 Debris propagation (evolutionary) models

B.3.1 Model overview

B.3.1.1 LEGEND model

The LEGEND model[25] [26] 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[27] [28] 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[29] 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 indicates examples of debris flux model among three models (ORDEM2000, MASTER2005 and MASTER2009). Details are discussed in References [30] to [32].

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.
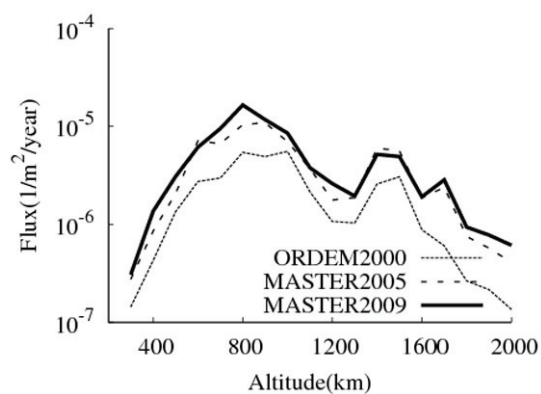
Table C.1 — Calculation conditions of models comparison

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	
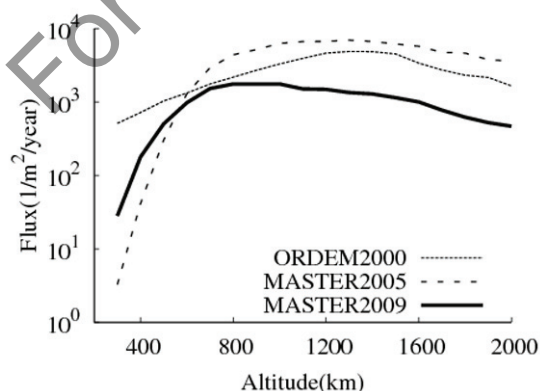
a) Diameter > 10 μm
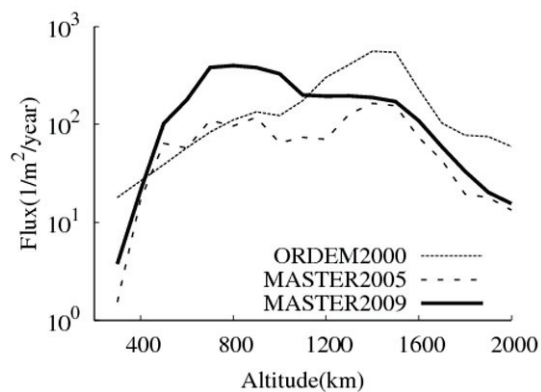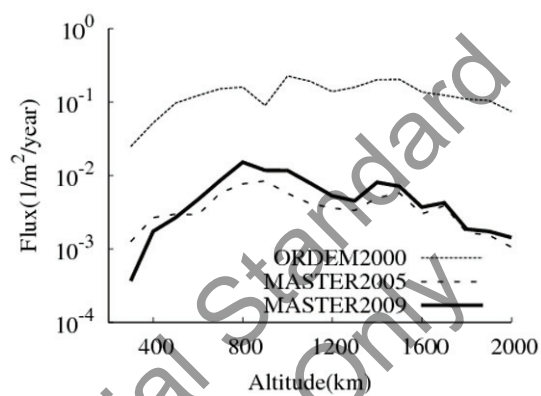
b) Diameter > 100 μm
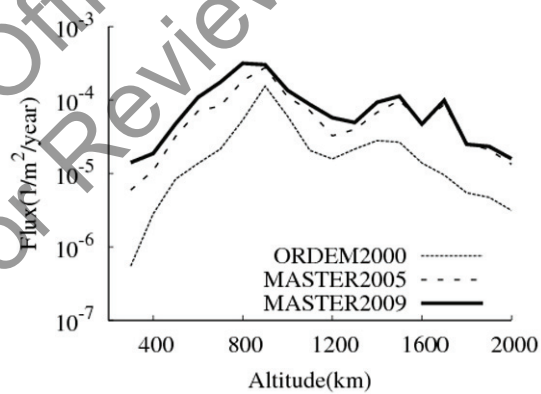
c) Diameter > 1 mm

d) Diameter > 1 cm

e) Diameter > 10 cm
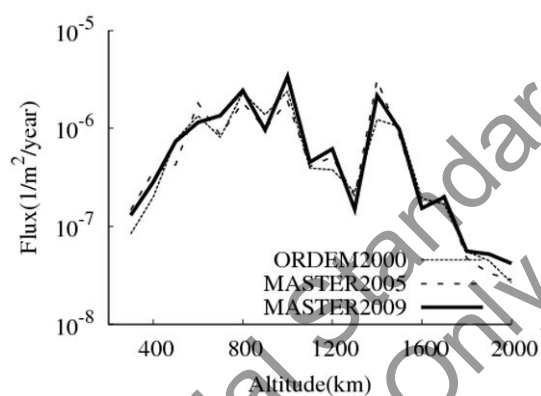
f) Diameter > 1 m

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

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